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Behavior of High Strength Reinforced Concrete Deep Beams with Openings

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ABSTRACT:-Concrete deep beams in building have become increasingly popular worldwide. The major codes of practice offer little guidance for design of deep beams especially when openings in the web region are provided for essential services, so an analytical model is proposed to solve this problem herein.

Thirty-Nine specimens evaluated analytically using finite element method (ANSYS 14.0 Program) to study the behavior of high–strength reinforced concrete deep beams with openings. Specimens are simply supported deep beams of effective span 1800 mm from support to support. An overhanging length of 240 mm from each support was to provide an adequate anchorage length of steel reinforcement and to prevent any local failure at support. Cross section dimensions of each beam are 120 mm width and 600 mm thickness.

The specimens divided to three sets, Set A, consists of sixteen specimens divided as four groups with same opening dimension (60 mm x 60 mm) and different location directions (Horizontal, Vertical, Diagonal and Perpendicular to the diagonal), four specimens are in each direction. Set B, examines fifteen specimens consists of three Groups, all of them have same opening location and different opening shape, such that square or rectangle. Finally set C examines eight specimens divided to two groups considering the behavior of the characteristic strength of concrete, one group contains four beams specimens of normal strength concrete while, the other group contains four beams of high strength concrete.

The crack patterns, failure load, beams deflection, ductility, stress distribution and stresses versus load are carried out. Conclusions are given out which show the behavior of deep beams with opening, the best location of opening in the four directions, the best size of opening, the beam which is most ductile, reducing ratio of stresses due to presence of opening.

KEYWORDS:-Deep beams, Openings, High strength, Crack Pattern and Finite element

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I. INTRODUCTION

In recent years, concrete deep beam interconnecting systems in building and precast construction have become increasingly popular worldwide. This is because there is a huge demand for structures to be built to high elevations due to the lack of land available, especially in major modern cities. The need for an accurate design methodology for deep beams with openings [1] [2] is becoming increasingly necessary with the subsequent growth in the use of deep beams in construction industry.

Deep beams demonstrate non-flexural behavior and are considered as discontinuity regions because the sectional strain distribution deviates from linearity. A deep beam is a beam in which a significant amount of the load is transferred to the supports by a compression thrust joining the load and the reaction [3]. The transition from reinforced concrete shallow beam behavior to that of deep beam is imprecise.

The design of deep beams with large openings is studied [4] and it was found that the strut-and-tie model [5] accurately estimated the shear strength according to the test results, due to large opening sizes and low opening locations, the deep beams with opening could have behaved under testing conditions as normal flexural beams [6]. A method developed to predict the ultimate shear strength of deep beams with web

II. PROGRAM OF STUDY

Thirty-Nine deep beam specimens were examined.An overall beam length of 2400 mm and 600 mm thickness, the effective span 1800 mm from support to support as detailed in Fig. 1, the width of all the specimens was maintained as 120 mm.

Specimens were categorized into three main Sets, Set A, B and C, aiming at examination of different mechanisms associated with varying deep beam parameters. To more effectively investigate the influence of different parameters, specimens in each Set were further classified into a number of test Groups. They are briefly explained as below;

Set A, consists of sixteen specimens, were classified to four groups (Group 1, 2, 3 and 4) to observe the effect of varying locations of the web opening square shape of size 60 mm × 60 mm, where considered as 10 % of deep beam depth. To study the effect of moving the opening location with respect to line passing from load to support (Strut and Tie theory), these groups included variations of the opening location along the horizontal, vertical and diagonal directions.

Group 1 with constant vertical distance from support (Y), where, moving opening location horizontally. Group 2 with constant horizontal distance from support (X) in Fig. 2, while, moving opening location vertically. Group 3 and Group 4 the opening location moved diagonal (Vertical and horizontal).

Set B consists of fifteen specimens where classified to three groups (Group 5, 6 and 7) to observe the effect of varying locations of the web opening rectangular shape of size 15 %, 20 %, 30 % and 40 % of the deep beam depth. Opening location moved through the line passing from load to support vertical and horizontal.

