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Nonlinear Analysis for behavior of Hollow Box Reinforced Concrete Arch Beams with Transverse Openings

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Abstract

This research is devoted to investigate the behavior and performance of reinforced concrete curved beams(the curved beam and the applied loads lie in same plane) with hollow cross section with and without openings, unstrengthened and strengthened(internally by steel reinforcement). The ultimate deflection and the horizontal displacement of roller end as well as the ultimate load carrying capacity are investigated experimentally and are compared with the control beam (without opening) and also the mode of failure of all the specimens are compared with the control beam in order to investigate the effect of opening location and shape on the overall behavior of each specimen and also to investigate the effect of openings strengthening method suggested by (Mansur 2006).

Keywords: Curved beam, hollow cross section, strengthening

1. Introduction

The main aim of arch is to enhance the load carrying capacity, which may come from the stiffening behavior due to membrane action (Zainul-Abideen, 2010). In the design of arch reinforced concrete bridge girders, hollow section is often adopted in order to (Nimnim, 1993).

1. Reduced the weight, which affects especially the cost of transport, handling and erection for precast cross sections and also reduce the weight transport for other members of construction.
2. Substantial reduction of material quantities, the materials required are usually much less than those needed for other conventional systems.
3. Hollow box cross section is used for concealed mechanical or electrical runs and also to provide partial flange rotational restraints.

So in order to use the hollow cross section arch beam to conceal electrical or mechanical runs it is necessary to install transvers openings through the profile of the beam in order to pass these runs. And the transvers openings may also be used to pass some primary services like telephone, sewage, and computer networks. There for the strengthening process for the openings suggested by (Mansur, 1998) is used in this study in order to enhance the load carrying capacity of the beams with openings.

2. Experimental Work

2.1 Description of Specimens

Eight arch hollow cross section reinforced concrete semicircular beams simply supported (hinge-roller) with and without web openings are tested. All specimens have a geometrical dimensions and cross section as shown in Figure (1). Figure (1) shows the geometrical details and the steel reinforcement of specimens**.**

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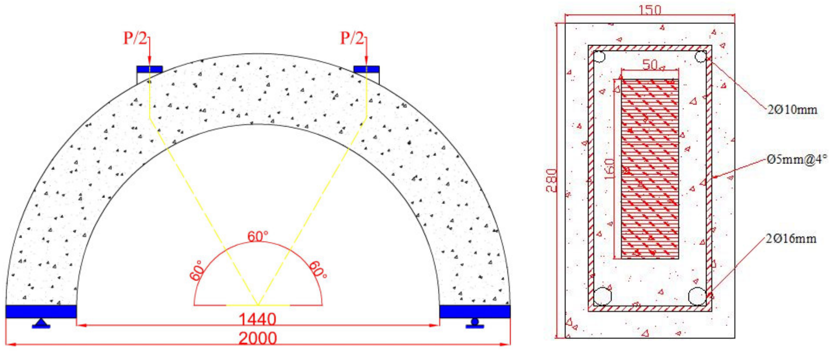


Figure (1): The Geometrical Details and the Steel Reinforcement of Specimens

Table (1) illustrates the identification for each tested Specimen.

Table (1): Description of Tested Specimens

Group No.	Specimen	Location of Openings	Shape of opening	Details	
				Web Reinforcement(Stirrups)	
				At Middle Sector	Around the openings
1st group without openings	B1	--------	--------	Ø5@4°	--------
	B2	--------	--------	--------	--------
2nd group with openings at ϴ=90°	B90	ϴ=90°	Rectangular(8×10)cm	Ø5@4°	--------
3rd group with Openings at ϴ=15°	B15	ϴ=15°	Rectangular(8×10)cm	Ø5@4°	--------
4th group with Openings at ϴ=45° (quarter)	B45	ϴ=45°	rectangular(8×10)cm	Ø5@4°	--------
	Bc45	ϴ=45°	Circular(Ø10cm)	Ø5@4°	--------
	S-B45	ϴ=45°	rectangular(8×10)cm	Ø5@4°	2 Ø 5 each side & Ø5@50mm top chord& Ø5@20mm bottom chord
	S-Bc45	ϴ=45°	circular(Ø10cm)	Ø5@4°	2Ø5 each side & Ø5@50mm top chord& Ø5@20mm bottom chord

