Engineering Structures 84 (2015) 287–299

Contents lists available at ScienceDirect

Engineering Structures

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

Mechanical performance of full-scale precast steel fibre-reinforced concrete pipes

Nedal Mohamed, Ahmed M. Soliman, Moncef L. Nehdi *

Department of Civil and Environmental Engineering, Western University, London, ON N6A 5B9, Canada

ARTICLE INFO

Article history:
Received 14 April 2014
Revised 24 September 2014
Accepted 21 November 2014

Keywords:
Precast concrete
Steel fibre
Pipe
Hybrid fibres
Three-edge bearing

ABSTRACT

This paper reports the findings of a laboratory-testing program performed on full-scale precast concrete pipes reinforced with dispersed steel fibres. Steel fibre reinforced concrete (SFRC) pipes had diameters of 450 and 600 mm. Two types of steel fibres having round cross-sections and hooked ends were used. Steel fibres had lengths and aspect ratios of 35 and 60 mm, and 65 and 80, respectively. The steel fibres content ranged from 0 to 40 kg/m^3. Plain (PC) and conventionally reinforced (RC) precast concrete pipes were also tested for comparison. Tested specimens were instrumented with strain gauges mounted on critical sections of each pipe. In addition, vertical and horizontal deformations of the pipe's cross-section were monitored using LVDTs. Precast pipes were tested using both the continuous and cyclic loading procedures as per the ASTM C497 and EN 1916 guidelines, respectively. Results showed that a fibre dosage of 30 kg/m^3 satisfied the strength requirements of ASTM C76 Class V pipe for 450 and 600 mm diameter pipes. In addition, the post-peak behaviour of SFRC pipes was comparable or superior to that of conventional RC pipes at small deformations. It was also found that the behaviour of SFRC pipes could be fully explored using the continuous three-edge-bearing test without need of an extra loading cycle as specified in the EN 1916 standard.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Steel fibres can significantly increase the toughness of concrete through bridging micro- and macro-cracks formed in the cementitious matrix [1]. As a result, steel fibre-reinforced concrete (SFRC) exhibits a more ductile behaviour compared to that of the normal plain concrete. Improvements in the engineering properties of concrete due to steel fibre addition depend on several variables, including the fibre shape, length, aspect ratio, and volume fraction with respect to the total concrete volume [2]. Approximately, 80 million cubic metres of fibre-reinforced concrete (FRC) are produced annually. However, only 5% of that volume is used in precast concrete, while the rest goes to other applications such as slabs on grade and shotcrete [1]. This can be ascribed to the fact that most concrete design codes, especially in North America, are strength based. Hence, users are reluctant in adopting SFRC in structural applications since design codes tend to neglect any increases in concrete strength imparted by steel fibre addition and generally do not recognize the post-cracking load bearing capacity of SFRC [3,1].

In precast concrete pipes, manufacturing of the reinforcing steel cage from conventional steel rebar requires special bending, welding, and placement machinery, which is costly and time-consuming. Conversely, pre-manufactured steel fibres can be added into the mixer of any concrete batch plant, similar to other mixture ingredients, without significant process modification. SFRC can be produced and cast in pipe moulds similar to ordinary plain concrete. Therefore, SFRC pipes can be an economical alternative to the conventionally reinforced concrete pipes [4]. However, detailed and commonly accepted guidelines for the design of SFRC structural members are still under development. In addition, there is a dearth of knowledge regarding the behaviour of SFRC pipes and their engineering properties.

MacDonald and Trangsrud [5] were among the first to investigate the possibility of including steel fibres in precast concrete pipes. They reported that the crushing strength of pipes increased with fibre inclusion. They also argued that the fibre dosage could be optimized to achieve the desired mechanical strength according to the specific pipe application. However, they provided no further information regarding the SFRC pipe structural behaviour (i.e. vertical and horizontal displacements, strain at critical sections, etc.).

Haktanir et al. [6] tested SFRC pipes in comparison with plain (PC) and conventionally reinforced concrete (RC) pipes. It was found that longer steel fibres achieved greater improvement of

* Corresponding author. Tel.: +1 (519) 661 2111x88308; fax: +1 (519) 661 3779.
E-mail address: mnehdi@uwo.ca (M.L. Nehdi).

http://dx.doi.org/10.1016/j.engstruct.2014.11.033
0141-0296/© 2014 Elsevier Ltd. All rights reserved.

Nomenclature

b	width of the SFRC specimen
$D_{0.3}$	D-load that induces a crack of 0.3 mm width and a length of 300 mm according to ASTM C76
D_{ult}	D-load at failure according to ASTM C76
d_f	steel fibre cross-section diameter
E_f	modulus of elasticity of steel fibres
E_{pre}	fracture energy of SFRC specimen up to peak load
E_{post}	post peak fracture energy at certain deflection $\delta = E_{total} - E_{pre}$
E_{total}	total fracture energy of SFRC specimen up to certain deflection δ
$F_{0.3}$	load that induces a crack of 0.3 mm width and a length of 300 mm according to ASTM C76
F_c	specified pipe proof (design) load according to EN 1916 and NBR 8890
F_{cr}	first cracking load of concrete pipe
F_f	tensile strength of steel fibres
$F_{post,max}$	maximum load reached in the second load cycle of TEBT according to NBR 8890
F_n	specified ultimate crushing load of concrete pipe according to EN 1916 and NBR 8890
F_{ult}	ultimate crushing load of concrete pipe
f_1	flexural strength of SFRC
f'_c	compressive strength of SFRC
f_t	splitting tensile strength of SFRC
h	depth of SFRC specimen
L	span of SFRC specimen
L_f	steel fibre length
PCS_m	post-crack strength of SFRC specimen at certain deflection L/m
V_f	fibre content in SFRC mixture
φ	fibre aspect ratio
δ_{peak}	specimen vertical deflection at spigot at $F_{post,max}$
δ	specimen vertical deflection (mm)

