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Behavior of Prestressed Concrete Beams with Openings in Shear Region

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ABSTRACT

In the construction of modern buildings many pipes and ducts are necessary to accommodate essentially services like (water supply, swage, air condition, electricity, telephone and computer network).To pass these ducts through transverse openings in the floor Prestressed concrete beams, some parameters must be studied to know the effect of these parameters on the strength and on the toughness of the Prestressed concrete beams, these parameters were the size and location of the openings and shear span of the tested beams. So ten beams were prepared and tested {two beams without openings (as a guide beams) and eight (8) beams with openings (with different openings dimensioning, different locations and different shear span)}.The tested of all the rectangular beams were carried out and the results were recorded and we noticed that, the strength of Prestressed concrete beams increase with decrease the size of the openings and with increase the shear span, (the toughness*) of the Prestressed concrete beams increase with increase the size of the openings and with the decrease of shear span.

1. Introduction

In the construction of modern buildings, a network of pipes and ducts is very necessary to accommodate essential services like water supply, sewage, air-conditioning, electricity, telephone, and computer network. Usually, these pipes and ducts are placed underneath the beam soffit and for aesthetic reasons are covered by a suspended ceiling, thus creating a dead space. Passing these ducts through transverse openings in the floor beams leads to a reduction in the dead space results in a more compact design. For small buildings, the savings thus achieved may not be significant, but for multistory buildings, any saving in story height multiplied by the number of stories can represent a substantial saving in total height, length of air-conditioning and electrical ducts, plumbing risers, wall and partition surfaces, and overall load on the foundation. Beam openings may be of different shapes, size and are generally close to the supports where shear is dominate. In practical life it quite often use to provide convenient passage of environmental services which reduce the story heights of buildings and weight of concrete beams as it improves the demand on the supporting frame both under gravity loading and seismic excitation which results in major cost saving. Openings should be positioned on concrete beams to provide chords with sufficient concrete area for developing ultimate compression

*Toughness is defined as the ability of a material to absorbed energy and plastically deform without fracturing, it is requires abalance of strength and ductility.

block in flexure and adequate depth for providing effective shear reinforcement [1].

Hanson (1969) tested a typical joist floor i.e. a series of longitudinally RC T-beams representing square and circular openings in the web and found that an opening located adjacent to the center stub (support) produced no reduction in strength [2].

The test data reported by **Somes and Corley** (1974) indicated that when a small opening (0.25) times the depth of the beam is introduced in the web of a beam, which is unreinforced in shear, the mode of failure remains essentially the same as that of a solid beam [3].

Salam (1977) investigated perforated beams of rectangular cross section under two symmetrical point loads [4]. **Siao and Yap** (1990) stated that the beams fail prematurely by sudden Formation of diagonal crack in the compression chord when no additional reinforcement is provided in the members near the opening (chord members) [5].

Mansur et al (1991) tested eight (8) RC continuous beams, each containing a large transverse opening and found an increase in depth of opening led to a reduction in collapse load. **Mansur** (1998) discussed about the effects of transverse opening on the behaviour and strength of RC beams under predominant shear and stated that opening represents a source of weakness and the failure plane always passes through the opening, except when the opening is very close to the support to bypass the potential inclined failure plane**. Abdalla et al**. (2003) used fiber reinforced polymer (FRP) sheets to strengthen the opening region [6].

2. Experimental Work

The experimental program consists of testing ten (10) Prestressed concrete beams with total depth (d) of 325 mm, total length (L) of 5300 mm. Eight beams (8 beams) with openings, Square openings (100*100 mm), rectangular openings (200*100 mm), two beams (2 beams) without openings as a control beams, all the beams had the same reinforcement (strand and reinforced steel), as shown in Fig. (5).

The beams were simply supported with a clear span of 5000 mm. Specimens were casted with nominal characteristic compressive strength of concrete cubes after 28 days not less than 400 kg/cm2 (40.0 Mpa). Concrete specimens were remoulded after 24 hours from casting, covered with wet burlap for 28 days, after that were stored under laboratory condition up to testing date. Voids (openings) with varying width and constant height (100*100, 200*100 mm) were applied as showing in Figures (3, 4). The details of all tested beams as shown in Table (3).

