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Flexural Behavior of Reinforced Concrete Beams with Arched Openings

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Abstract:- *In the past, the arch represents one of the few structural systems which make it possible to cover large spans. Nowadays, the same importance is presented especially in the construction of bridges and arched structures that are constructed in different shapes and from various materials such as brick, steel, and reinforced concrete. This paper presents an experimental investigation for three beams one control beam with arced open only and two beams with arched and rectangular open once in shear and another in flexure, the present analytical study by using ANSYS program and present some of the parametric studies. The beams were tested under four points bending test. Ultimate loads, load-deflection curves, cracking and crushing patterns for experimental beams, study verification for the experimental work, and the effect some of the parametric study (open size and open shape).The result showed thatwhen the rectangular opening whose dimensions are (0.09 L' * 0.35 t) at the shear zone, at a distance of (d/2) which is measured from the support to the center of the opening, the bearing capacity of the beam with arched opening decreases by about 5 % and the deflection decreases by 17 % compared to control beam BC1 also the beam changes its behavior every 0.05 L' when the opening is rectangular at flexural zone.*

Keywords: *-Arched beam, Opening, flexure, load capacity*

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I. Introduction

There are two important topics to study. The first topic is the openings in the concrete beams to accommodate basic services such as air conditioning ducts, water supply, electricity, and heating ducts, but the creation of such openings in the current RC beams causes a break in the natural flow of stress which reduces beam capacity and its stiffness. Creating a web opening for a beam causes early diagonal cracks and significantly reduces the beam shear capacity,where the shear capacity decreases when the opening depth and/or width is greater, the circular and rectangular openings are most common.[1]The openings of the circular, rectangular, triangular and even irregular shapes are considered. When the size of the opening is concerned, many researchers have used the terms small and large. From a survey of available literature, however, it has been noted [2-3]that the essence of such classification lies in the structural response of the beam. When the opening is small enough to maintain the beam-type behavior or, in other words, if the usual beam theory applies, then the opening may be termed as a small opening. When it comes to opening size, it has been observed [2-3] that the substance of this classification lies in the structural response of the beam. When the opening is small enough to maintain beam-type behavior, in other words, if the usual beam theory applies, the opening can be called a small opening. When the beam-type behavior stops due to the provision of openings, the opening may be classified as a large opening, and therefore the beams with small and large openings need separate methods in design. According to [4],a small opening can be considered when its depth d or its diameter D is less than or equal to 0.25 times the depth of the beam h and its length is less than or equal to its depth d. In such a case, the beam action may be assumed to prevail. Therefore, the analysis and design of a beam with small openings may follow a similar course of action that a solid beam follows. Thus, small openings are defined as sufficiently small openings and located in such a way that allows Strut and Tie to jump over openings without causing additional vertical or horizontal struts in the chords above and below the openings [5]Compared to a beam with small openings, large openings can be defined as an opening that requires additional vertical and horizontal struts in the chords above and below the opening [5].Bernoulli's hypothesis of plane strain distribution is invalid with respect to the whole cross-section through a large opening [5], so the opening can be considered large when its depth d or diameter D is greater than 0.25 times the depth of the beam h and its length is greater than its depth d because the insertion of these openings reduces the strength of the beam [6].The second topic is the arc, which is used to support a load of more than a straight beam. [7]. This situation is in line with concrete materials, which are relatively low to carrying tension and shear stresses but are able to carry compressive stresses. Many specialists provided experimental and analytical investigations of reinforced concrete arches. These tests were started in 1960 by Jin [8]. Also, the behavior of the curved beam under constant load on different cross-shapes and the special requirements have been studied by several authors through numerous experimental programs such as; Al-Thabhawi (2012) [9], and Hamza (2013) [10]. Comprehensive experimental and analytical studies have been conducted to investigate non-prismatic beams behaviors under various loading methods that are widely used in many engineering structures such as Hans et.al in 2012 [11], in 2013,Rojas [12], Orr et al. (2014) [13], and Nabbat (2015) [14-15].

II. Experimental Work

2.1 Test Materials

The following materials had beenselected and tested according to the Egyptian specifications and standards; the materials used in concrete mix as follows:

- **Cement** isa (CEM I, 52.5N) product by theSuez cement factory. Its chemical andphysical characteristics satisfy the requirements of the Egyptian Standard Specifications (E.S.S. 4756-1/2018) [16].
- The used fine aggregate in the experimental program is natural siliceous sand. Its characteristics satisfy the requirements of the Egyptian Code of Practice (E.S.S. 1109/2018) [17]. Its physical properties are shown in **Table (1)**,and its grading is shown in **Table (2)**.
- **The coarse aggregate** used is Crushed dolomite, has a maximum size 25mm. Its characteristics satisfy the requirements of the Egyptian Code of Practice (E.S.S. 1109/2018) [17]. Its physical properties are shown in **Table (3)**,and its grading is shown in **Table (4)**.
- **Water** Mixing of drinkable clean water, fresh and free from impurities is used for mixing processes of the tested samples according to the (E.C.P. 203/2018)[18].
- **Reinforced stee**l bars high strength steel (steel 52) of (12) mm diameter are used as a lower reinforcement in RC beam, (steel 48) of (8) mm diameter used as an upper reinforcement and also stirrups,. It meets the requirements of (E.S.S. 262/2018) [19].