ϴ: measured from support

2.2 Hollow section construction

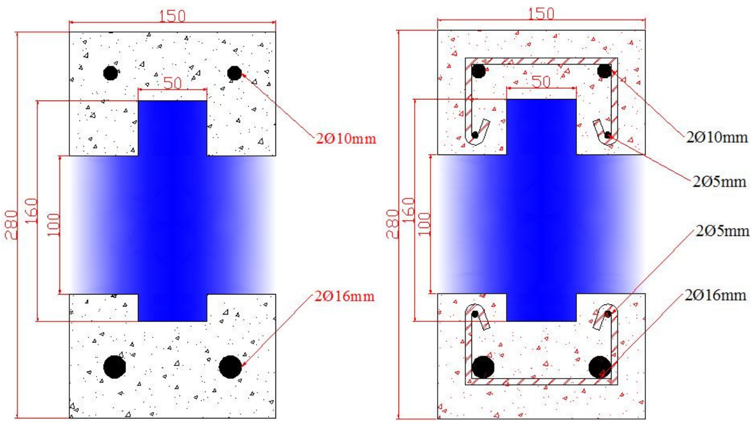
The hollow cross-section of all the specimens is made by putting a rectangular cross-sectional cork. Figure (2) shows the cork pieces and the fastening of it by using iron wires.

Figure (2): The Cork Pieces and the Fastening of it by Using Iron Wires

2.3 Strengthening System

The method of design suggested by (Mansur, 1998) for straight beam is used in strengthening of openings of Specimens S-B45 and S-Bc45 were strengthened by U shaped stirrups (Ø5mm) for top and bottom chords of opening, respectively to resist frame type failure. And two piers of full depth stirrups (Ø5mm) for each side of opening to resist beam type failure. Figure (3) shows typical cross-section through unstrainthed and strengthed openings. The design specification of ACI 318-2011 was satisfied for steel bars reinforcement.

Figure (3): Typical cross-section Through Unstrengthed and Strengthed Openings



2.4 Material Properties of Tested Specimens

2.4.1 Concrete

The materials used in producing concrete are:

1. Ordinary Portland cement was used throughout this investigation for casting all the specimens
2. Natural sand of maximum size of 4.75 mm was used in this investigation
3. A maximum size of 12.5mm of semi-crushed gravel was used in the current study.
4. A powder of limestone with maximum size of 0.125mm is used as inert mineral filler
5. High range water reducing admixture is used in order to reduce the amount of water used in mix design
6. Tap water has been used for mixing concrete and curing all the beams

2.4.2 Reinforcing Steel

Three sizes of reinforcing steel used for all the specimens, (Ø10 mm) and (Ø16mm) were used as main reinforcing steel and (Ø5 mm) were used as closed stirrups. Figure (4) shows the cage of reinforcement.

Figure (4): The Cage of Reinforcement

The tensile test results of Steel Reinforcing Bars illustrated in Table (2)

Table (2): Tensile Test Results of Steel Reinforcing Bars

Nominal diameter(mm)	Measured diameter(mm)	Yield stress(*) (Mpa)	Ultimate strength(*) (Mpa)
5	4.7	520	630
10	9.91	580	650
16	15.7	605	706

(*)Each value is an average of three specimens

2.5 Mechanical Properties of Hardened Concrete

The compressive strength ($f_{c'}$) and splitting tensile strength (f_t) for each specimen are presented in Table (3), the average of testing three cylindrical specimens (150mm × 300mm) for compressive strength and the average of testing three cylindrical specimens (100mm × 200mm) for splitting tensile strength for each beam is presented in Table (3)

Table (3): Properties of Hardened Concrete

Specimen No.	Compressive strength of concrete $f_{c'}$ (MPa)	Splitting tensile strength f_t(MPa)
B1	40.7	5.35
B2	43.2	5.56
B90	39.4	5.21
B15	43.06	5.58
B45	38.74	5.05
Bc45	41.25	5.47
S-B45	44.63	5.85
S-Bc45	36.64	4.84

2.6 Test Procedure

Tests were carried out using hydraulic testing machine as shown in Figure (5)

Figure (5): Loading Machine and Readings of Dial Gages Used in the Tests

2.7 Loading and Support Condition

The details of (hinge-roller) support condition are shown in Figure (6)

