HBRC Journal (2016) xxx, xxx–xxx

Housing and Building National Research Center

HBRC Journal

http://ees.elsevier.com/hbrcj

FULL LENGTH ARTICLE

Behavior of corroded bonded partially prestressed concrete beams

Mohamed Moawad [a,*], **Anwar Mahmoud** [b], **Hossam El-karmoty** [b], **Ashraf El zanaty** [a]

[a] *Cairo University, Giza, Cairo, Egypt*
[b] *Housing and Building National Research Center, Dokki, Giza, Egypt*

Received 2 August 2015; revised 30 December 2015; accepted 7 January 2016

KEYWORDS

Beam;
Corrosion;
Deterioration;
Partially prestressed;
High strength concrete

Abstract Prestressed concrete is widely used in the construction industry in buildings. And corrosion of reinforcing steel is one of the most important and prevalent mechanisms of deterioration for concrete structures. Consequently the capacity of post-tension elements decreased after exposure to corrosion. This study presents results of the experimental investigation of the performance and the behavior of partially prestressed beams, with 40 and 80 MPa compressive strength exposed to corrosion. The experimental program of this study consisted of six partially prestressed beams with overall dimensions equal to 150 × 400 × 4500 mm. The variables were considered in terms of concrete compressive strength, and corrosion location effect. The mode of failure, and strain of steel reinforcement, cracking, yield, ultimate load and the corresponding deflection of each beam, and crack width and distribution were recorded. The results showed that the partially prestressed beam with 80 MPa compressive strength has higher resistance to corrosion exposure than that of partially prestressed concrete beam with 40 MPa compressive strength. Not big difference in deterioration against fully/partially corrosion exposure found between partially prestressed beams at the same compressive strength. The most of deterioration incident in partially prestressed beam acts on non prestressed steel reinforcement. Because the bonded tendons are less likely to corrode, cement grout and duct act as a barrier to moisture and chloride penetration, especially plastic duct without splices and connections. The theoretical analysis based on strain compatibility and force equilibrium gave a good prediction of the deformational behavior for high/normal partially prestressed beams.

Introduction

Many concrete structures suffer from reinforcing steel corrosion especially in marine environments. The concrete structures experience unacceptable loss in load carrying capacity, stiffness and ductility. Many researchers have attempted to

* Corresponding author.
E-mail address: msmmah83@yahoo.com (M. Moawad).
Peer review under responsibility of Housing and Building National Research Center.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.hbrcj.2016.01.003
1687-4048 © 2016 Housing and Building National Research Center. Production and hosting by Elsevier B.V.

characterize the behavior of prestressed concrete beams and corrosion damaged R.C elements.

Omnia [1], studied the behavior of fully and partially prestressed concrete beams and concluded that presence of the prestressing force delays the concrete cracking and increases the initial stiffness. Hussien et al. [2], studied the behavior of bonded and unbonded prestressed normal and high strength concrete beams and concluded that increasing the nominal compressive strength for bonded prestressed beams led to a slight increase in the ultimate and cracking loads. Ismail [3], studied the behavior of statically determinate prestressed concrete beams subject to fire and concluded that the partially prestressed concrete beams with concrete cover equal to 25 mm have higher resistance to fire exposure than that of fully prestressed concrete beam in terms of ultimate capacity and ductility. Also the high strength partially and fully prestressed concrete beams had lower fire resistance than normal strength beams.