Concrete Mix was designed to have a compressive strength of 30 N/mm2 after 28 days by using (absolute volume method) and according to **the requirements Egyptian standard specifications** by conducting trial mixes and making suitable adjustments in the mix proportion for good slump and required strength, by using cubic of dimension (150 x 150 x 150) and tested after 7and 28 days, the following mix proportion has finally been arrived at as shown in **Table (5)**. The six cubes were cast to ensure the value of the concrete strength. The result of the compressivestrength value of the concrete was 25.5 N/mm2after 7 days, 31.7 N/mm2after 28 days.

Table(1) Physical and mechanical properties of sand used.

Property		Value	ES 1109/2018 Limits
Specific gravity	(t/m3)	2.58	2.5 - 2.7
Volume weight	(t/m3)	1.73	-------
Absorption	(%)	0.78	0 - 2
Void ratio	(%)	33.80	-------
Fineness modulus		2.72	2.0 - 3.75

Table(3) Physical and mechanical properties of dolomite used.

Property		Value	ES 1109/2018 Limits
Specific gravity	(t/m3)	2.62	2.5 - 2.7
Volume weight	(t/m3)	1.84	-------
Absorption	(%)	0.74	0.5 - 1
Void ratio	(%)	31.00	-------
Fineness modulus		6.44	5 - 8

Table (2) Grading of the sand used according to (ESS 1109/2018)

Sieve size	4.5 mm	2.36mm	1.18mm	0.6 mm	0.3mm	0.15mm
	No. 4	No.8	No.16	No. 30	No. 50	No. 100
% Passing ESS 1109/2010	95-100	65-100	45-100	25-80	5-48	2-10
% Passing Used sand	97	91	81	41	14	4

Table(4) Grading of the dolomiteused according to(E.S.S. 1109/2018)

Sieve size (mm)	25	19	12.5	9.5
%Passing used sand	100	97	50	5
%Passing (E.S.S. 1109/2018)	100	90 - 100	20 - 55	0 - 10

Table(5) Concete mix proportion, kg/m3.

CEMENT	Water	Coarse aggregate	Fine aggregate
(kg/m^3)	(Liter/m^3)	(kg/m^3)	(kg/m^3)
350	140	1148	765

2.2Test specimens

Three specimens of concrete beams has been tasted, each specimen has a cross-section 150 * 250 mm, total length 1500 mm and effective span 1350 mm. The first beam is considered to be a control beam without inner opening,while the second has a rectangular opening at the shear zone, whereas the last one has a rectangular opening at the flexural zone.**Fig.(1)** illustratesthe tested beams in theexperimental program. The beams were tested under the effect of two points load by using the compression machinedial gauge was used to measure the deflection in beams. All beams has the same reinforcement, two bars with 12 mm diameter are used for the main reinforcement (2 Ø 12 mm) whereas 8 mm diameter is used for the secondary reinforcement (2 Ø 8 mm), and transverse reinforcement was stirrups of diameter 8 mmand spacing 150 mm, also the characteristic strength of concrete beams is 30N/mm2. All this is explained in **table (6).**

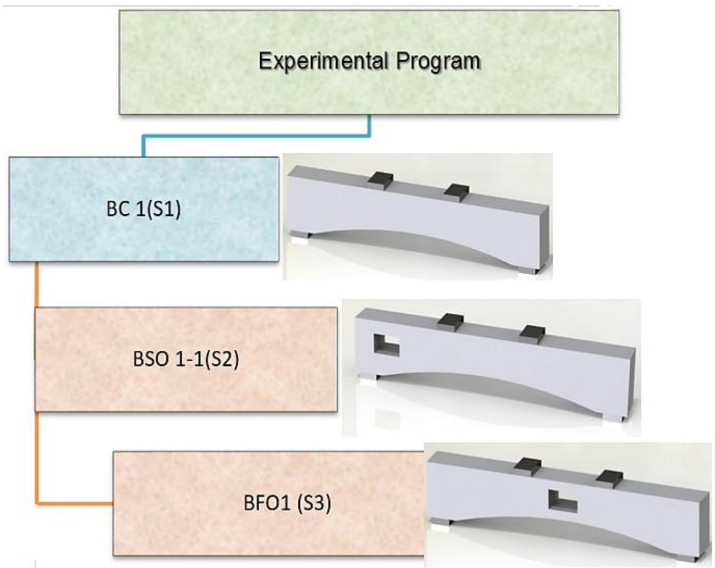


Fig. (1)the shape and lable of the tested beams

Table (6) Detail sand reinforcement of beams models

Beam No	f_{cu}Mpa	Reinf.lower	Reinf.upper	Stirrups	Strengthening
BC1					control
BSO1-1	30	2Ø12	2Ø8	1Ø8@ 150mm	control + rectangular shear opening
BFO1					control + rectangular flexural opening