2.1 Test Program.

The Experimental test program was included ten test specimens (15*35*500 cm), were tested in shear under two point loading. Ten specimens were divided into two groups as shown in Table (3) as the following:-

Group (1), Where [Shear span / depth ratio, (a /d) equal to 2.5] consists of five specimens as the following:-one Beam without openings (as a reference beam) (B1). Beam with square openings (S) and location (X1)… B1-1 (S). Beam with square openings (S) and location(X2) … B1-2 (S). Beam with rectangular openings (R) and location (X1)… B1-1(R). Beam with rectangular openings (R) and location (X2)… B1-2 (R).

Group (2), where [Shear span / depth ratio, (a /d) equal to 4.0] consists of five specimens as the following:-
One Beam without openings (B2) (as a reference beam). Beam with square openings (S) and location (X1) B2-1(S), Beam with square openings(S) and location(X2)...B2-2(S), Beam with rectangular openings (R) and location(X1)…B2-1(R). Beam with rectangular openings (R) and location (X2)… B 2-2 (R).

2.2 Test Setup

The beams were subjected to two vertical point loads, up to failure using a hydraulic .machine of 500 – KN capacity. The load was measured using a load cell of (500 KN) capacity as shown in Figures (1, 2), Photos (3, 4). The load was applied on the beam using a strake control system. The data was collected using a data acquisition and “lab view” software at a rate of one sample per second.

Table (1): The materials used in mix design

Component	***Weight (kg)***	***S.G (Kg/m³)***	***Volume(m³)***
Sand	606	2620	0.23
Dolomite	1212	2640	0.46
Cement	450	3150	0.14
Water	171	1000	0.17
admixtures	9		

Table (2): Show the properties of prestressed steel

Strand type	**ASTM A416-85-Grad 270**
Diameter	15.24 mm
Area	140 mm²
Mass	1.10 kg/m
Yield stress	1670 kN/mm²
Ultimate strength	1860 kN /mm²
Modules of elasticity	19500 kN /mm²
Relaxation after 100 Hr	Max 2.5 percent

Table (3): The detailed of the all tested beams.

Groups	**Beams**	**Dimension of opening (mm)**	**Shear span / depth ratio, (a/d)**	**Distance from center of opening to the support (X1) cm**	**Distance from center of opening to the applied load (X2) cm**
Group (1)	B1	Without openings	2.5	-	-
	B1-1 (S)	100x 100	2.5	32.5	
	B 1-1 (R)	200 x 100	2.5	32.5	
	B 1-2 (S)	100 x 100	2.5		32.5
	B 1-2 (R)	200 x 100	2.5		32.5
Group (2)	B2	Without openings	4		
	B 2-1 (S)	100 x 100	4	32.5	
	B2-1 (R)	200x100	4	32.5	
	B 2-2 (S)	100 x 100	4		32.5
	B 2-2 (R)	200 x 100	4		32.5

Deflection was measured using three variable differential transducers, LVDT01, LVDT02 and LVDT03, where LVDT01 (at the beam mid-span), LVDT02 and LVDT03 {(at right support and left support respectively), as shown in photos (3, 4).

2.3 Test Specimens.

All tested specimens at {shear span/ depth, (a/d) = 2.5} are known as Group (1) {B1, B1-1(S), B1-1(R), B1-2(S), B1-2(R)}. All tested specimens at {shear span/ depth, (a/d) = 4.0} are known as Group (2) { B2,B2-1(S),B2-1(R),B2-2(S),B2-(R)}.Where specimens (B1), (B2) were tested as a control specimens without openings. Specimens {(B1-1 (S)} and {B1-2 (S)} had openings with dimension of 100*100 mm at locations X1, X2 respectively. Specimens {(B1-1(R)} and {B1-2(R)} had openings of 200*100 mm with locations of X1, X2 respectively. Specimens {(B2-1(S)} and {B2-2 (S)} had openings with dimension of 100*100 mm at locations X1, X2 respectively, Specimens {(B2-1(R)} and {B2-2(R)} had openings of 200*100 mm with locations of (X1, X2) respectively.

The data of moment, toughness and deflection are obtained a shown in Figures (6, 7, 8), Tables (4, 5, 6).

