Civil and Environmental Research
ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online)
Vol.9, No.10, 2017
www.iiste.org

Torsional Behavior of Hybrid Reinforced Concrete Box Girders Composed of Conventional Concrete and Modified Reactive Powder Concrete

Aamer Najim Abbas
College of Engineering, Al-Mustansiriayah University, PO box 46049, Baghdad, Iraq

Ahmed Mahdi Jassim
College of Engineering, Al-Mustansiriayah University, PO box 46049, Baghdad, Iraq

Abstract

This paper investigates experimentally the torsional behavior of hybrid reinforced concrete box beams composed of conventional concrete at side walls and modified reactive powder concrete at top and bottom flanges. Hybrid reinforced concrete members is used extensively to deal with the members strength requirements related to flexural, shear and torsion in structural systems. The torsion failure is an undesirable failure because it's occurred in a brittle nature, it is necessary to avoid this type of failure in the earthquake areas. Three reinforced concrete box beams with dimensions (300x300x1200) mm of (width x height x length) respectively and interior hollow dimensions (140x140)mm were cast and tested to failure by using two opposite cantilevers arms which contribute in transferring the torque to the central part of the box beam. One of the beams was poured with conventional concrete, second beam with modified reactive powder concrete and third beam was poured as a hybrid member. Experimental data on ultimate capacity, cracking torsional loads, failure pattern and twisting angle for each of the box beams were gained. The experimental results show that the ultimate torsional strength value of hybrid box beam higher than conventional concrete beam by about (58) % and lower than modified reactive powder concrete specimen by about (40.75)%.

Keywords: Hybrid reinforced concrete, conventional concrete, modified reactive powder concrete and torsion.

1. Introduction

If the external loads apply on a distance away from the vertical plane of bending moment, the beam is behaved as a torsional member because of its twisting about its longitudinal axis, in addition to bending moment and shearing force. Curved bridge girders, edge beams of slabs, shells, spiral stair cases and eccentrically loaded box beams are constitute examples for members subjected to high twisting moment accompanied by bending moments and shear forces [1]. Two types of torsion can be considered in reinforced concrete structures; Primary torsion, usually designated equilibrium torsion, exists when the external load supported by torsional moment. In this case the torsional moment required to achieve the static equilibrium for the member such as the cantilever slabs. The applied loads on the slabs surface cause torsional moment act along the span of the supported beam. There are equated by the internal resistance torque supplied at the columns.

The second type of torsion called secondary torsion also named statically indeterminate torsion exists between adjacent members of structure. In this case, an internal resisting arises from the requirements of continuity. Neglecting the continuity in the design and analysis will lead to significantly cracking but will not lead to collapse. An application of secondary torsion can be seen in the edge beam supporting concrete panel. If the edge beam has small torsional stiffness and does not contain a torsional reinforcement, the crack will occur and cause reduction in its torsional stiffness and the slab edges will work as a hinged edge. If the moment takes into account in design, the collapse will not occur [2].

The use of reinforced concrete box beams is a principle application for structural components used on bridge and high way construction. A reinforced concrete box beam is basically a supplied box of reinforced concrete that has been designed by structural engineer to support large loads and forces. The cross sectional strength of a box is substantial. Box beams and girders are extremely important to several of the major bridge and highway projects currently under way across the globe [3].

In recent years, hybrid reinforced concrete structures have most attention of engineers due to their economic and good performance under loading. The concept of hybrid section in concrete members can briefly explained by using a specific type of concrete in a specific zone of the section. Hillman[4] is considered the first one that works in the field of hybrid structures in (1994). The structural validations start in 1999 by Transportation Research Board in United States of America. The first hybrid beam was six meters using post-tensioned bars with diameter (36 mm) and they used high strength concrete in the arch. The beam gave a great result of about (180%) more than the designed capacity. In 2007, the Material Cooperative Highway Research Program performed another hybrid beam with (9m) long. In 2013, Ayidin[5] present the potential application of hybrid GFRP box sections. Also, Azad[6] in 2013 has conducted study on using ultra high performance fiber concrete to be used as a tension reinforcement of beam. It was concluded that ultra-high performance concrete improving the flexural tensile strength of about (30 MPa) at failure without any slip between layers.