2.3Preparingof the specimens

The three beam spicemens has been prepared through out the following steps:

1- Reinforcement was prepared for beams, as shown in **Fig.(2)**

2- Wooden forms were prepared according to the dimensions of the beam specimens, as shown in **Fig.(3)**

3-Aggregate were weighted (dolomite and sand) and mixed according to the requirements of the specification, the mixer mixed both fine and coarse aggregate for two minutes at least to ensure a quite mixing, the required amount of cement was added to the mixture and the mixer worked for two minutes, water was then added to the batch and mixed for five minutes and then placed in the forms as shown in **Fig.(4)**.

4- Curing concrete by immersing the beams in curing tanks containing water at 23 C, as shown in **Fig. (5)**.

5- Paint the specimens so that we can identify the cracks early accurately and clearly during the loading test, see

Fig. (6).

Fig.(2) Reinforcement for specimens

Fig.(3) Wooden forms

Fig.(4)concrete mixing and casting

Fig. (5) Immersion the specimens with water

Fig. (6) Paint the specimens

III. Numerical Work

3.1 Verification of the analytical model.

3.1.1 Geometry of specimens

Three analytical models for the experimental tested beams has been carried out using ANSYS program, these beams were tested under two-point load. The beams have a total length (Lt=1500 mm), the effective span (loading span) (L'= 1350 mm), and shear span (a= 450 mm). Also, the overall depth at each beam end (t=250 mm), the effective depth is (d= 225 mm) and the width of the beam section is (b=150 mm) as shown in **Fig. (7)**and**table(7)**. Regarding reinforcement, two bars with 12 mm diameter were used for the main reinforcement (2 Ø 12 mm) whereas 8 mm were used for the secondary reinforcement (2 Ø 8 mm),and The transverse reinforcement (stirrups) was Ø 8 mm of spacing 150 mm, as shown in **Fig. (8)**.

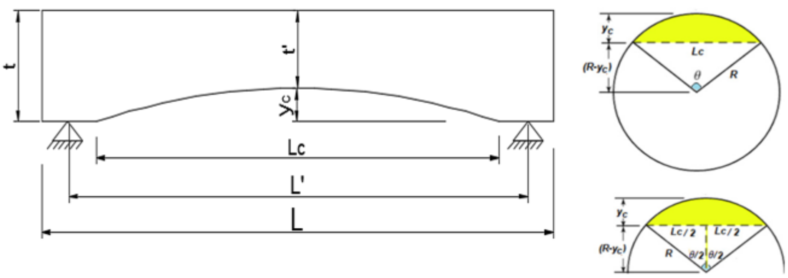
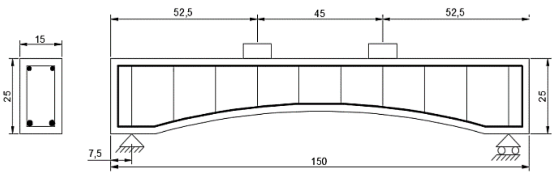


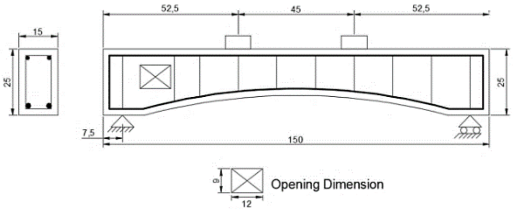
Fig. (7) Segmental arch and beam geometry

Table (7) Details of beams of Segmental Arch

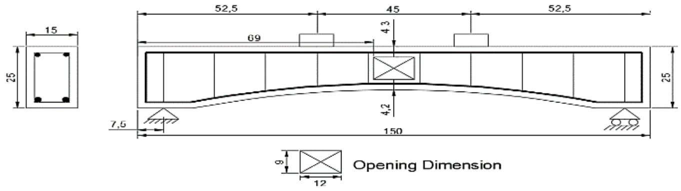
specimen	Lc(m)	yc(m)	Lc/L ratio	R(m)	θ (degree)	θ (radian)	A arch (m^2)
BC 1, BSO 1-1 and BFO 1	1.180	0.075	0.87	2.358	28.98	0.161π	0.06



Beam without opening (control) (BC 1)



Beam with a shear opening (BSO 1-1)



Beam with a flexural opening (BFO 1)

Fig. (8) Details of beams used in the analytical model (Dimensions are cm)

3.1.2 Element types

The input data for the concrete and steel bars properties are shown in **tables (8)** and **(9)**, where there are multiple parts of the material model for each element.

