Construction and Building Materials 183 (2018) 554–564

Contents lists available at ScienceDirect

Construction and Building Materials

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

Shear behavior of ultra-high performance concrete

Masoud Pourbaba [a], Abdolreza Joghataie [b], Amir Mirmiran [c,*]

[a] Department of Civil Engineering, Maragheh Branch, Islamic Azad University, Maragheh, Iran
[b] Department of Civil Engineering, Sharif University of Technology, Tehran, Iran
[c] Department of Civil Engineering, University of Texas at Tyler, Tyler, TX 75799, USA

HIGHLIGHTS

- Ultra-high performance concrete has significant advantages in structural applications.
- This study focuses on a detailed parametric study of shear behavior of UHPC.

ARTICLE INFO

Article history:
Received 5 July 2017
Received in revised form 31 May 2018
Accepted 14 June 2018

Keywords:
Beams
Shear
Ultra-high performance concrete (UHPC)

ABSTRACT

The application of ultra-high performance concrete (UHPC) as an alternative to conventional/normal concrete (NC) has grown rapidly in recent years. However, there is limited knowledge on its shear behavior, which is essential for developing design guidelines for structural applications. A detailed parametric study was conducted on 38 beam specimens, half of which were made of UHPC and the other half made of NC. To ensure applicability of findings, two types of UHPC mixes were used, a proprietary and a generic mix. Eighteen of the beams were prepared and tested in Tabriz, Iran, while the other 20 were made and tested in Miami, FL. Test parameters included type of concrete (UHPC and NC), shear span-to-depth ratio (0.8, 1.2, and 2.8), reinforcement ratio (2.2% to 7.8%) and reinforcement anchorage. All specimens had the same length but different cross sections. Test results proved UHPC specimens to have much higher shear strength and ductility than NC beams. Normalized shear and shear strength both increased for shorter shear spans and higher reinforcement ratios. The anchorage did not affect UHPC beams, while it improved ductility of NC beams. Theoretical shear strengths, as determined by RILEM equations for UHPC beams, proved very conservative, confirming the need for more accurate assessment of shear strength of UHPC.

1. Introduction

As a new cementitious material, ultra-high performance concrete (UHPC) has seen a rapid growth in construction. This may be attributed to its exceptional properties such as high compressive strengths of above 150 MPa as well as durability [1], making UHPC a suitable alternative to conventional/normal concrete (NC) with more slender sections and potentially cost-saving applications [1–3].

Graybeal [4] tested three 910-mm deep AASHTO Type II prestressed UHPC girders in shear, with each girder failing in a different manner, from pre-existing horizontal cracks at the base of the web resulting from prior flexure tests, to diagonal tension failure and a combination of diagonal tension and strand slippage. In the absence of any shear reinforcement or draped strands, he concluded that shear capacity could be determined by assuming that all shear forces are carried by diagonal tension and compression in the web of the girder [4]. In another project, Russell and Graybeal [5] tested three 840-mm deep pi-girders, and compared their test results favorably with the AASHTO LRFD Bridge Design Specifications [6]. Maguire et al. [7] tested two full-size double-tee beams with shear reinforcement consisting of welded wire reinforcement with cross wires for anchorage. Both girders had a shear capacity higher than their calculated shear strength, implying that the AASHTO LRFD Bridge Design Specifications [6] for shear design of I-girders could be applied to UHPC girders.

Baby et al. [8,9] investigated the shear performance of UHPC beams, with several test variables, including prestressed versus nonprestressed beams, stirrups for shear reinforcement, as well as fiber reinforcement orientation and effectiveness as shear reinforcement in the web. The study determined that shear design recommendations contained within the SETRA-AFGC UHPFRC Design

* Corresponding author.
E-mail addresses: pourbaba@iau-maragheh.ac.ir (M. Pourbaba), amirmiran@uttyler.edu (A. Mirmiran).

https://doi.org/10.1016/j.conbuildmat.2018.06.117
0950-0618/Published by Elsevier Ltd.

Guidelines [10] were conservative for these beams. In another study, Bunje and Fehling [11] conducted shear tests of UHPC beams without conventional shear reinforcement, and showed that all specimens failed in flexure.

Voo et al. [12] tested eight prestressed concrete I-beams in shear. Test variables included shear span-to-depth ratio and the amount and type of steel fibers. The beams were all 8.6 m long and 650-mm deep, with 50-mm wide webs, 500-mm wide flanges, and six 15.2 mm diameter high-strength prestressing steel strands. The tests showed a significant distribution of shear cracking that occurs through the web before the formation of the dominant failure crack. The study revealed that for members with a significant

Table 1
Test Matrix.