2. Experimental program

Two type of concrete mix were cast using ordinary Portland cement[7], normal sand 5mm maximum size, glass sand about 600 µm sizes, course gravel with maximum size of 8 mm[8], silica fume[9], steel fiber and super plasticizer[10]. The type of cement used in this study is ordinary Portland cement (Type I). Each series contained different mix proportion, i.e., one normal strength concrete with the formulation of w/c (water to cement) = 0.45, cement 400 kg/m3, sand 600 kg/m3 and gravel 1200 kg/m3 and another modified reactive powder concrete with formulation of w/c of 0.25, cement 900 kg/m3, sand 693kg/m3, gravel 297 kg/m3, silica fume 10% of cement, super plasticizer 0.8 lit/100 kg of cement and steel fiber 0.8% of total volume[11].

Concrete cylinders (150 mm x 300 mm) were poured in three layers. Each layer is compacted using table vibration. On the next day, the cylindrical specimens are de-molded then cured in water up the age of 28 days. The compressive strength test was done according to (ASTM C39/C39M-05) [12] (American Society for Testing and Materials) and B.S (British standards) 1881 [13]. The cylindrical and cubical compressive strength are shown in Table (1).

Two types of deformed reinforcement bars with same type of ribs; the Ø8 mm and Ø10 mm steel bars were cold deformed and had a large yielding capacity [14]. The average yield strength of Ø8 mm is 563 MPa and Ø10 mm is 548 MPa. The average ultimate strength of Ø8 mm is 650 MPa and Ø10 mm is 637 MPa.

3. Results and Discussions

3.1 Ultimate Torsional Capacity

The torsional capacities of the beam (M1S1SF1) which molded with modified reactive powder concrete failed under torsional moment (T=130 kN.m) while beam (NS1) (which molded with conventional concrete) failed under torsional moment (T=48.75 kN.m), this seems to support the thesis that the steel fiber in modified reactive powder concrete blocked to good extent the propagation of cracks through the section by bridging effect (the steel fiber work as a bridge connect both sides of the cracks), in addition to improve the internal resistance of the section by increasing the concrete compressive strength. On the other hand, the beam (M1NS1SF1) (hybrid section) failed under torsional moment (T=77.025 kN.m). Here, specimen (M1NS1SF1) failed at a lower torsional capacity level than fully modified reactive powder concrete specimen (M1S1SF1) by about (40.75%) and higher than fully conventional concrete specimen by about (58%), see Table (2).

3.2 Cracking Torsional Capacity

The cracking capacity of the member is defined as the load that the tensile stresses at the member reach the tensile strength of the concrete that used in this member. The cracking capacity of the modified reactive powder concrete specimen (M1S1SF1) is larger than the cracking capacity of the reference conventional concrete specimen (NS1) by about (169.9%), while the hybrid specimen (M1NS1SF1) has first cracking torque about (61.12%) higher than the reference conventional concrete specimen (NS1), see Table (3). High compressive strength with a specific amount of steel fiber in modified reactive powder concrete layers restrained the initiation of the first crack. As a result of weakness the interaction between layers, the cracking capacity of hybrid section member less than that of modified reactive powder concrete member.

3.3 Torsional Moment versus Angle of Twist Analysis

Here the angle of twist of each specimen is compared with the angle of twist of reference specimen (NS_1). The specimen ($M_1S_1SF_1$) (cast with modified reactive powder concrete) is better than the reference specimen (NS_1). The twist angle is lower when member casted with modified reactive powder concrete. The use of steel fiber and high compressive strength had effect in delaying the propagation of cracks.