Table (8) Summary data for analtyical models

Item	Type of Element	Material Model number	Real constantnumber
Concrete	SOLID 65	30	30
Main (lower)reinforcement	LINK 180	12	12
Secondary (upper) reinforcement	LINK 180	8	8
Transverse bars (stirrups)	LINK 180	8	8
Steel plates	SOLID 185	666	-

Table (9).Properties of Each Element

Material No.	Element Type	Material Properties	
1	SOLID65 (concrete)	**Linear Isotropic**	
		EX, is equal to 26017 N/mm^2	
		Poisson's Ratio, PRXY, is equal to 0.20	
		Multilinear Isotropic	
		the stress-strain curve for concrete shown in **Fig. (9)**	
		Concrete	
		Open Shear Transfer Coeff.	0.45
		Closed Shear Transfer Coeff	0.9
		Uniaxial Cracking Stress(Modules of rupture)	3.98
		Uniaxial Crushing Stress	30
		Biaxial Crushing Stress	0
		Hydrostatic Pressure	0
		Hydro Biax Crush Stress	0
		Hydro Uniax Crush Stress	0
		Tensile Crack Factor	0
2	SOLID185 (steel plates)	**Linear Isotropic**	
		Elasticity Modulus, EX, is equal to 2e5 MPa	
		Poisson's Ratio PRXY is equal to 0.30	
3	LINK180 (reinforcement)	**Linear Isotropic**	
		Elasticity Models, EX, is shown in **table (10)**	
		Poisson's Ratio PRXY is equal to 0.30	
		Bilinear Isotropic	
		Yield Stresses is shown in **table (10)**	
		Tangent Modulus, Tang Mod, is 10 N/mm2	

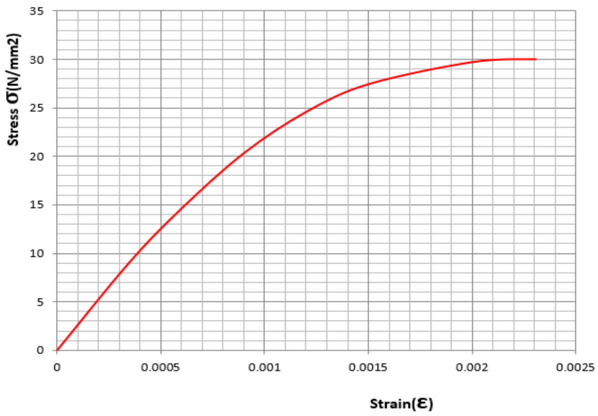


Fig. (9) the stress-strain curve for concrete

Table (10) Material properties for reinforcement

Beam	Yield strength, fy (MPa)			Modulus of Elasticity, Es (MPa)
	top	bottom	stirrups	
BC 1	280	550	280	2e5
BSO 1-1				
BFO 1				

3.1.3 Modeling

The model is 150 mm wide, with a total length (Lt) of 1500 mm, the effective span (L') was 1350 mm, and the shear span (a) was 450 mm. Also, the overall depth at each beam end (t) was 250 mm. The concrete volume Created in ANSYS. Two steel plates of 150 mm width, 100 mm length and 50 mm thickness is modeled to support the concrete beams at the ends, so the combined volumes of the plates and beam are shown in **Fig.(10)**