Set C considered the effect of concrete characteristics strength. It consists of eight specimens, classified into two groups (Group 8 and 9), where group 8 four specimens of normal strength reinforced concrete (NSRC), while group 9 four specimens of high strength reinforced concrete (HSRC).

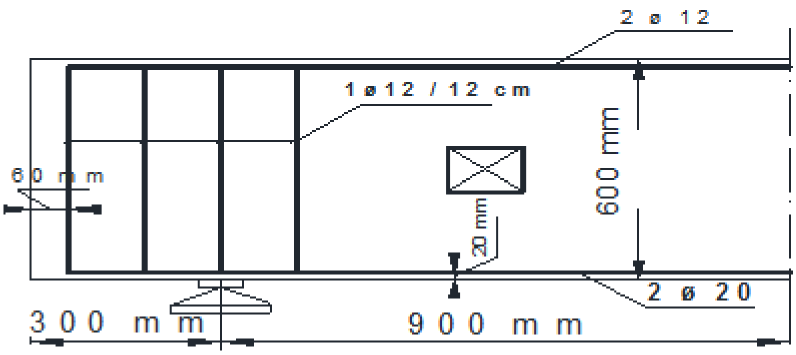


Fig. 1: Details of Deep Beam Specimens (Dimensions in mm)

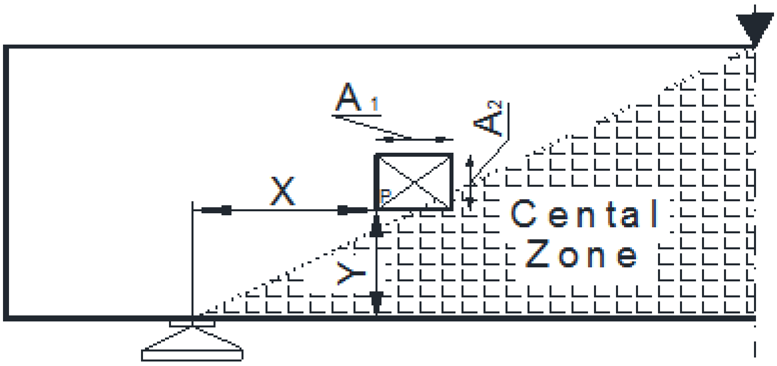


Fig. 2: Opening Size and Location

All dimensions A1, A2, X and Y are in mm

TableI:Location and Size of Openings Beam Specimens

Set	Group	Spec.	A_1 x A_2 mm	X mm	Y mm
Set A	Group 1	A–1–1	60 x 60	460	260
		A–1–2	60 x 60	580	260
		A–1–3	60 x 60	340	260
		A–1–4	60 x 60	220	260
	Group 2	A–2–1	60 x 60	400	320
		A–2–2	60 x 60	400	380
		A–2–3	60 x 60	400	200
		A–2–4	60 x 60	400	140
	Group 3	A–3–1	60 x 60	500	320
		A–3–2	60 x 60	580	390
		A–3–3	60 x 60	320	200
		A–3–4	60 x 60	220	140
	Group 4	A–4–1	60 x 60	320	320
		A–4–2	60 x 60	220	380

		A–4–3	60 x 60	500	200
		A–4–4	60 x 60	580	140
Set B	**Group 5**	B–5–1	60 x 60	400	260
		B–5–2	90 x 60	390	255
		B–5–3	120 x 120	360	240
	Group 6	B–6–1	120 x 60	400	260
		B–6–2	240 x 60	400	260
		B–6–3	120 x 60	340	260
		B–6–4	240 x 60	220	260
		B–6–5	180 x 60	340	260
		B–6–6	240 x 60	320	260
	Group 7	B–7–1	60 x 120	400	260
		B–7–2	60 x 180	400	260
		B–7–3	60 x 120	400	200
		B–7–4	60 x 180	400	140
		B–7–5	60 x 180	400	200
		B–7–6	60 x 240	400	180
Set C	**Group 8**	C–8–1	150 x 150	338	225
		C–8–2	180 x 180	320	200
		C–8–3	210 x 210	300	195
		C–8–4	240 x 240	270	170
	Group 9	C–9–1	N/A	N/A	N/A
		C–9–2	150 x 150	338	225
		C–9–3	180 x 180	320	200
		C–9–4	210 x 210	300	195