When casting the member in hybrid configuration, it was found that the hybrid specimen ($M_1NS_1SF_1$) had twist angle lies between conventional concrete specimen (NS_1) and modified reactive powder concrete specimen ($M_1S_1SF_1$), see Figure (1). As shown in Figure (2), which contains a comparison between cracking torque and ultimate torque of beams (NS_1, $M_1S_1SF_1$ and $M_1NS_1SF_1$), it can be concluded that the residual torsional strength beyond cracks appearance in modified reactive powder concrete specimen ($M_1S_1SF_1$) (R=29.3 kN.m) larger than the residual strength of other specimens (NS_1) and ($M_1NS_1SF_1$), the residual strength is about (R=11.45 kN.m) and (16.925 kN.m) respectively. While the residual torsional strengths of specimen beyond crack appearance of specimen ($M_1NS_1SF_1$) is larger than the residual torsional capacity of specimen (NS_1). This gives an indication about the improvement in the energy absorption of tested specimens as a result of using modified reactive powder concrete member and replacing the top and bottom normal concrete layers by modified reactive powder concrete. At the same time, the torsional stiffness at cracking stage is varies from one specimen to another; the torsional stiffness of reference specimen at first crack is about (62.4 kN.m/deg), while the torsional stiffness of modified reactive powder concrete specimen is about (122.8 kN.m/deg), this variation in torsional stiffness is attributed to the difference in the modulus of rigidity between modified reactive powder concrete and conventional concrete. Likewise, the torsional stiffness of hybrid reinforced concrete member ($M_1NS_1SF_1$) more than control specimen (NS_1) and less specimen ($M_1S_1SF_1$), it have a torsional stiffness about (80.27 kN.m/deg).

4. Types of failure in concrete structure

Generally, primary helocohelioidal crack was occurred before failure. Secondary cracks along the member were observed at the surface. The member (NS_1) had less primary cracks without appearing secondary cracks; this member was poured with conventional concrete. Whereas for member ($M_1S_1SF_1$) it has wide cracks with several secondary cracks, this member poured with modified reactive powder concrete. In hybrid reinforced concrete member ($M_1NS_1SF_1$), it is clearly observed that number of primary cracks is larger than that of conventional concrete specimen (NS_1) but less than the modified reactive powder concrete specimen ($M_1S_1SF_1$), this member have top and bottom layers of modified reactive powder concrete with conventional concrete at side walls, the ductile nature of the failure was not as evident in the normal concrete, see Figure (3), Figure (4), and Figure (5).

5. Stiffness of Tested Members

A member may have a rotational stiffness (K) given by $K= m/\theta$

where:

m= is the applied moment (kN.m).

θ= is the rotational (degree).

Rotational stiffness can be defined as the rigidity of the member-the extent to which it resists deformation in response to applied torque. In this study, it was observed that the amount of resistance to deformation in modified reactive powder concrete specimen higher than the conventional concrete specimen, it have a rotational stiffness higher than the rotational stiffness of conventional concrete specimen by about (362.3%). The deformability of hybrid reinforced concrete member appears larger than the conventional concrete member by about (65.8%). While, the torsional stiffness of modified reactive powder concrete (K=92.4 kN.m/deg) larger than the hybrid concrete specimen by about (175%), see Table (4).

6. Conclusions

The following conclusions can be drawn from the experimental work of this investigation.

1. In general, the ultimate torsional capacity of hybrid reinforced concrete lies between the ultimate torsional capacity of normal and modified reactive powder concrete specimens.
2. The number of cracks in hybrid reinforced concrete beam is larger than the conventional concrete beam and less than modified reactive powder concrete beam.
3. The cracking torsional capacity of hybrid reinforced concrete member lies between the cracking capacity of normal concrete and modified reactive powder concrete members.
4. The twist angle is decreased in modified reactive powder concrete member when compared to the hybrid reinforced concrete and normal concrete members.
5. Also, the torsional stiffness is increased in modified reactive powder concrete member when comparison with hybrid concrete and conventional concrete members.

References

Mashhour, G., and Mahmoud, E., "Design of Reinforced Concrete Structures-2nd edition", Cario, 2007*, AL-Balagh Publishing Company.*

Nilson, H. A., Darwin, D. and Dolan, W. C., "Design of Concrete Structures-Fourteenth Edition", USA, 2010, *Published by McGraw-Hill, New York.*

Arendts, G. J, "Load Distribution in Simply Supported Concrete Box Girder Highway Bridges" *Ph.D. Thesis, University of Low state,* Michigan, USA, 1969.