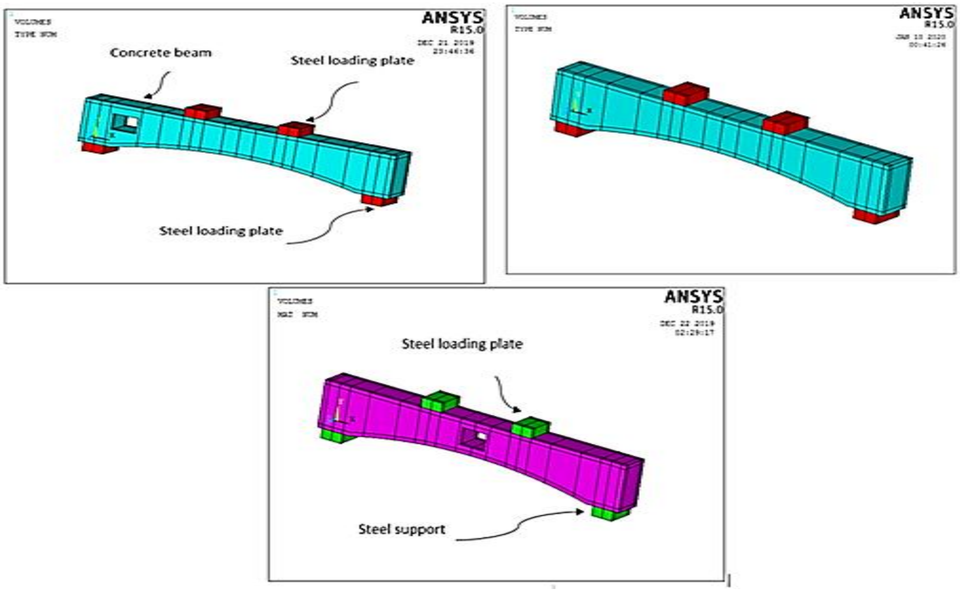


Fig.(10) Combined volumes of the plate and RC beam

3.1.4 Meshing

The beams are modeled using the nonlinear solid element SOLID65. To obtain good results from the SOLID65 element, the use of a rectangular mesh is recommended. Therefore, the mesh was set up such that square or rectangular elements were created. The volume sweep command was used to mesh the steel plates and supports. This property sets the width and length of elements in the plates to be consistent with the elements and nodes in the concrete portions of the model. No mesh of the reinforcement is needed because individual elements were created in the modeling through the nodes created by the mesh of the concrete volume. However, the necessary mesh attributes as described above need to be set before each section of the reinforcement is created. Therefore, the mesh was set up such that square elements with 25 mm in length, as shown in **Fig.(11)**.

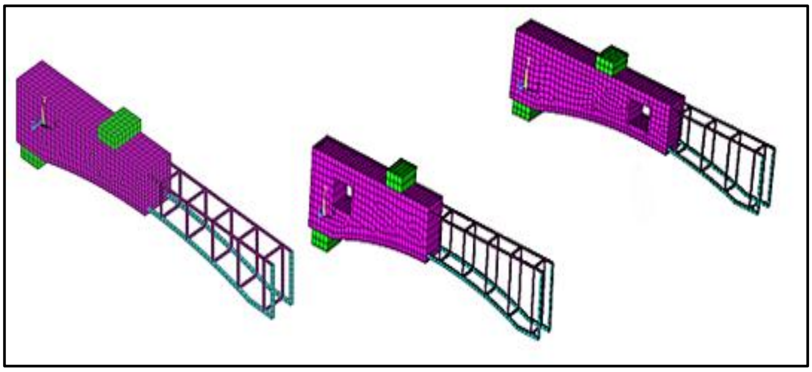


Fig.(11) Combined volumes of the reinforcement, concrete and plates

3.1.5 Loading

Nonlinear structural analysis was performed to study the nonlinear behavior of RC beams. In the nonlinear analysis, the applied load to a finite element model is divided into a series of load increments called load step, after each load increment the ANSYS15 program uses Newton-Raphson equilibrium iterations for updating the model stiffness. For the nonlinear analysis, automatic stepping in the ANSYS15 program predicts. The maximum and minimum load step sizes are required for the automatic time stepping. The boundary conditions were chosen to simulate the experimental conditions. **Fig.(12)** shows the boundary conditions and loading of specimens.

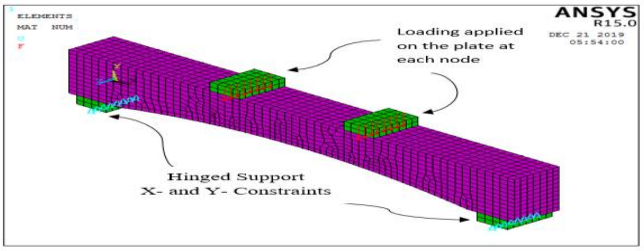


Fig. (12) Boundary conditions and Specimen loading

3.2 Parametric studies

Parametric study has been prepared to study the effect of the opening width and shape in the behavior of the arched beam with opening at the mid-span. **Fig.(13) and Table (11),** illustrates the parameters used in this study

The first part includes 7 specimens with rectangular openings, which studied the width change (0.09 L’, 0.12 L’, 0.15 L’, 0.18 L’, 0.22 L’, 0.26L’ and 0.30 L’) when the height is constant (0.50 t’) because it's limited,from **BFO 1** to **BFO 7**.

The second part includes 2 specimens with circular openings, which studied the effect of the circular opening and the change in the diameter (0.45 t’ and 0.55 t’), at **BFO 8** and **BFO 9** respectively.

Where L '**:** the effective span of the beam, t’**:** the depth of the beam at mid-span.