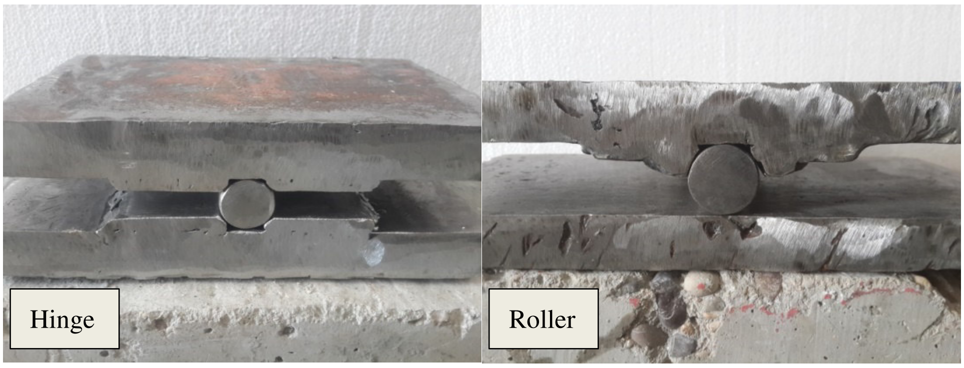


Figure (6): (Hinge-Roller) Support Condition

and the loading system (of two point load) is shown in Figure (7)

Figure (7): Loading System (of Two Point Load)

3. Experimental results

All the specimens tested under two point loads. First cracks, ultimate load, mode of failure and the decrease in the ultimate loads with respect to the control beam B1 for all the tested beams are illustrated in Table(4).

Table (4): First cracking load, Failure loads, Mode of failure and the decrease in ultimate loads with respect to the control beam B1

Beam symbol	First crack load (kN)	Failure load (kN)	Failure load difference (*) (%)	Mode of failure
B1	84	378	---------	Crushing of concrete
B2	73	204	46.03	Splitting failure (due to curvature forces)
B90	84	356	5.82	Crushing of concrete
B45	83	224	40.74	Shear failure (frame type failure in opening)
B15	85	365	3.43	Shear failure (at the shear region)
Bc45	87	254	32.8	Shear failure (frame type failure in opening)
S-B45	93	276	26.98	Shear failure (frame type failure in opening)
S-Bc45	71	315	16.66	Shear failure (frame type failure in opening)

(*) difference= {(Failure load (B1)-Failure load) / Failure load (B1)} ×100%

As shown in Table (4) the most effective location of the opening at 45^o. This due to the combination of shear force, bending moment and compression force in that location. So in order to study the effect of opening shape and the strengthening method suggested by (Mansur 1998) the location of combined shear force, bending moment and compression force is chosen. The mode of failure of control beams are shown in Figure (8)

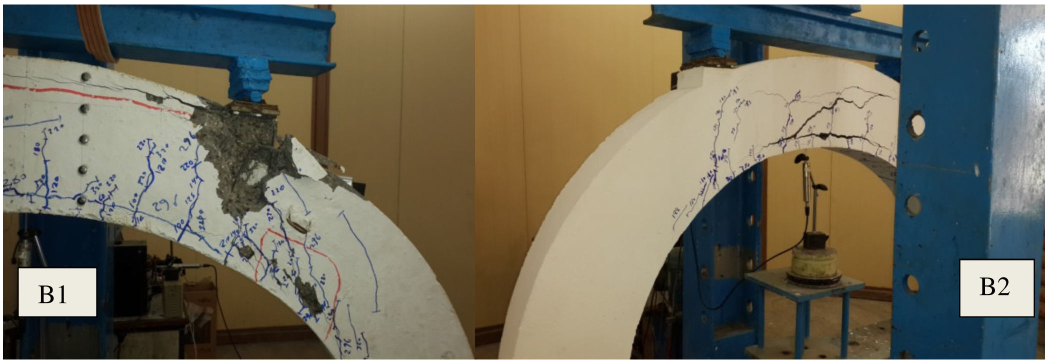


Figure (8): Modes of Failure of Control Beams (B1, B2)

As shown in Figure(8) the failure of control beam B2 is by splitting of concrete cover along the middle sector while the failure of the control beam B1 is by crushing of concrete in compression face. This due to absence of confining stirrups to resist the curvature forces generated from the horizontal movement of the roller end of the beam. Figure (9) to Figure (11) shows modes of failure of the other beams with openings.

Figure (9): Modes of Failure of Beams (B90, B15)

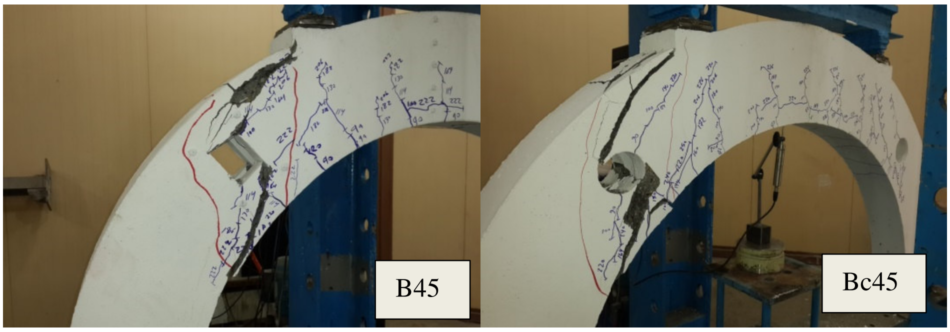


Figure (10): Modes of Failure of Beams (B45, Bc45)