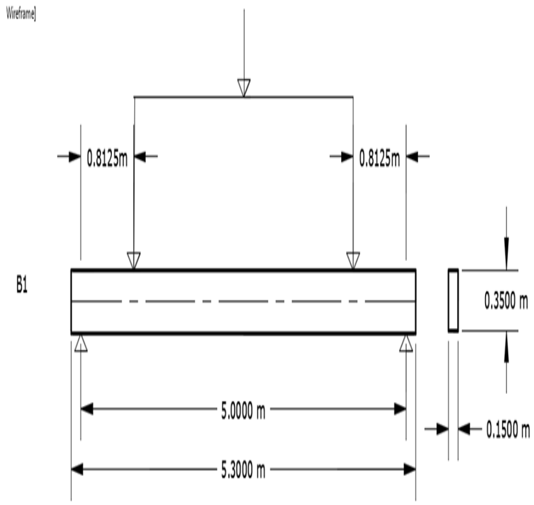

Fig (1): Loading of group (1)

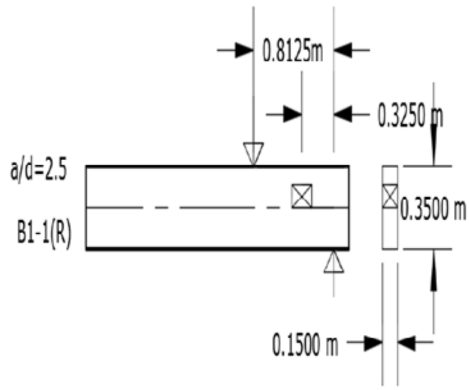

Fig (3): Tested beam B1-1(R), group (1),

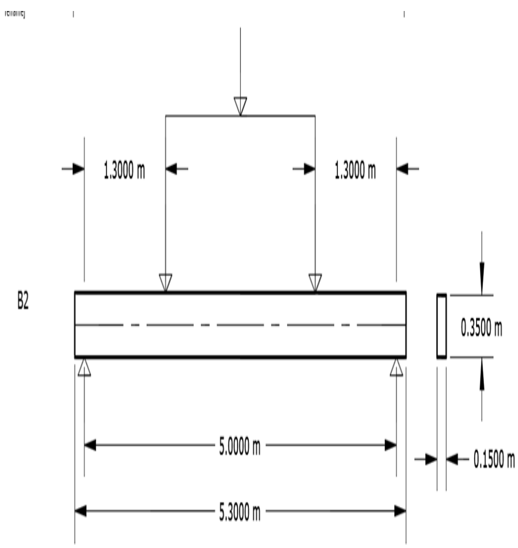

Fig (2): Loading of group (2)

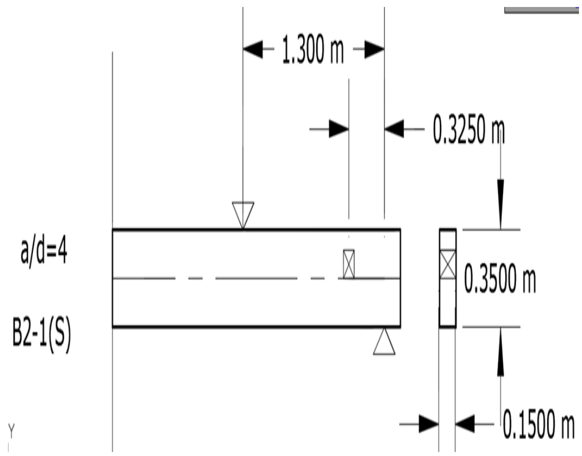

Fig (4): Tested beam B2-1(S), group (2)