Table (11) Dimensions of variable openings for flexure set

Beam code	**BFO 1**	**BFO 2**	**BFO 3**	**BFO 4**	**BFO 5**
Dimension	0.09 L` *0.50 t` =120mm*90mm	0.12 L` *0.50 t` =160mm*90mm	0.15 L` *0.50 t` =200mm*90mm	0.18 L` *0.50 t` =245mm*90mm	0.22 L` *0.50 t` =300mm*90mm
Beam code	**BFO 6**	**BFO 7**	**BFO 8**	**BFO 9**	
Dimension	0.26 L` *0.50 t` =350mm*90mm	0.30 L` *0.50 t` =400mm*90mm	0.45 t` D=80mm	0.50 t` D=100mm	

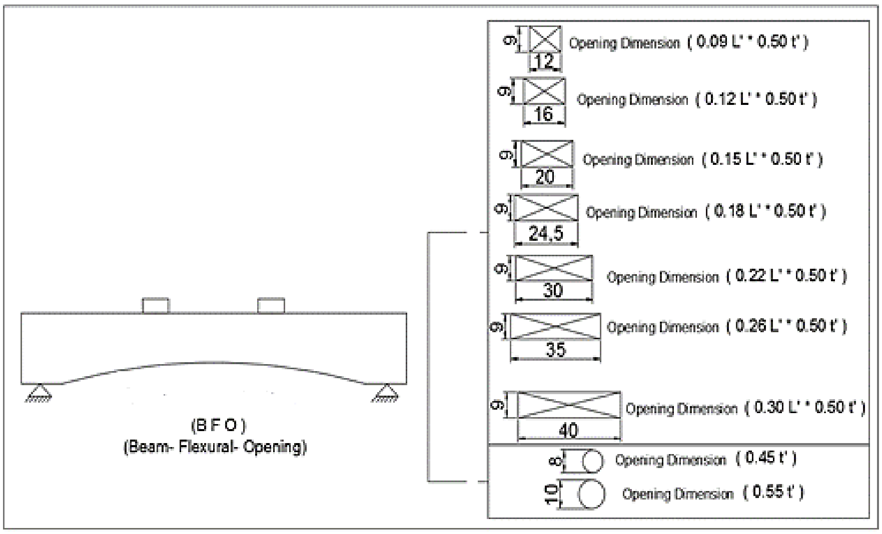


Fig. (13). Shape and dimensions of the beam openings (all dimensions are cm).

IV. Results and Discussion

4.1 Results of the tested beams

The specimens were tested under two point's load (four-points bending tests) using the testing machine,where **figures 14, 15 and 16** show the three tested beams and the created cracks for each one.

Fig. (14). Shows that, for the arched beam without opening, the cracks has been created in the flexural zone only, while there is no cracks occurred in the shear zone, while **Fig. (15).**Of the beam with opening in the shear zone shows that the cracks has been created in both flexure and shear zones, and**Fig. (16).**Of the opening with opening in the flexure zone shows that the cracks has been created in the flexure zone only.

(a) (b)

Fig. (14). Cracks Pattern for the Beam (BC 1)

(a) (b)

Fig. (15) Cracks Pattern for the Beam (BSO 1-1)

Fig. (16). Cracks Pattern for Beam (BFO 1)

4.2 Comparison between numerical and experimental results

The validity of the numerical model is checked through extensive comparisons between finite element models and experimental results of RC beams under two points load. From **Fig. (17)**and**Fig.(18)** shows the load-deflection relationship obtained from both experimental and analytical results. In general,the figures show that the analytical models give very accurate results with respect to the experimental results.

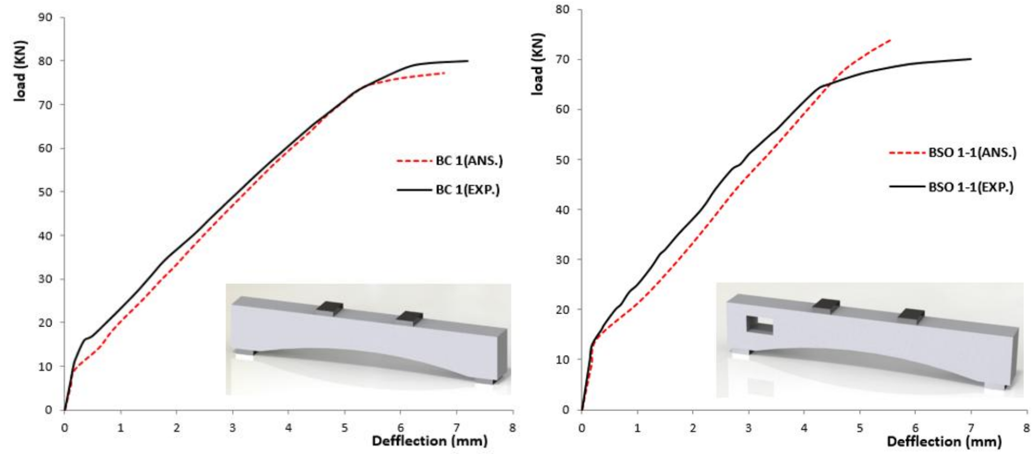


Fig. (17) Comparison Between Experimental Versus Numerical Result for (BC1 and BSO 1-1).