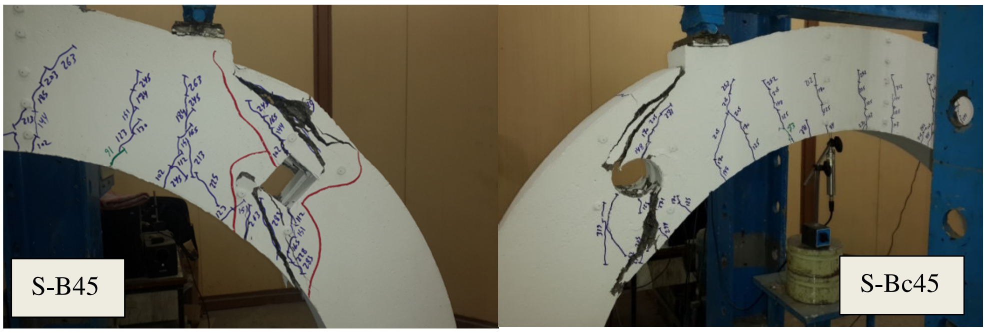


Figure (11): Modes of Failure of Beams (S-B45, S-Bc45)

The comparison in load-deflection curves between control beam B1 and other specimens are shown in Figure (12) to Figure (19).

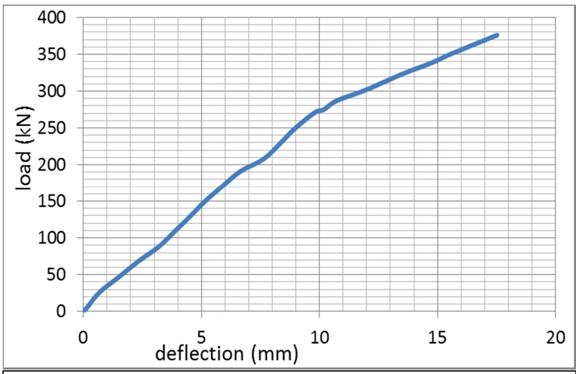


Figure (12): Load-Deflection of Beam (B1)

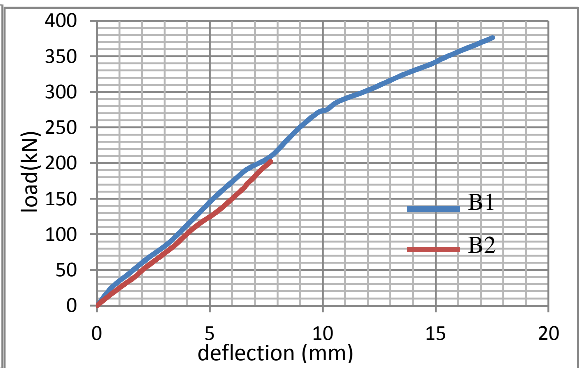


Figure (13): Load-Deflection Comparison of Beam (B1, B2)

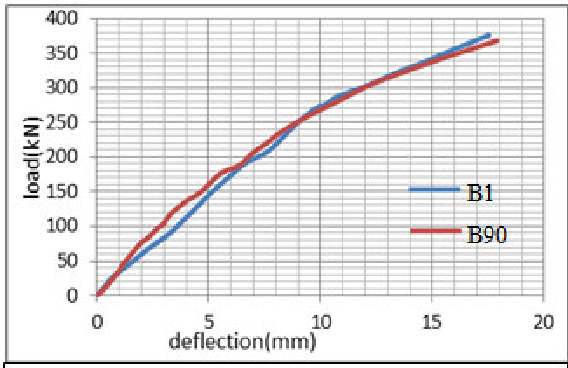


Figure (14): Load-Deflection Comparison of Beam (B1, B90)

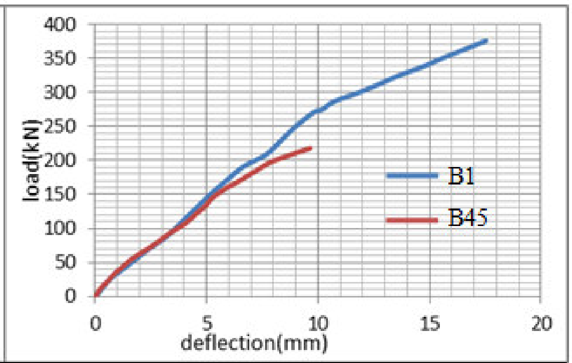


Figure (15): Load-Deflection Comparison of Beam (B1, B45)