Name	Section b × h (mm)	Rebars	d (mm)	Concrete Type	Rebar Type	Anchorage Nut	f_c' (MPa)	f_c (MPa)	ρ	a/d	Reinforcement Index
B1*	152 × 152	3Ø25	125	UHPC	MMFX	Yes	137	690	0.078	1.2	0.393
B2*	152 × 152	3Ø22	126	UHPC	MMFX	Yes	137	690	0.060	1.2	0.302
B3*	152 × 152	3Ø25	125	UHPC	Mild Steel	Yes	137	414	0.078	1.2	0.236
B4*	152 × 152	3Ø22	126	UHPC	Mild Steel	Yes	137	414	0.060	1.2	0.181
B5*	152 × 152	3Ø19	128	UHPC	Mild Steel	Yes	137	414	0.044	1.2	0.133
B21	152 × 152	3Ø20	127	UHPC	Mild Steel	Yes	125	400	0.049	1.2	0.157
B22	152 × 152	3Ø18	128	UHPC	Mild Steel	Yes	125	400	0.039	1.2	0.125
B23	152 × 152	3Ø20	127	UHPC	Mild Steel	No	125	400	0.049	1.2	0.157
B24	152 × 152	3Ø18	128	UHPC	Mild Steel	No	125	400	0.039	1.2	0.125
B29	102 × 203	2Ø20	178	UHPC	Mild Steel	No	125	400	0.035	0.9	0.112
B30	102 × 203	2Ø16	180	UHPC	Mild Steel	No	125	400	0.022	0.9	0.070
B35	152 × 76	3Ø14	54	UHPC	Mild Steel	No	125	400	0.056	2.8	0.179
B36	152 × 76	3Ø10	55	UHPC	Mild Steel	No	125	400	0.041	2.8	0.131
B37	152 × 76	3Ø10	56	UHPC	Mild Steel	No	125	400	0.028	2.8	0.090
B6*	152 × 152	3Ø25	125	NC	MMFX	Yes	33	690	0.078	1.2	1.631
B7*	152 × 152	3Ø22	126	NC	MMFX	Yes	33	690	0.060	1.2	1.255
B8*	152 × 152	3Ø25	125	NC	Mild Steel	Yes	33	414	0.078	1.2	0.979
B9*	152 × 152	3Ø22	126	NC	Mild Steel	Yes	33	414	0.060	1.2	0.753
B10*	152 × 152	3Ø19	128	NC	Mild Steel	Yes	33	414	0.044	1.2	0.552
B25	152 × 152	3Ø20	127	NC	Mild Steel	Yes	32	400	0.049	1.2	0.613
B26	152 × 152	3Ø18	128	NC	Mild Steel	Yes	32	400	0.039	1.2	0.488
B27	152 × 152	3Ø20	127	NC	Mild Steel	No	32	400	0.049	1.2	0.613
B28	152 × 152	3Ø18	128	NC	Mild Steel	No	32	400	0.039	1.2	0.488
B31	102 × 203	2Ø20	178	NC	Mild Steel	No	32	400	0.035	0.9	0.438
B32	102 × 203	2Ø16	180	NC	Mild Steel	No	32	400	0.022	0.9	0.275
B41	152 × 76	3Ø14	54	NC	Mild Steel	No	32	400	0.056	2.8	0.700
B42	152 × 76	3Ø12	55	NC	Mild Steel	No	32	400	0.041	2.8	0.513
B43	152 × 76	3Ø10	56	NC	Mild Steel	No	32	400	0.028	2.8	0.350

* These specimens were tested in duplicates (a & b) in Miami to confirm repeatability of test results.

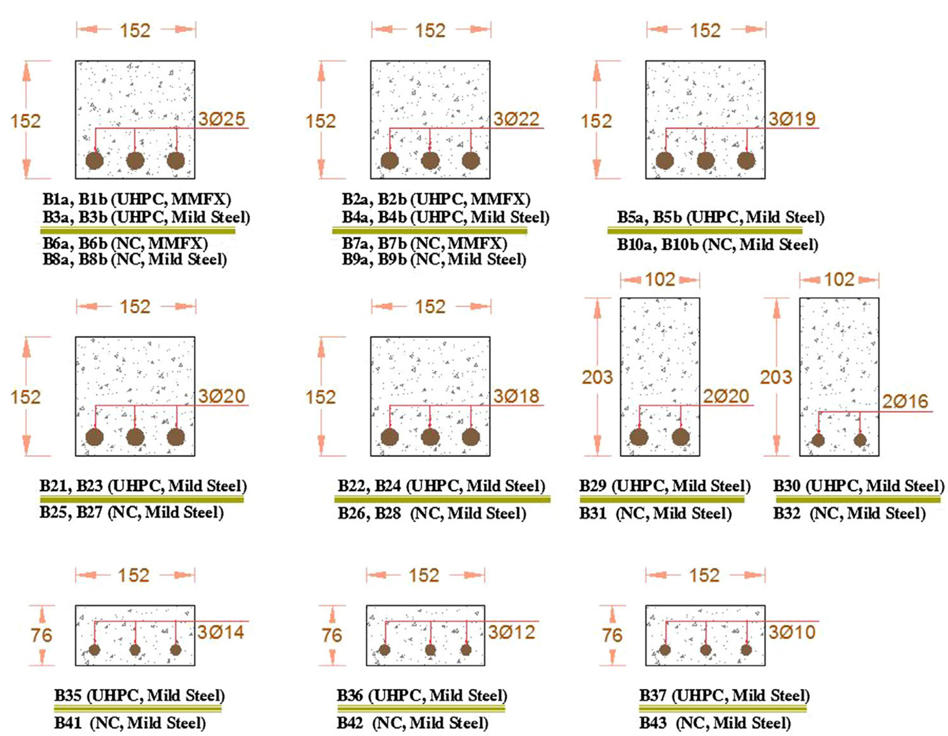

Fig. 1. Cross Sections of Test Specimens.