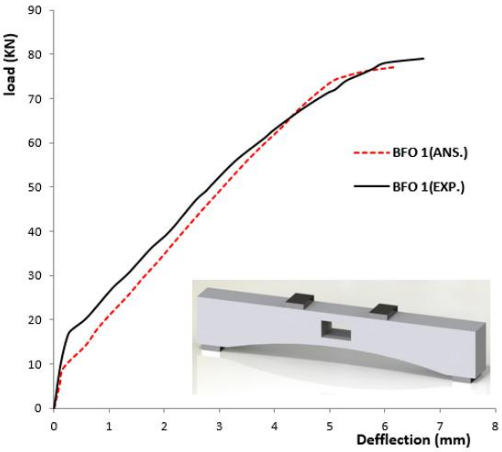


Fig. (18) Comparison Between Experimental Versus Numerical Result for (BFO 1)

To inspect the accuracy of the nonlinear finite element approach, the obtained results are compared with test experimental results. A comparison between the recorded experimental ultimate failure load Pu, Exp. and the failure load for the tested simple ordinary beams calculated from the finite element model Pu, FEM. is given in **table (12)**. The mean value of the ratio difference between Pu, FEM. and Pu, Exp. for beams BC 1, BSO 1-1 and BFO 1 are 3.5, 5.6 and 2.34 % respectively, which demonstrates that the nonlinear finite element model provides an accurate prediction of the ultimate load for the tested beams. Whereas the Δu (FEM) give less deflection ratio than the Δu (Exp) of 5.97, 20.57 and 7.31%, which shows that the FE models are stiffer structures than the experimental spicemens for all beams. Also, it is clear that the adopted nonlinear finite element model provides a useful tool in understanding the behavior beams of the segmental arch at the bottom face.

Table (12) Comparison Between Experimental and FEM

Sample Name	**P_{cr}. Exp (kN)**	**P_{cr}. FEM. (kN)**	**Diffe. Ratio %**	**Δcr (Exp) (mm)**	**Δcr (FEM) (mm)**	**P_{ul}. Exp (kN)**	**P_{ul}. FEM (kN)**	**Diffe. Ratio %**	**Δu (Exp) (mm)**	**Δu (FEM) (mm)**	**Diffe. Ratio %**
BC1	17	15.2	10.5	0.5	0.65	80	77.19	3.5	7.2	6.77	5.97
BSO1-1	14	14.9	6	0.26	0.25	70	73.98	5.6	7	5.56	20.57
BFO1	18	14.4	20	0.35	0.58	79	77.19	2.34	6.7	6.21	7.31

Where:**P_{cr}&Δcr:**the load and the displacement at the initial cracking respectively**,** while**P_{ul}**&**Δu:** the load and the displacement at the ultimate load respectively.

4.3 Results ofparametric studies

Fig.(19-a) and table (13)show the results**,** when changing the width of the rectangular openings (120 mm, 160 mm, 200 mm, 245 mm, 300 mm, 350 mm, and 400 mm), while the height of the openings is 90 mm for all openings.It is summarized that two main factors influenced the beam when changing the opening width.

The first factor is the moving away from the top of the arched opening, whereas**,** the second factor was the proximity to the loading plate.

It has been found that the behavior of the beam changed when the opening width changed due to both factors, where, for BFO 1, BFO 2, the max-load 77.192 kN and 74.92 kN respectively also the deflection 6.21 mm and 6.04 mm respectively were gradually decreasing slightly, compared to BFO 1.While BFO 3, the load reduced to become 72.965 kN also with increasing deflection 6.63 mm, compared to BFO 2, then for BFO 4 the load reduced to become 61.648 kN at deflection 5.28 mm, compared to BFO 3.As for BFO 5, the load increased slightly to become 68.435 kN, and also deflection 8.48 mm, compared to BFO 4, then for BFO 6 the load reduced to become 59.75 kN at deflection 7.13 mm, compared to BFO 5, and in the last specimen, BFO 7, the load increased a little more to become 61.648 kN compared to BFO 6, and also deflection 8.23 mm.

table (13) Parametric study results of arched beams with rectangular openings

Sample Name	**BFO 1**	**BFO 2**	**BFO 3**	**BFO 4**	**BFO 5**	**BFO 6**	**BFO 7**
P_{ul}. FEM (kN)	77.19	74.92	72.96	61.64	68.435	59.75	61.648
Δu (FEM) (mm)	6.21	6.04	6.63	5.28	8.48	7.13	8.23

While**Fig. (19-b)and table (14)**show the results, when changing the diameter of the circular openings (80 mm and 100 mm) respectively.