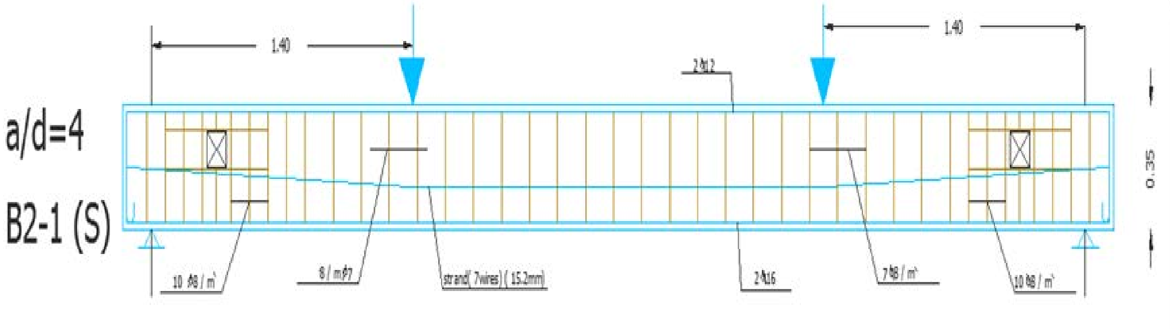

Fig. (5): Detailed of reinforced and Prestressed steel (strand) in beam B2-1(S)

Photo (1): Stretched the strands

Photo (2): Injection the grouting

Photo (3): Tested beam {B2-1(S)}

Photo (4): Tested beam {B2-1(R) during the test.

4 - Results

4.1 Effect of the different shapes of web openings (S, R) on the strength and on the Toughness.

Table 4: The effect of the size and shape of openings {(square, rectangular) openings} Of the tested beams on the strength and toughness.

		Effect of shapes of openings (S,R)			
Groups	**Beams**	**Moment (kN.m)**	**% of increasing in Moment**	**Toughness**	**% of Reduction in Toughness**
Group (1)	B1-1 (S)	87.8	2.0 %	10145	14.00%
	B1-1 (R)	86.0		11528	
	B1-2 (S)	91	1.3 %	7792	21.00%
	B1-2 (R)	89.8		9388	
Group (2)	B2-1 (S)	101.4	7.0 %	6986	10.00%
	B2-1 (R)	95		7653	
	B2-2 (S)	97.5	5.0 %	7654	6.00%
	B2-2 (R)	93		8077	

From Table (4) it was noticed that:-

4.1.1 Effect of the different shapes of web openings (S, R) on the strength

For group (1)

The effect of different shapes of web openings (S,R) on the strength of specimens at the same location(X1) and the same shear span(a) [group (1]) .where the maximum

Moment of the specimen {B1-1(S)} more than the maximum. moment of the specimen {B1-1(R)} by (2.0 %).The effect of different sizes of web openings (S,R) on the strength of specimens at the same location(X2) and the same shear span(a) [group (1)], Where the maximum moment of the specimen {B1-2(S)} more than the maximum moment of the specimen {B1-2(R)} by (1.30 %).

For group (2)

The effect of different shapes of web openings (S, R) on the strength of specimens at the same location (X1) and the same shear span (a) [group (2)]. Where the maximum moment of the specimen {B2-1(S)} more than the maximum moment of the specimen {B2-1(R)} by (7.0 %).

The effect of different shapes of web openings(S,R) on the strength of specimens at the same location(X2)and the same shear span(a2) [group (2)].Where the maximum moment of the specimen {B2-2(S)} more than the maximum moment of the specimen {B2-2(R)} by (5.0 %).

4.1.2 Effect of the different shapes of Web openings (S, R) on the toughness.

For group (1)

The effect of different shapes of web openings (S,R) on the toughness of specimens at the same location(X1)and the same shear span(a/d=2.5) [group (1)]. Where the Toughness of the specimen {B1-1(S)} little than the Toughness of the specimen {B1-1(R)} by (14.0 %).The effect of different shapes of web openings (S,R) on the Toughness of specimens at the same location (X2)and the same shear span ratio (a/d=2.5) [group (1)], Where the Toughness of the specimen {B1-2(S)} little than the Toughness of the specimen {B1-2(R)} by (21.0 %).

For group (2)

The effect of different shapes of web openings (S,R) on the Toughness of specimens at the same location (X1) and the same shear span ratio (a/d=4.0) [group (2)]. Where the Toughness of the specimen {B2-1(S)} little than the toughness of the specimen {B2-1(R)} by (10.0 %).

The effect of different shapes of web openings(S,R) on Toughness of specimens at the same location(X2) and the same shear span ratio (a/d=4.0) [group (2)]. Where the Toughness of the specimen {B2-2(S)} little than the Toughness of the specimen {B2-2(R)} by (6.0 %).