III. NUMERICAL ANALYSIS

A three dimensional finite-element program 'ANSYS' was used for the numerical analysis of the thirty - nine beams. In the analysis, appropriate material models were employed to represent the behavior of concrete, the steel reinforcement, and the steel plates. They are described in detail in the ANSYS manual set.

A solid element, SOLID65, is used to model the concrete in ANSYS. The solid element has eight nodes with threetransitional degrees of freedom at each node. In addition, the element is capable of simulating plastic deformation, cracking in three orthogonal directions, and crushing. The steel plates at the supports for the beams are modeled using Solid185 elements. This element has eight nodes with three degrees of freedom at each node – translations in the x, y, andz directions. In order to obtain the internal strains in the reinforcement bars and keep them in their right positions, the discrete technique using the 3D spar Link180 element is followed. This element has two nodes with three degrees of freedom translations in the x, y, and z directions. This element is also capable of plastic deformation.

The mesh was taken square to obtain good results with the test one; it was taken 20 x 20 x 20 mm as shown in Fig. 3.

The command merge items merge separate entities that have the same location. These items will then be merged into single entities. Caution must be taken when merging entities in a model that has already been meshed because the order in which merging occurs is significant. Displacement boundary conditions are needed to constrain the model to get a unique solution. The model being used is symmetric about two planes. The supports were modeled such as a roller and hinge support. For roller support a single line of nodes were constraint in the (UY) and (UZ) directions. For hinged support, single lines of nodes were constraint in the (UX), (UY) and (UZ) directions. For loading boundary conditions, the force applied at steel plate as shown in Fig. 3.

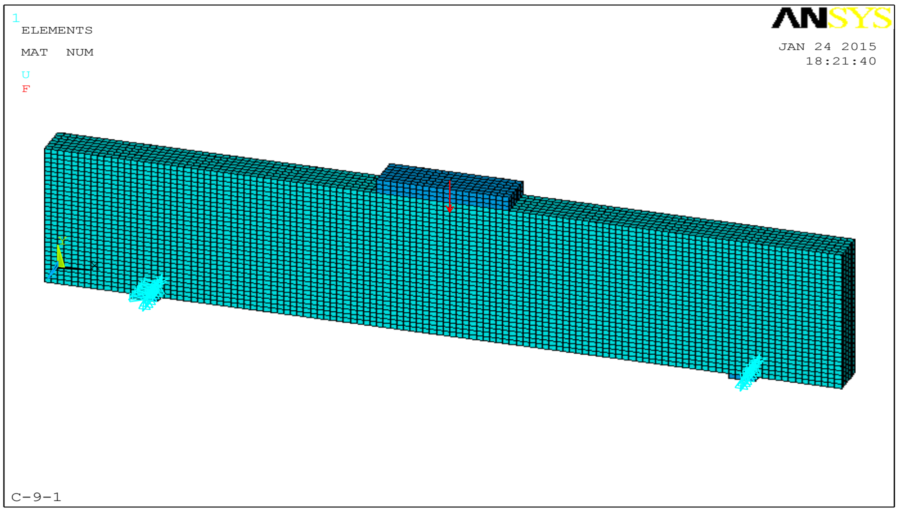


Fig. 3: Model of Boundary Condition and Loading

In this study the total load applied was divided into a series of load increments (or) load steps. Newton – Raphson equilibrium iterations provide convergence at the end of each load increment within tolerance limits. The automatic time stepping in the ANSYS program predicts and controls load step sizes for which the maximum and minimum load step sizes are require.