El-Hefnawy [4], conducted another experimental study on carbonation depth. He measured the carbonation depth for concrete of 18 months age for specimens with/without silica fume by treating a freshly broken concrete surface by phenolphthalein. He found that the addition of silica fume as a partial replacement of cement increases its tendency to react with carbon dioxide in the atmosphere. El-Hefnawy [5], conducted experimental and theoretical study to estimate the residual ultimate capacity of reinforced concrete beams exposed to different degrees of corrosion. EL-Hefnawy found that corrosion-induced cracks were unrelated to the degree of rebar corrosion. In addition, he noticed also that none of the tested beams, even severally corroded beams, suffered from spalling of concrete cover. In the theoretical study and because of the irregular shape of the corroded rebar, a statistical approach based on ISO 12491:1997 [6] was carried out to estimate the probable minimum area of the corroded rebar (AF), using four diameters measured at four different random locations along corroded rebar length. Gestsdottir and Gudmundsson [7], investigated bond behavior of naturally corroded reinforcement in concrete structures. The experiments showed that higher degree of corrosion leads to decrease of ultimate load and longer available anchorage length leads to increase of ultimate load. Furthermore the ultimate load is not connected where load shear or flexural crack forms, and the free end slip of the main bars starts at a load of 90–97% of the maximum load. AL-ATTAR, and ABDUL-KAREEM [8] Investigated the influence of chloride ions source on corrosion of steel embedded introduction in different exposure to the external chloride increases both total and free chloride inside the concrete specimens; the results indicate that the ratio between (CL_{free}/CL_{total}) for high performance concrete mixes is always less by about 76–82% than that of normal concrete mixes; and this could be caused by using high cement content and metakaolin. Khafaga and Bahaa [9], investigated the structural behavior of reinforced concrete beams initially deteriorated by corrosion of web reinforcement through an experimental program that comprised tests of eight large-scale beams. The results indicated that corrosion of web reinforcement adversely affected the structural performance of the reinforced concrete beams in terms of strength, stiffness, and ductility. Deterioration of the concrete cover was observed and was more severe for beams reinforced with closely spaced stirrups. Losses in the yield and ultimate capacities up to 36% were recorded. Elgabry et al. [10], investigated the behavior of reinforced concrete frames exposed to corrosion of steel bars and repaired using CFRP. Corrosion of reinforcement steel leads to reduction in ultimate load capacity, stiffness and ductility of the corroded R.C frames. Rehabilitation using CFRP resulted in enhancement in ultimate load carrying capacity up to 44.7%. Using CFRP in rehabilitation of corroded frames limited the propagation of the cracks and increased the cracking load significantly.

Research program

Experimental program

The experimental program consists of testing six beams with overall width, depth and length of 150 mm, 400 mm and 4500 mm respectively, and the beams were simply supported with a clear span of 4200 mm, as shown in Fig. 1. The top longitudinal reinforcement of all specimens was two 10 mm diameter bars. The stirrups were 10 mm diameter bars every 200 mm at middle part of the beams and every 100-mm at edges for a distance 1400 mm from support to middle span of beam, as shown in Fig. 2. Fig. 3 shows the prestressing strand had a draped profile similar to the shape of the bending moment produced by acting loads. One strand with diameter 12 mm in addition to two 10 mm diameter bars was used to reinforce the partially prestressed beams. Additional horizontal stirrups were added at anchor zone to resist the splitting force, which is produced at the anchor zone; these stirrups were calculated according to recommendation of the Egyptian code [11]. The variables were considered in this study, concrete compressive strength, and corrosion location effect. As given in Table 1. The prestressing strand was placed inside polyethylene duct and fixed with the beam stirrups using horizontal steel chairs. The grouting fitting was placed at distance of 300 mm from each side of beam. The strands were stressed after the concrete had reached an age of 28 days, and then grouted with cementations according to specification instructions.

During prestressing, the strand elongation was measured and the prestressing force was recorded. Table 2 shows the experimentally measured and theoretically calculated force and elongation for partially prestressed beams.

Materials properties

Natural siliceous sand and crushed stone had a nominal maximum size of 10 mm. Ordinary Portland Cement (OPC), silica fume, and tap drinking water were used in this work. Also super plasticizer admixture Sikament-163 M and Viscocrete 20 HE were used. The admixture complies with the ASTM C 494 type A and F. Testing of these materials was carried out according to Egyptian Standard Specifications and the ASTM Standards.

Deformed high grade steel bars of 10 mm diameter with yield strength of 470 N/mm^2 and ultimate strength of 610 N/mm^2 were used as stirrups and longitudinal tension and compression reinforcement. Steel bars were tested and comply with Egyptian Standard Specifications [11].

Fabrication of tested beams

The specimens were fabricated at two stages. The first stage was the casting of six partially prestressed concrete beams,

Please cite this article in press as: M. Moawad et al., Behavior of corroded bonded partially prestressed concrete beams, HBRC Journal (2016), http://dx.doi.org/10.1016/j.hbrcj.2016.01.003