4.2 Effect of locations (X1, X2) on the strength and on the toughness.

Table **5**: presents the effect of the locations of the openings (X1, X2) of the tested beams on the strength and toughness. From Table (4) we noticed that:-

4.2.1 Effect of locations (X1, X2) on the strength.

For group (1)

The effect of different locations (X1, X2) on the strength with the same openings (100*100 mm), and with the same shear span (a) [group (1)], Where the moment of the specimen {B1-1 (S)} little than the moment of the specimen {B1-2(S)} by (4.0 %).

The effect of different locations (X1, X2) on the strength with the same openings (200*100 mm), and with the same shear span (a) [group (1)], Where the moment of the specimen {B1-1 (R)} little than the moment of the specimen {B1-2(R)} by (5.0 %).

For group (2)

The effect of different locations (X1, X2) on the strength with the same openings (100*100 mm), and with the same shear span (a) [group (2)], Where the moment of the specimen {B2-1 (S)} more than the moment of the specimen {B2-2 (S)} by (4.0%). The effect of different locations (X1,, X2) on the strength with the same openings (200*100 mm), and with the same shear span (a) [group (2)], Where the moment of the specimen {B2-1 (R)} more than the moment of the specimen {B2-2 (R)} by (2.0%).

4.2.2 Effect of locations (X1, X2) on the toughness.

For group (1)

The effect of different locations (X1, X2) on the toughness with the same openings (100*100 mm), and the same shear span ratio (a/d=2.5) [group (1)], Where the toughness of the specimen {B1-1 (S)} .more than the toughness of the specimen {B1-2(S)} by (30.0 %).

The effect of different locations(X1, X2) on the toughness with the same openings (200*100 mm) and the same shear span (a) [group (1)]. Where the toughness of the specimen {B1-1 (R)} more than the toughness of the specimen {B1-2 (R)} by (23.0 %).

For group (2)

The effect of different locations (X1 , X2) on the toughness with the same openings (100*100 mm), and the same shear span ratio (a/d=4.0) [group (2)], Where the toughness of the specimen {B2-1 (S)} little than the toughness of the specimen {B2-2(S)} by (10.0 %).The effect of different locations (X1, X2) on the toughness with the same openings (200*100 mm), and the same shear span (a) [group (2)], Where the

Table 5: The effect of the locations of the openings (X1, X2) of the tested beams on the strength and toughness.

		Effect of locations (X1, X2)			
Groups	**Beams**	**Moment (KN.m)**	**Percentage of increasing and decreasing in Moment**	**Toughness**	**Percentage of decreasing and increasing in Toughness**
Group (1)	B1-1 (S)	87.8	4.0 %	10145	30.0%
	B1-2 (S)	91		7792	
	B1-1 (R)	86	5.0 %	11528	23.0%
	B1-2 (R)	89.8		9388	
Group (2)	B2-1 (S)	101.4	4.0 %	6986	10.0%
	B2-2 (S)	97.5		7654	
	B2-1 (R)	95	2.0 %	7653	6.0%
	B2-2 (R)	93		8077	

4.3 The effect of shear span/depth (ratio) [a/d] on the Strength and on the Toughness.

Table 6: The effect of the shear span of the tested beams on the strength and toughness.

	Effect of shear span {(a/d) ratio}			
Beams	**Moment (KN.m)**	**Percentage of decreasing in Moment**	**Toughness**	**Percentage of increasing in Toughness**
B1	100	3.0 %	18287	17.0 %
B2	102.7		15673	
B1-1 (S)	87.8	16.0 %	10145	45.0 %
B2-1 (S)	101.4		6986	
B1-1 (R)	86	11.0 %	11528	51.0 %
B2-1 (R)	95		7653	
B1-2 (S)	91	7.0 %	7792	2.0 %
B2-2 (S)	97.5		7654	
B1-2 (R)	89.8	4.0 %	9388	16.0 %
B2-2 (R)	93		8077	

4.3.1 The effect of shear span/depth (ratio) [a/d] on the strength

As shown in Table (6): we noticed that:-

For control specimens (without openings)

The effect of shear span/depth (ratio) on the strength of the specimens without openings (control specimens). Where the moment of the specimen (B1) with shear span / depth (ratio) {(a/d=2.5) group (1)} little than the moment of the specimen (B2) with shear {(a/d=4.0) group (2)} by (3.0 %).

