Construction and Building Materials 38 (2013) 482–490

Contents lists available at SciVerse ScienceDirect

Construction and Building Materials

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

Bending behavior, deformability and strength analysis of Prefabricated Cage Reinforced Composite beams

Chithra Rethnasamy [a,*], Thenmozhi Rajagopal [b], Hareesh Muthuraj [c]

[a] Structural Engineering, Department of Civil Engineering, Government College of Technology, Thadagam Road, Coimbatore – 641 013, Tamilnadu, India
[b] Department of Civil Engineering, Thanthai Periyar Government Institute of Technology, Vellore – 632 002, Tamilnadu, India
[c] L&T Ramboll, Chennai – 600 032, Tamilnadu, India

HIGHLIGHTS

- ▶ The experimental and analytical flexural behavior of PCRC beams is deeply analyzed.
- ▶ The partial confinement provided by Prefabricated Cage enhances the flexural response.
- ▶ The confinement offered by prefabricated cage prolonged the initiation of cracks.
- ▶ This beam system exhibits an improved ductility and energy absorption capacity.
- ▶ The beams are capable of withstanding impact forces due to higher ductile response.

ARTICLE INFO

Article history:
Received 31 May 2011
Received in revised form 9 August 2012
Accepted 16 August 2012
Available online 4 October 2012

Keywords:
Prefabricated Cage
Composite beams
Cold formed steel sheet
Ductility
Energy absorption

ABSTRACT

The principal aim of this paper is to examine, both experimentally and analytically, the bending behavior of Prefabricated Cage Reinforced Composite (PCRC) beams. This paper presents comprehensive data and their interpretation on strength, deformation characteristics, ductility and mode of failure of beams in terms of effects of thickness of sheet, concrete strength and amount of tension reinforcement. A total of 18 PCRC beam specimens and 3 Rebar Reinforced Cement Concrete (RCC) beam specimens were considered in this study: Nine were made from cold formed steel sheet with average yield strength of 260 N/mm^2 and the rest of the beams with average yield strength of 400 N/mm^2. Theoretical model was developed for flexural strength and its accuracy was verified against experimental data. A three dimensional finite element model using ANSYS was also proposed to simulate the overall flexural behavior of PCRC beams. The experimental results infer that the confinement offered by prefabricated cage prolonged the initiation and propagation of cracks when compared to RCC beam specimens and the beams exhibited well defined post peak behavior. In PCRC beams, the flexural strength was not significantly influenced by yield strength of steel. This type of beam system exhibits an improved ductility and energy absorption capacity making it suitable for seismic resistant structures. Reduced construction time of these beams can play a vital role in fast track construction.

1. Introduction

In recent years, fast track construction has made significant advances in multistory buildings and bridges. Fast track construction can be achieved by using prefabricated elements in construction activities. Recently prefabricated reinforcement system proposed by Shamsai and Sezen [8], prepared by perforating steel tubes or steel plates was reported to function as both longitudinal and transverse reinforcement connected monolithically and working compositely with the concrete.

Sezen and Shamsai [4] experimentally investigated the behavior of PCS reinforced columns with normal strength concrete. A total of 16 specimens were constructed and tested to investigate the strength and displacement capacity of PCS reinforced columns and was compared with those of equivalent rebar reinforced specimens. The test results indicated that PCS reinforced specimens have similar elastic behavior, comparable peak strength and better performance in the residual strength section beyond the peak strength and were found to be more ductile and absorb more energy than equivalent rebar reinforced columns. The crossties help to prevent the PCS tube from buckling and therefore, improve the confinement, strength and displacement capacity. Sezen and Shamsai [5] investigated the confinement provided by

* Corresponding author.
E-mail address: chithrajothin@gmail.com (Chithra Rethnasamy).

0950-0618/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.conbuildmat.2012.08.017

Nomenclature

A_{st}	area of tension steel	f_t	splitting tensile strength of concrete
f_{ck}	compressive strength of concrete	f_y	yield strength of steel
P_{cr}	cracking load	$M_{u\,the}$	theoretical moment of resistance
ϕ_y	curvature at which the tension steel yields	$M_{u\,exp}$	experimental moment of resistance
ϕ_u	curvature corresponding to Δ_u	$M_{u\,ANSYS}$	moment of resistance predicted in ANSYS
$\mu\phi$	curvature ductility factor	t	thickness of steel sheet
Δ_u	displacement at failure stage	P_u	ultimate load
Δ_y	displacement based on equivalent elasto-plastic yield	P_y	yield load
μ_Δ	displacement ductility factor	E_c	young's modulus of concrete
d	effective depth of beam	E_s	young's modulus of steel sheet
b	width of beam		

Prefabricated Cage System (PCS) by comparing the results from 6 small-scale column tests. The test results showed that PCS provided much better concrete confinement than rebar reinforcement system.

Shamsai et al. [9] reported that the usage of prefabricated cage reinforcement results in a 33.3% time savings and a 7.1% cost savings over rebar for each column. This resulted in an average of 3.6% savings on total project cost, an average of 22.2% savings on total column costs and provides a time savings of 116 days, which was equivalent to 20.4% savings on total project time period, 33.3% savings on columns construction time period. The cost savings were estimated based on the production of small quantities of PCS reinforcement and mass production of PCS reinforcement could result in even higher cost savings. Sezen and Shamsai [5] conducted test on high strength concrete columns with Prefabricated Cage System and proved that this reinforcement in columns improves the structural performance with various additional advantages in various aspects.