Hillman, JR., "Hybrid-composite Beam (HCB) Design and Maintenance Manual", Aug., 2012, *The Missouri Department of Transportation.*

Aydin, F. and Saribiyik, M., "Investigation of Flexural Behaviors of Hybrid Beams Formed with GFRP Box Section and Concrete", *Construction and Building Materials*, Vol. 41, April, 2013, pp. 563-569.

Abul k. Azad and Ibrahim Y. Hakeem, "Flexural Behavior of Hybrid Concrete Beams Reinforced with UHPC Bar", *Construction and Building Materials*, Vol. 49, 2013, pp. 128-133.

Iraqi Specification (IQS) No. 5, 1984, "Portland Cement", Baghdad, Iraq.

Iraqi Standard specification (IQS) No. 45/1984, "Aggregate from Natural Sources for Concrete and Construction", Baghdad, Iraq.

ASTM C1240-04 "Standard Specification for Silica Fume Used in Cementitious Mixture", 2004.

ASTM C494/C494 M -01"Standard Specification for Chemical Admixtures for Concrete", 2001.

Kareem, A. S. W., " Behavior of Reinforced Modified Reactive Powder Concrete Knee Joints ", *M.Sc. Thesis, University of AL-Mustansiriyah* , Baghdad, Iraq, 2014.
ASTM C39/C39M-05, "Standard Test Method for Compressive Strength of Cylindrical Test Specimens", 2005.
B.S. 1881, part 116, "Method of Determination of Compressive Strength of Concrete Cubes", *British Standards Institution, 1989.*
ASTM A615/615M-13, "Standard Specification for Deformed and Plain Carbon Structural Steel Bars for Concrete Reinforcement", 2013.

Table 1. The cylindrical and cubical compressive strength of concrete*

Concrete Type	Compressive Strength of Cube fcu* MPa	Compressive Strength of Cylinders f 'c* MPa
MRPC1	96	89
MRPC2	83	74
Normal	39	32

*Each value was an average of three specimens.

Table 2. Ultimate Torsional Capacities of The Tested Specimens

Specimen configuration	Tult (kN.m)	% of Difference
NS_1	48.75	R*
$M_1S_1SF_1$	130	166.7
$M_1NS_1SF_1$	77.025	58

R*: refer to reference beam

Table 3. Cracking Torsional Capacities of The Tested Specimens

Specimen configuration	Tcr (kN.m)	% of Difference
NS_1	37.3	R*
$M_1S_1SF_1$	100.7	169.9
$M_1NS_1SF_1$	60.1	61.12

R*: refer to reference beam

Table 4. Stiffness of Specimens at Failure

Specimen configuration	Stiffens at failure (kN.m/degree)	% of Difference
NS_1	19.9	R*
$M_1S_1SF_1$	92.4	362.3
$M_1NS_1SF_1$	33.6	65.8

R*: refer to reference specimens.