The effect of shear span on the strength of the beams with the openings of (100x100 mm) and location of (X1). Where the maximum moment with shear span/ depth (ratio) {(a / d =2.5) group (1)} little than the maximum moment with shear span/ depth (ratio) {(a /d=4.0) group (2)} by (16.0 %).

The effect of shear span on the strength of the beams with the openings of (200x100 mm) and location of (X1),Where The maximum moment with shear span/ depth (ratio) {(a /d=2.5) group (1)} little than the maximum moment with shear span/ depth (ratio) {(a /d=4.0) group (2)} by (11.0 %).

The effect of shear span on the strength of the beams with the openings of (100x100 mm) and location of (X2),where The maximum moment with shear span/ depth (ratio) {(a/d=2.5) group (1)} little than the maximum moment with shear span/ depth (ratio) {(a/d=4.0) group (2)} by (7.0 %).

The effect of shear span on the strength of the beams with the openings of (200x100 mm) and location of (X2),Where The maximum moment with shear span/ depth (ratio) {(a/d=2.5) group (1)} little than the maximum moment with shear span/depth (ratio) {(a/d=4.0) group (2)} by (4.0 %).

4.3.2 The effect of shear span/depth (ratio) [a/d] on the toughness.

As shown in Table (6), the following are noticed:-

- For control specimens (without openings):

The effect of shear span/depth (ratio) on the Toughness of the specimens without openings (control specimens).Where The Toughness of the specimen (B1) with shear span/depth (ratio) {(a1/d=2.5) group (1)} more than the Toughness of the specimen (B2) with shear {(a/d=4.0) group (2)} by (17.0 %).

- For the specimens with openings:

The effect of shear span on the Toughness of the beams with the openings of (100x100 mm) and location of (X1),Where The Toughness with shear span/ depth (ratio) {(a /d=2.5) group (1)} greater than the Toughness with shear span/depth (ratio) {(a/d=4.0) group (2)} by (45.0 %).

- The effect of shear span on the Toughness of the beams with the openings of (200 x 100 mm) and location of (X1),Where The Toughness with shear span/ depth (ratio) {(a /d=2.5) group (1)} greater than the Toughness with shear span/ depth (ratio) {(a /d=4.0) group (2)} by (51.0 %).
- The effect of shear span on the Toughness of the beams with the openings of (100x100 mm) and location of (X2),Where The Toughness with shear span/ depth (ratio) {(a /d=2.5) group (1)} greater than the Toughness with shear span/ depth (ratio) {(a /d=4.0) group (2)} by (2.0 %).
- The effect of shear span on the Toughness of the beams with the openings of (200x100 mm) and location of (X2),Where The Toughness with shear