IV. THEORETICAL RESULTS

Kong and Sharp (1977) [8] tested a further 32 deep beams, covering a wider range of web reinforcement patterns as well as shear span-to-depth and clear shear span-to-depth ratios. A verification processed to compare the experimental results to the analytical results, which illustrated in the following table.

Table II: Experimental and Analytical Results

Set	Group	Spec.	$P_{Exp.}$ (kN)	$P_{Anal.}$ (kN)	$\frac{P_{Exp.}}{P_{Anal.}}$	Ductility (mm)	Absorbed Energy (kN.mm)
Set A	Group 1	A–1–1	353	391	0.90	1.71	681
		A–1–2	416	369	1.13	1.50	597
		A–1–3	422	390	1.08	1.78	704
		A–1–4	422	396	1.07	1.80	893
	Group 2	A–2–1	348	281	1.24	0.75	344
		A–2–2	402	394	1.02	1.70	678
		A–2–3	268	211	1.27	0.50	162
		A–2–4	241	191	1.26	0.60	124
	Group 3	A–3–1	303	263	1.15	0.70	300
		A–3–2	254	213	1.20	0.60	163
		A–3–3	190	136	1.40	0.15	54.0
		A–3–4	178	189	0.94	0.50	123
	Group 4	A–4–1	454	390	1.16	1.60	709
		A–4–2	458	408	1.12	1.60	598
		A–4–3	232	173	1.34	0.26	113
		A–4–4	185	186	0.99	0.50	133
Set B	Group 5	B–5–1	309	262	1.18	0.80	293
		B–5–2	194	180	1.08	0.40	86.5
		B–5–3	113	142	0.80	0.25	71.0
	Group 6	B–6–1	167	142	1.18	0.20	50.0
		B–6–2	123	136	0.90	0.20	95.5
		B–6–3	174	175	1.00	0.30	128
		B–6–4	123	142	0.87	0.20	78.0
		B–6–5	146	141	1.03	0.16	86.5
		B–6–6	138	136	1.02	0.20	79.0
	Group 7	B–7–1	307	291	1.05	1.20	326
		B–7–2	158	142	1.11	0.20	56.5
		B–7–3	135	129	1.05	0.15	40.2

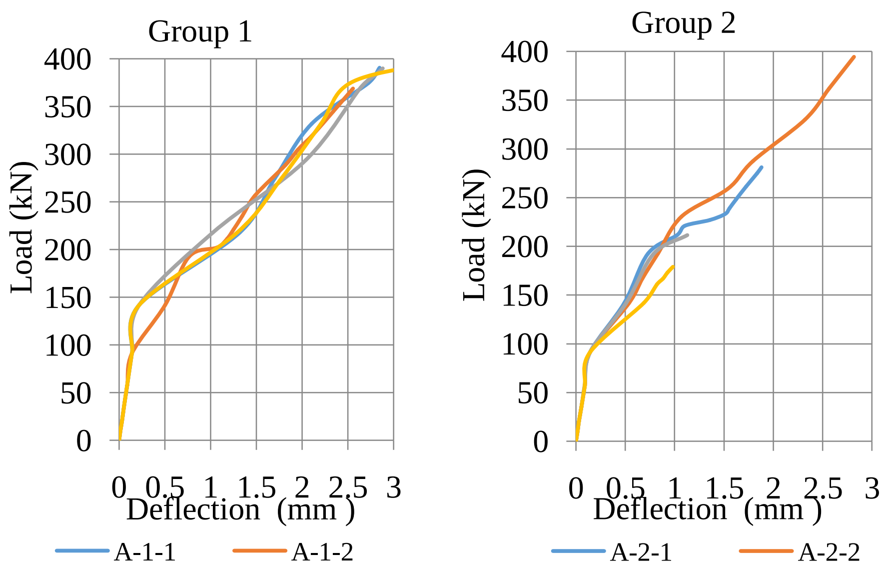
		B–7–4	112	116	0.96	0.15	11.6
		B–7–5	110	136	0.81	0.20	66.0
		B–7–6	81	117	0.70	0.15	12.0
Set C	**Group 8**	C–8–1	88	91	0.97	0.15	10.0
		C–8–2	87	91	0.95	0.15	42.5
		C–8–3	80	91	0.87	0.28	52.0
		C–8–4	72	58	1.26	0.16	13.2
	Group 9	C–9–1	490	471	1.04	2.15	1036
		C–9–2	126	116	1.08	0.15	11.0
		C–9–3	73	101	0.72	0.13	28.0
		C–9–4	79	91	0.86	0.13	8.75