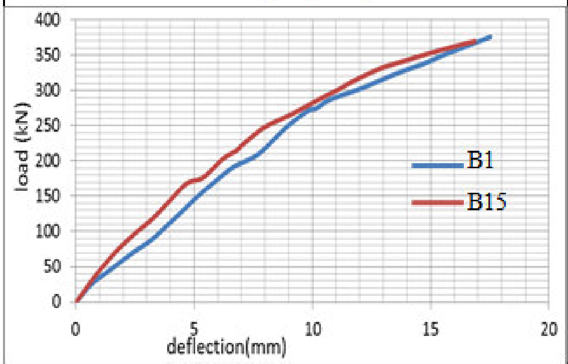


Figure (16): Load-Deflection Comparison of Beam (B1, B15)

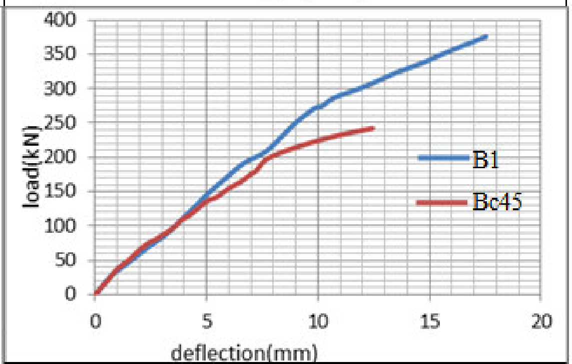


Figure (17): Load-Deflection Comparison of Beam (B1, Bc45)

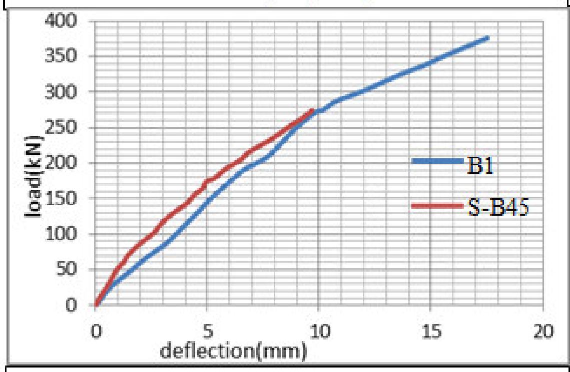


Figure (18): Load-Deflection Comparison of Beam (B1, S-B45)

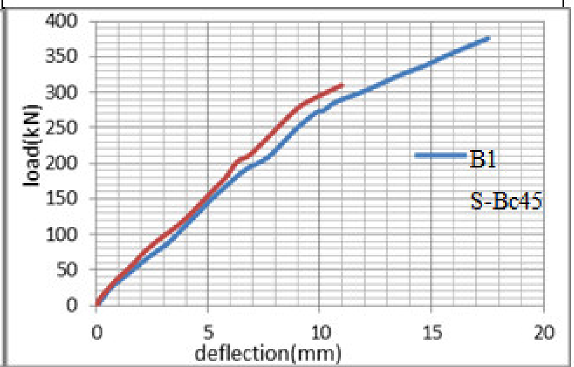


Figure (19): Load-Deflection Comparison of Beam (B1, S-Bc45)

4. Conclusion

The test results showed that the absence of the confining stirrups lead to decrease the ultimate load when compared with the control beam by about (46%). This due to the curvature forces generated in the beam. The location of the opening has a great effect on the load carrying capacity. The locating of opening near the support and at the pure bending zone has no noticeable effect on the ultimate load carrying capacity when compared with the locating of opening in combined shear force, bending moment and compression force which has a great effect in decrease load carrying capacity compared with the control beam by approximately (40.74% for rectangular opening) and (32.8% for circular opening). The shape of the opening has also a noticeable effect on the load carrying capacity where the unstrengthed circular opening give an increase by about (12.5%) in the load carrying capacity when compared with unstrengthed rectangular opening has the same area, cross sectional depth and location. The design method suggested by (Mansur 1998) has also a noticeable effect on the load carrying capacity and led to increase the load carrying capacity by about (23.21%) and (24%) for both circular and rectangular strengthed openings when compared with circular and rectangular unstrengthed openings, respectively.

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