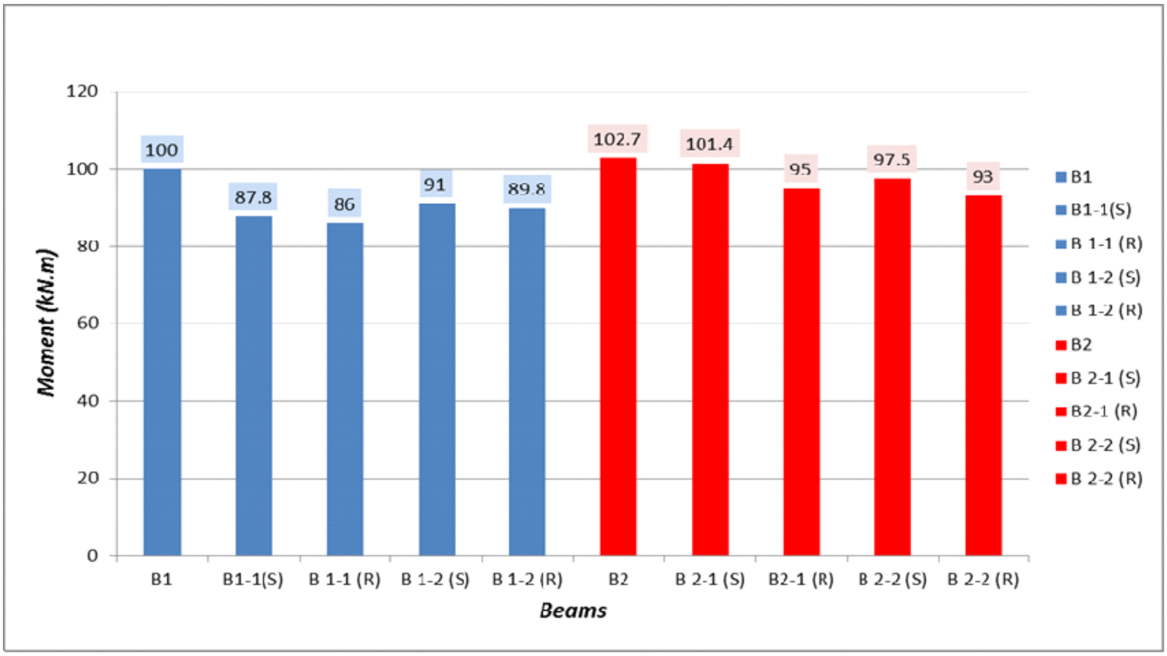

Fig (6): Values of (Maximum Moment) for all tested beams.

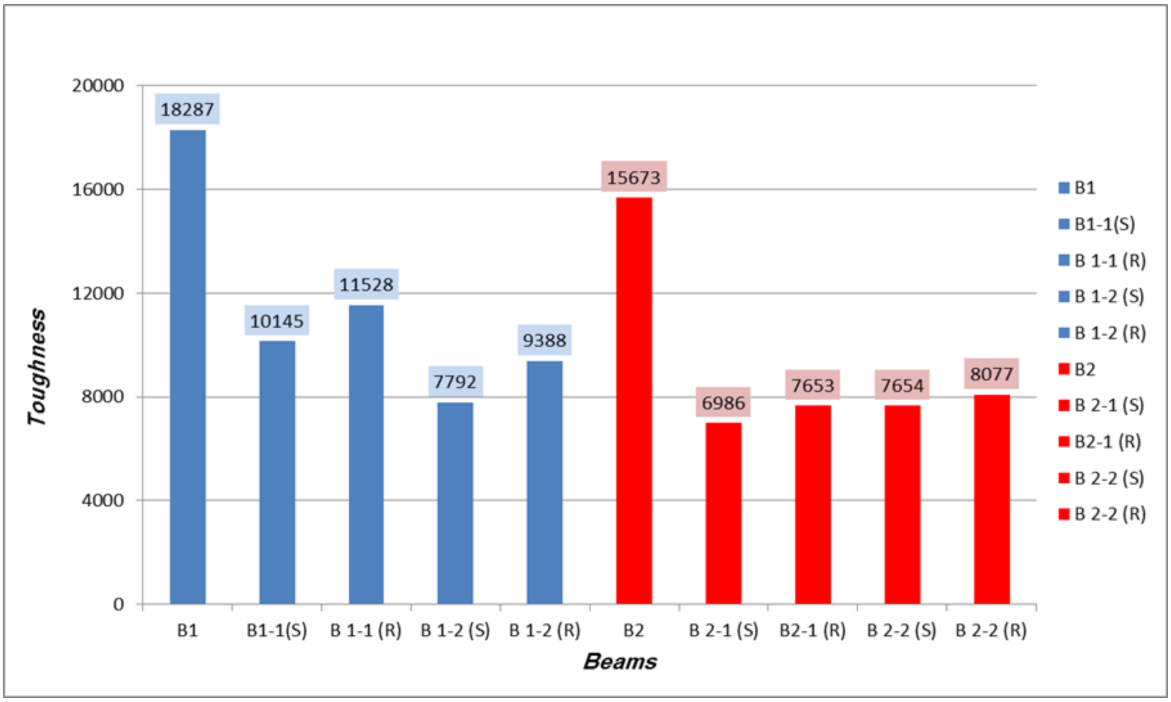

Fig (7): Values of (Toughness) for all tested beams.