Fig. 4 shows the load–deflection relationships for specimens in set (A). Deflection measured in the middle bottom of each beam. The opening dimensions are constant of (60 mm x 60 mm). While the opening location changed, the failure load decreases when the beam opening lies inside the central zone, for group 1 which its opening location moves in the horizontal direction has the highest values of failure load and deflection, while group 3 which its opening location moves in diagonal direction has the smallest values of failure load and deflection.

Fig. 5 shows the load–deflection relationships for specimens in set (B); in which the opening size dimensions are increased, while the opening location is fixed. When the opening shape is square as in group 5, it is found that as the opening area increased as the failure load decreased. For group 6 in which the opening shape is rectangular, if the horizontal dimension is changed and the vertical dimension is constant (60 mm), it is found that the failure load values are approximately equal while their deflection values are different. For group 7 in where the opening shape is rectangular and the vertical dimension is changed, while and the horizontal dimension is constant (60 mm), it is found that the highest failure load is for specimen (B–7–1) in where its vertical dimension increases by 20 % upward of the central zone.

Fig. 6 shows the load – deflection relationships for specimens in set (C); in which the compressive strength of concreate changes from high strength reinforced concrete (HSRC) of 80 MPa to normal strength reinforced concrete (NSRC) of 40 MPa, it is found that the specimens with normal strength concrete have lower failure load but highest deflection values which make it more stiff.

Figs. 7, 8and 9 show the measurement of ductility values for specimens in sets (A), (B) and (C); where the measurement of ductility is the considered as the deflection value at 70 % of failure load, it is found that the most ductile specimen is (A–1–4); which has opening size (60 mm x 60 mm) and its location changes in horizontal direction by 30 % outward the central zone, while the lowest ductile values are in specimen (C–9–4); which has opening size (210 mm x 210 mm) and locate at mid-point.



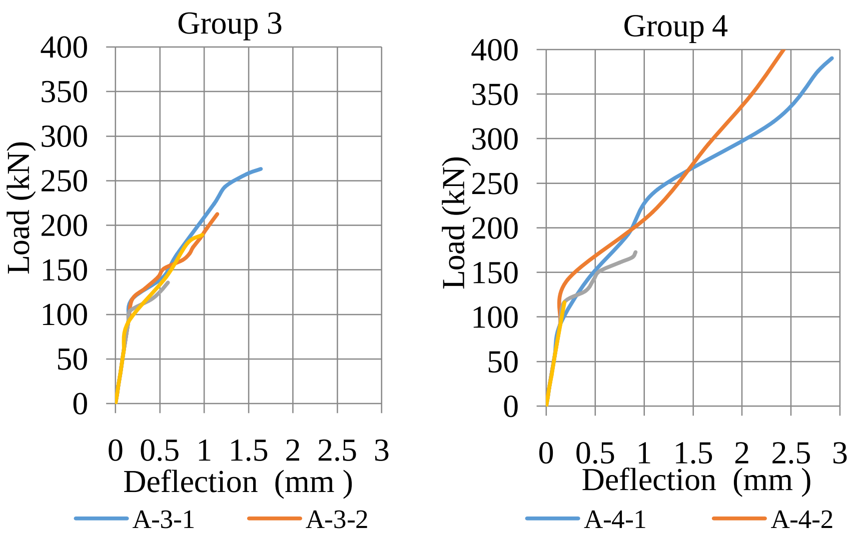


Fig. 4: Load–Deflection Relationship for Specimens in Set (A)