However, the behavioural response of the concrete beams reinforced with prefabricated reinforcement system has its own significance and was considered for study in this paper. The beams were then termed as Prefabricated Cage Reinforced Composite (PCRC) beams based on the composite action assured by the perforations in steel sheet. Experimental and analytical investigations were carried out to assess the performance level of eighteen series of PCRC beams with variations in key input parameters namely the thickness of the steel sheet, concrete grade, yield strength of the steel sheet and width of perforations and three RCC beams. The influence of these parameters on the overall structural performance of the PCRC beams was also analyzed and compared with RCC beams.

2. Materials and methods

2.1. Materials and specimens

Eighteen PCRC beam specimens and three equivalent RCC beam specimens were considered in this study. All the beams had the same dimensions $150 \times 200 \times 2500$ mm and the typical cross-sectional details are shown in Fig. 1. Rectangular cold formed steel sheet of length 2.5 m was used to produce the reinforcement cage. Two separate cold form steel sheets of required size were taken. The perforations were made in the two sheets using CNC cutting as shown in Fig. 2. Then the plates were bent in a plate bending machine. After bending, the plates were connected along the edges on both sides throughout the length of the specimen to form tube shaped reinforcement as shown in Fig. 3. Nine of the specimens (G, H, I series) were made with mild strength steel sheet while the others (J, K, L series) were made with high tensile strength cold form steel sheet. However, the percentage of tension reinforcement was varied in both the sets in such a way that all the beams had merely same equivalent area of steel ($A_{st}f_y$), where A_{st} is the area of steel in mm^2 and f_y is the yield strength of steel in N/mm^2.

To compare the behavior of PCRC beams with conventional reinforced concrete beams, three RCC beams of same compressive strength and with equivalent area of steel as that of G, H, I series beams were also cast as control specimens. The RCC beam specimens were reinforced with 2 nos. of 12 mm diameter bars at bottom and 2 nos. of 8 mm diameter bars at top.

The mix proportions of concrete mixtures and properties of hardened concrete are summarized in Tables 1 and 2 respectively. The coarse aggregate used were 12.5 mm maximum size crushed gravel aggregate. Locally available river sand was used as fine aggregate. The mechanical properties of the cold formed steel sheets are tabulated in Table 3.

The beams were named considering the variations in thickness of steel sheet and concrete strength. Specimens G1, G2, G3 had a concrete strength of 33.10 N/mm^2 where the numbers 1, 2, 3 in the specimen names corresponds to 1.6 mm, 2.0 mm, 2.5 mm thickness steel sheet respectively. Specimens H1, H2, H3 and I1, I2, I3 remained the same as that of G1, G2, G3 specimens respectively except for the variation in the concrete strength of 38.80 N/mm^2 and 45.20 N/mm^2 respectively against the concrete strength of 33.10 N/mm^2 of the later.

Beams of G, H, I series exhibited a profile with two layers of tension reinforcement against the profile of specimens J, K, L with single layer of tension reinforcement. The numbers in the J, K, L specimens represents the thickness of steel sheet similar to that of G, H, I specimens. The compressive strength of J, K, L specimens was 32.80 N/mm^2, 38.30 N/mm^2 and 44.20 N/mm^2 respectively.

2.2. Test procedure and instrumentation

The beams were white washed at the surfaces before testing. The locations of the supports, Linear Variable Differential Transformer (LVDT) points to measure deflections were marked. A precision reaction frame of 50 ton capacity fixed over strong floor was used for testing. The beams were simply supported with an effective span of 2080 mm c/c. Two point loads were applied transversely at one fourth distances from each support using a cross beam. A paste of plaster of paris was spread at the two load points. Two distribution plates of 25 mm width were placed on the plaster of paris and pressed into it to get a level surface, and this was checked by a spirit level. Two rollers were placed over the distribution plates and a loading beam (a rolled steel I-joist) was mounted on the beam.

LVDTs were used to measure the deflection of the beams. One LVDT was kept at the mid span of the beam and other two were kept under the loading points. A curvature meter was used to determine the strains at the top and bottom most fibers of the beam section. Loading was applied by means of 20 ton power pack. The load applied by the power pack was measured using a Proving Ring of capacity 30 ton. The behavior of the beams was keenly observed from the beginning till the collapse. The appearance of the first crack, the development and propagation of cracks due to the increase of load were also recorded. The loading was continued beyond the peak load. The test set up is shown in Fig. 4.

2.3. Theoretical model

2.3.1. Model assumptions

The following assumptions are made in the analytical study:

1. Plane sections remain plane even after bending.
2. The stress–strain curve for cold formed sheet is the same both in tension and compression.
3. Tensile strength of concrete is neglected.
4. Compressive stress distribution is represented by a rectangular stress block.
5. The steel in the compression zone is neglected in the calculation of moment of resistance.
6. The stress strain relationships for steel and concrete are elastic perfectly plastic. The plastic strength of the steel is equal to f_y (f_y is the yield strength of the steel). The plastic compressive strength of the concrete f_c is equal to the characteristic compressive design strength of the concrete material f_{ck}).
7. The enhancement in concrete strength due to partial confinement provided by prefabricated cage is taken as the partial safety factor for materials.