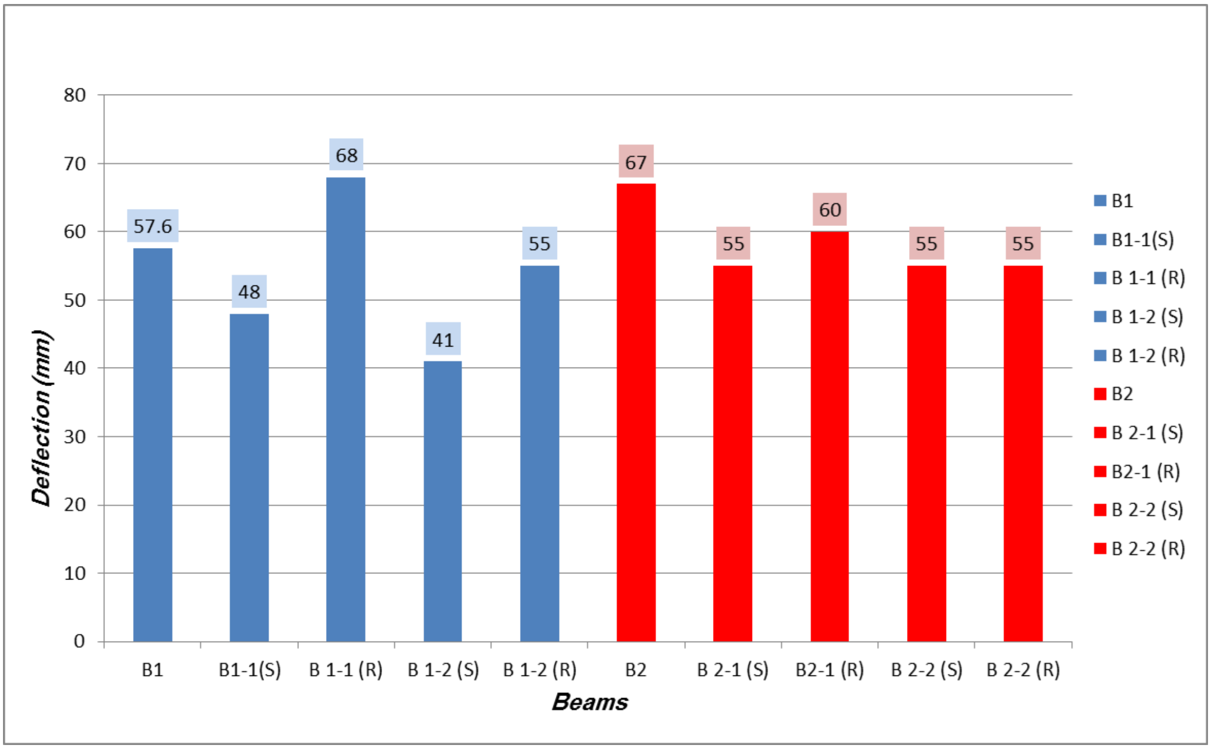

Fig (8): Values of (Deflection) for all tested beams.

Photo (5) Failure of the tested beam {B1-1 (S)}.

Photo (6) Failure of the tested beam {B1-2 (S)}.

span/ depth (ratio) {(a /d=2.5) group (1)} greater than the Toughness with shear span/ depth(ratio){(a /d=4.0) group (2)} by (16.0 %).

Conclusion

1 - Effect of the shapes of the openings (S, R) on Strength and Toughness:-
With increasing the dimensions of the web openings in the Prestressed concrete beams that is leads to decrease Strength and increase toughness.

2 - Effect of the locations of the openings (X1, X2) on Strength and Toughness.
In case of decreasing shear span ratio (a/d = 2.5) (group 1) the following were remarked:-
With the openings near the applied load (X2) that is leads to increase Strength and decrease Toughness.
In case of increasing shear span ratio (a/d = 4.0) (group 2). The following were remarked:-
With the openings near the support, (X1) that is leads to increase Strength and decrease Toughness.

3- Effect of shear span ratio (a/d) on Strength and Toughness:-
With increasing shear, span ratio (a/d) in the prestressed concrete beams that leads to increase Strength and decrease Toughness.

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