the pipe strength than that of short fibres. In addition, they reported that a 60% increase in the fibre dosage (from 25 to 40 kg/m^3) induced minor improvements in the pipe strength and cracking behaviour.

More recently, a series of SFRC precast pipes with different steel fibre dosages have been tested [7,8]. In this work, the relative vertical displacement of the pipe crown towards its invert at both of the pipe spigot and pipe bell were recorded during loading. They reported that monitoring the displacement at the pipe bell is unnecessary since the deformation of the spigot would always govern the pipe behaviour and its cracking pattern [8]. They reported that SFRC pipes achieved similar or higher loads, depending on the fibre content, compared to that of RC pipes at lower levels of displacement and cracking [8]. In addition, a fibre dosage of 40 kg/m^3 provided a strain hardening behaviour and it could be considered as an optimum content for the investigated conditions [8].

Moreover, Abolmaali et al. [9] tested SFRC precast pipes having different pipe dimensions, fibre dosage and fibre properties. They reported that SFRC pipes achieved a comparable performance to that of RC pipes in terms of strength, stiffness, and ability to withstand large crack widths. However, no data was reported regarding strains at critical cross-sections and the overall post-cracking behaviour of SFRC pipes.

This paper is part of an ongoing comprehensive research program that aims at developing technical recommendations and design guidelines for SFRC precast pipes. The study reported herein aims at providing the precast concrete industry with reliable data on the performance of SFRC pipes. It attempts to capture the full behaviour of SFRC pipes incorporating different steel fibre dosages and types. Hence, both the ASTM C497 (Standard Test Methods for Concrete Pipe, Manhole Sections, or Tile) [10] and EN 1916 (Concrete pipes and fittings, unreinforced, steel fibre and reinforced) [11] testing procedures were adopted to gain an enhanced understating of the behaviour of SFRC pipes under mechanical loading.

2. Research significance

The structural behaviour of full-scale SFRC precast pipes in terms of crack, ultimate, and post-peak loads, load versus deformation and associated strains at critical sections was explored. The steel fibre content needed to satisfy the strength requirements for Class V 450 and 600 mm diameter pipes according to ASTM C76 (Standard Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe) [12] was identified. The experimental data reported herein will be used for calibrating numerical models for such pipes. Moreover, the continuous crushing test and the cyclic crushing test, specified in ASTM C497 and EN 1916, respectively, were compared, which provides insight into how SFRC pipes should be tested in the future.

3. Test methods

The Three-Edge-Bearing Test (TEBT) is a standard test commonly used for evaluating the mechanical strength of reinforced concrete pipes in the precast concrete pipe industry. In this test, the load is applied as a line load along the crown of the pipe, while the pipe is supported over two closely spaced bearing strips along the invert (Fig. 1). According to the ASTM C497 standard method; the pipe performance is evaluated based on two criteria: (i) the load that produces a crack with a width of 0.3 mm and a length of 300 mm ($F_{0.3}$ also called the design load), and (ii) the ultimate crushing load of the pipe (F_{ult} or the ultimate load). The ASTM C76 standard defines the $F_{0.3}$ and F_{ult} of RC pipes in terms of D-loads (i.e. $D_{0.3}$ and D_{ult}). A D-load is the total load per metre of pipe length divided by the inside diameter of the pipe in millimetres. Thus, a group of pipes that have the same strength will support the same D-load regardless of the pipe diameter.

On the other hand, EN 1916 evaluates the RC pipe performance based on proof and ultimate loads. The proof load (F_c) is defined as 0.67 F_n where F_n is the minimum crushing load. The ultimate load F_{ult} is the ultimate crushing load of the pipe. Contrary to the ASTM C76 standard, the EN 1916 standard requires that the load be held at F_c for at least 1 min to allow the crack, if any, to stabilize [11].

Moreover, the EN 1916 standard specifies a crushing test method for SFRC pipes, in which the pipe should withstand the proof load F_c for 1 min without showing any cracks. If no crack is found, the load is increased to the ultimate (collapse) load F_{ult}, which should be greater than F_n. The load is then completely released after the sustained load has fallen to 95% or less of the ultimate (collapse) load. Finally, the pipe is reloaded up to F_c and the load is held for 1 min. If the pipe could sustain that load without collapsing, it is considered as passing the test.

In the present study, one additional step was added to the EN 1916 testing procedure according to the Brazilian standard NBR

Download English Version:

https://daneshyari.com/en/article/6740580

Download Persian Version:

https://daneshyari.com/article/6740580

Daneshyari.com