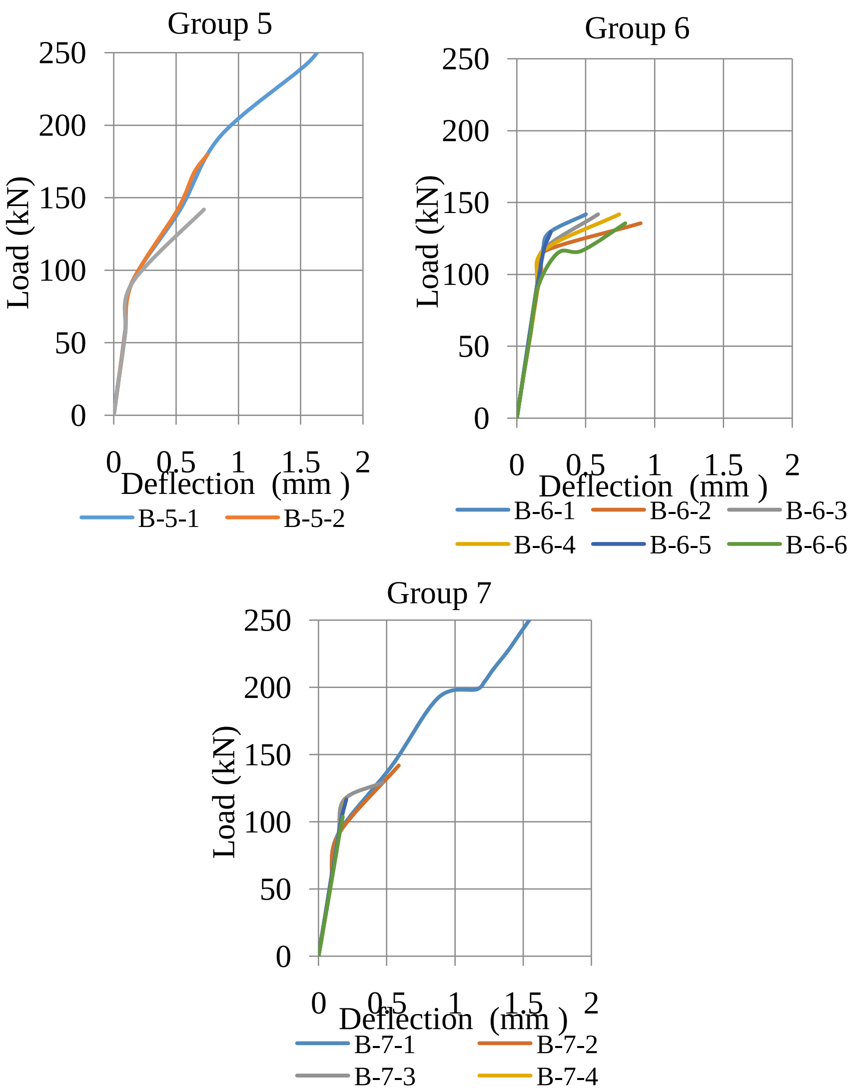


Fig. 5: Load–Deflection Relationship for Specimensin Set (B)