For BFO 8, the maximum load in which the beam reached was 77.611 kN at the displacement of 6.15 mm, while BFO 9, the maximum load was 76.361 kN, which was less than the first case at the displacement of 5.62 mm.

table (14) Parametric study results of arched beams with circular openings

Sample Name	**BFO 8**	**BFO 9**
P_{ul}. FEM (kN)	77.61	76.361
Δu (FEM) (mm)	6.15	5.62

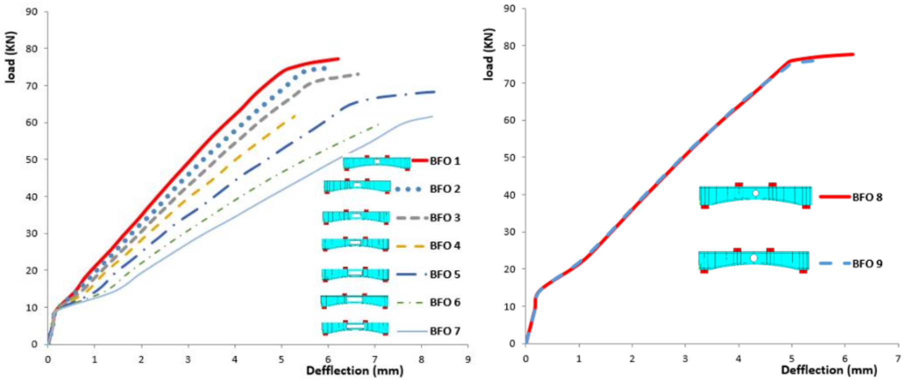


Fig.(19) Parametric study results**a-** rectangular openings **b-** circular openings

V. Conclusions

This paperaimed to investigate the behavior of the arched reinforced concrete beams with openings. The work presented in this dissertation consists of two parts; **the first part** Based on the experimental results and the analytical model developed in this research, whereas **the second part:** It consists of the arched beams with openings, which have openings in the flexural zone, in which the comparison of dimensions and shape of openings.The following conclusions are reached:

The first part:

- It was found that when the arched opening length is 87 % of the effective span of the beam (L') and its height is 30 % of the depth of the beam (t), the load capacity of the beam is about 7.7 ton and deflection 6.77 mm.
- While when the rectangular opening whose dimensions are (0.09 L' * 0.35 t) at the shear zone, at a distance of (d/2) which is measured from the support to the center of the opening, the load capacity of the beam decreases by about 5 % and the deflection decreases by 17 %.
- Whereas when the rectangular opening whose dimensions are (0.09 L' * 0.35 t) at the flexural zone, the load capacity of the beam decreases by about 0.1 % and the deflection decreases by 8 %.
- The above analysis shows that the excistance of the openings decreases both of load capacity and ductility of the arched beam.
- For the same size of the opening, it's better to locate the opening in the flexure zone than in the shear zone.

The second part:

- In general the load capacity and ductility decrease when the opening increase. Also, for the same opening size, the rectangular opening gives more load capacity than the circular opening.
- When the beam has a rectangular opening area of approximately twice the circular opening area,its capacity decreases by about 0.5 %,but the deflection increases by 0.97 %.
- The greater the rectangular opening area in the beam at the flexure zone, the less of its the bearing capacity, but with a low proportion

Also,for rectangular opening, it was found out that the arched beam behavior changes with the incremental increase of opening by 0.05 L' :

- when the rectangular opening whose dimensions are (0.09 L' * 0.50 t'), the load capacity of the beam decreases by about 0.1 % and the deflection decreases by 8 %. While when the rectangular opening whose dimensions are (0.12 L' * 0.50 t'), the opening area increased by 33%, its load decreases by about 3 % and the deflection decreases by 10.5 %.
- when the rectangular opening whose dimensions are (0.15 L' * 0.50 t'), the load capacity of the beam decreases by about 5.5 % and the deflection decreases by 2 %. While when the rectangular opening whose dimensions are (0.18 L' * 0.50 t'), the opening area increased by 22.5%, its load capacity decreases by about 20 % and the deflection decreases by 22 %.
- when the rectangular opening whose dimensions are (0.22 L' * 0.50 t'), the bearing capacity of the beam decreases by about 11 % but the deflection increases by 25 %. While when the rectangular opening whose dimensions are (0.26 L' * 0.50 t'), the opening area increase by 16.6%, its capacity decreases by about 22.5 % but the deflection increases by 5 %.
- when the rectangular opening whose dimensions are (0.30 L' * 0.50 t'), the bearing capacity of the

beam decreases by about 20 % but the deflection increases by 21.5 %.

- The ratio of the opening dimensions (width to depth) has a big effect on the beam load capacity, the load capacity decreased when the ratio of beam width to depth increasedbut with rate less than the percentage increase of the opening area.
- It is found that when the circular opening whose dimensions are (0.45 t), the load capacity of the beam decreases by about 0.5 % and the deflection decreases by 9 %. While when the circular opening whose dimensions are (0.55 t), the opening area increased by 56%, its capacity decreases by about 1 % and the deflection decreases by 17 %. The rate of decrease in load capacity is much less than the increase in the opening area.

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