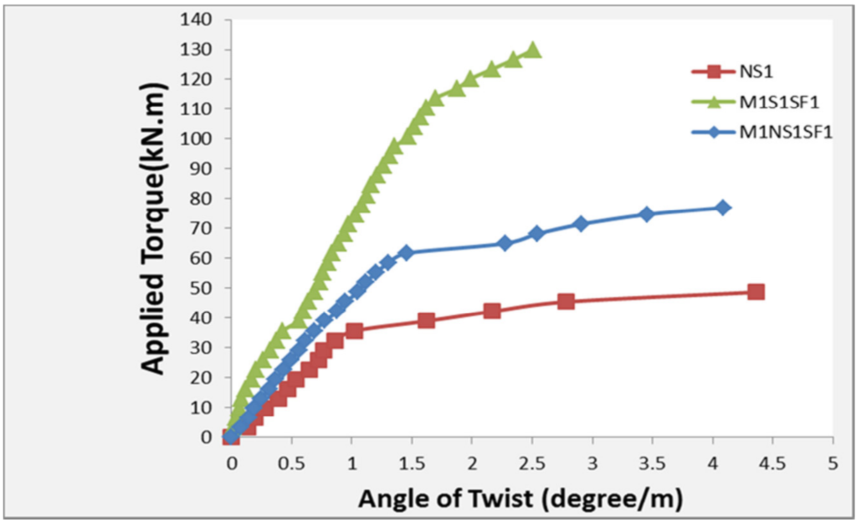

Figure 1. Relationship between Applied Torsion and Angle of Twist of Beam (NS_1, $M_1S_1SF_1$ and $M_1NS_1SF_1$)

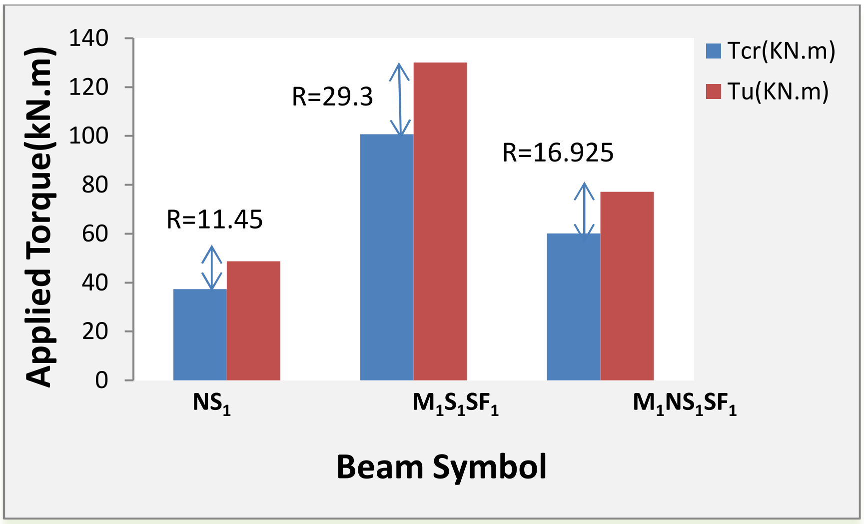

Figure 2. Comparison between Cracking and Ultimate Torsion of Beam (NS_1, $M_1S_1SF_1$ and $M_1NS_1SF_1$)

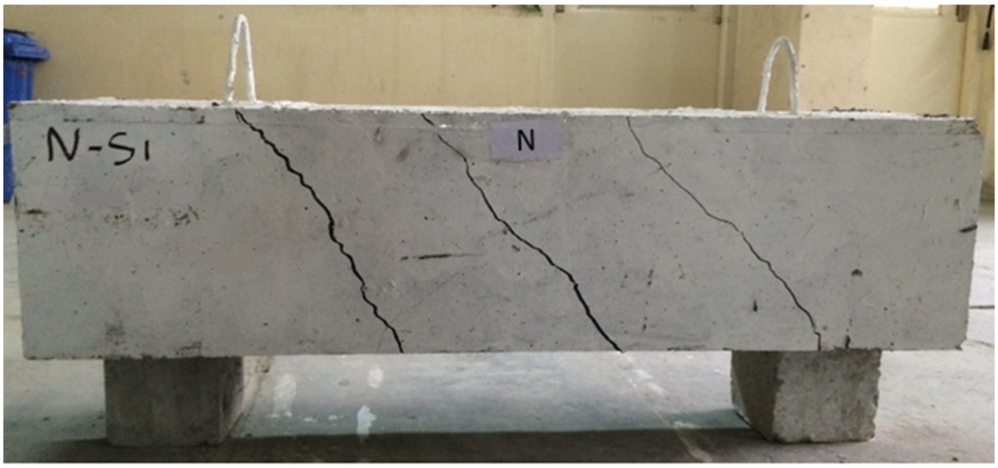

Figure 3. The failure mode for the beam (NS_1)

Figure 4. The failure mode for the beam ($M_1S_1SF_1$)

Figure 5. The failure mode for the beam ($M_1NS_1SF_1$)