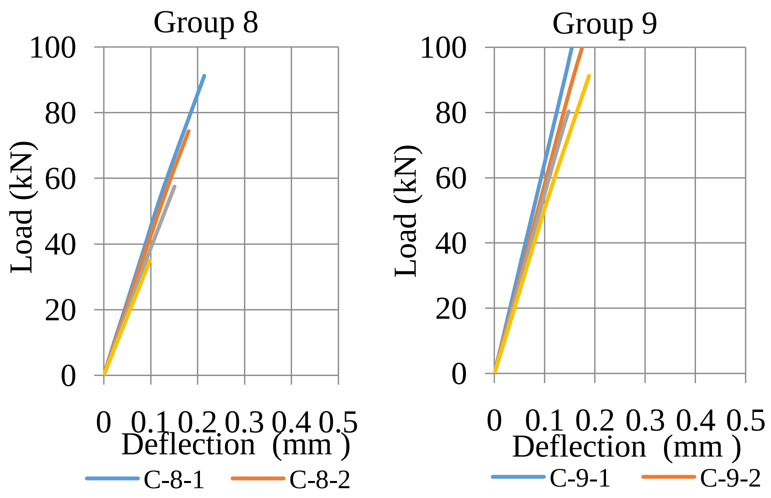


Fig. 6: Load–Deflection Relationship for Specimensin Set (C)

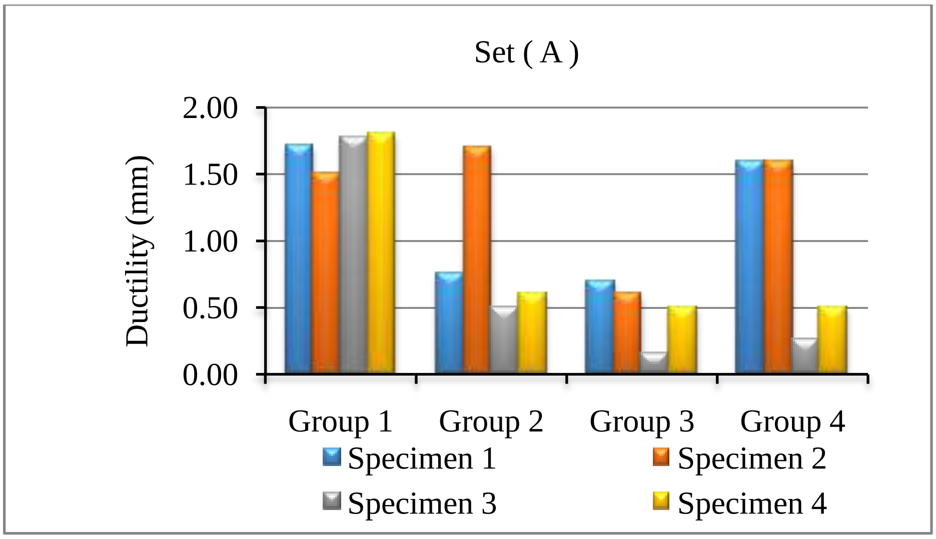


Fig. 7: Ductility for Specimens in Set (A)

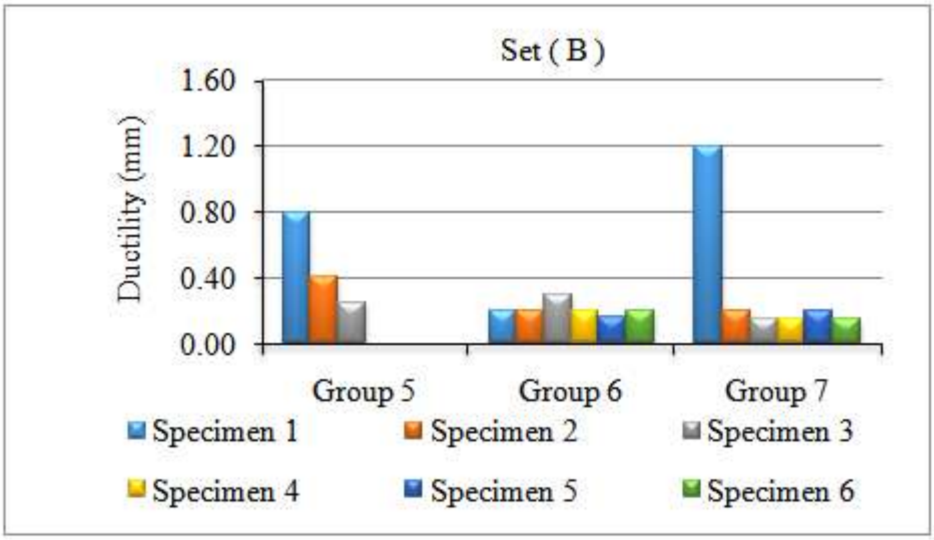


Fig. 8: Ductility for Specimens in Set (B)

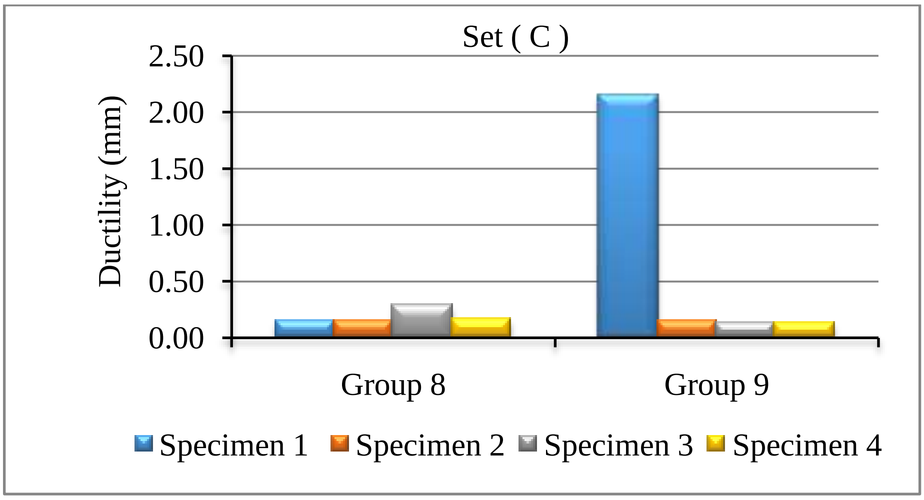


Fig. 9: Ductility for Specimens in Set (C)

Fig. 10 and Fig. 11 show the Crack pattern for specimens (A–2–2) and (A–2–4) respectively; the two specimens are in group 2 where the beam opening dimensions are fixed (60 mm x 60 mm) while its location changes in the vertical direction, it is obvious that specimen (A–2–2) where the beam opening location is 20 % upward the central zone has a large number of cracks and failure load of 394.21 kN, but specimen (A–2–4) where the beam opening location is 20 % downward the central zone has a small number of cracks and failure load of 190.86 kN.

Fig. 12 and Fig. 13 show the Crack pattern for specimens (B–5–1) and (B–5–3)respectively ; the two specimens are in group 5 where the beam opening location is fixed at the midpoint while its dimensions changes in squared shape, it is obvious that specimen (B – 5 – 1) where the beam opening size is 10 % from height (60 mm x 60 mm) has a large number of cracks and failure load of 262.11 kN, but specimen (B–5–3) where the beam opening size is 20 % from height (120 mm x 120 mm) has a small number of cracks and failure load of 141.88 kN.

Fig. 14 and Fig. 15 show the Crack pattern for specimens (B–6–1) and (B–7–1)respectively; the two specimens have fixed opening location at the midpoint and fixed rectangular opening area (10 % x 20 %) but the opening orientation is changeable, in specimen (B–6–1) the opening orientation is in horizontal direction has a small number of cracks and failure load of 141.88 kN, but in specimen (B–7–1) the opening orientation is in vertical direction has a large number of cracks and failure load of 291.12 kN.

Fig. 16 and Fig.17 show the Crack pattern for specimens (C–8–2) and (C–9–3)respectively; the two specimens have fixed opening location at the midpoint and fixed square opening area 30 % from height (180 mm x 180 mm) but the specimen compressive strength is changeable, in specimen (C–8–2) the beam is from normal strength concrete with compressive strength 40 MPa has a large number of cracks and failure load of 91.25 kN, but in specimen (C–9–3) the beam is from high strength concrete with compressive strength 80 MPa has a small number of cracks and failure load of 101.38 kN.

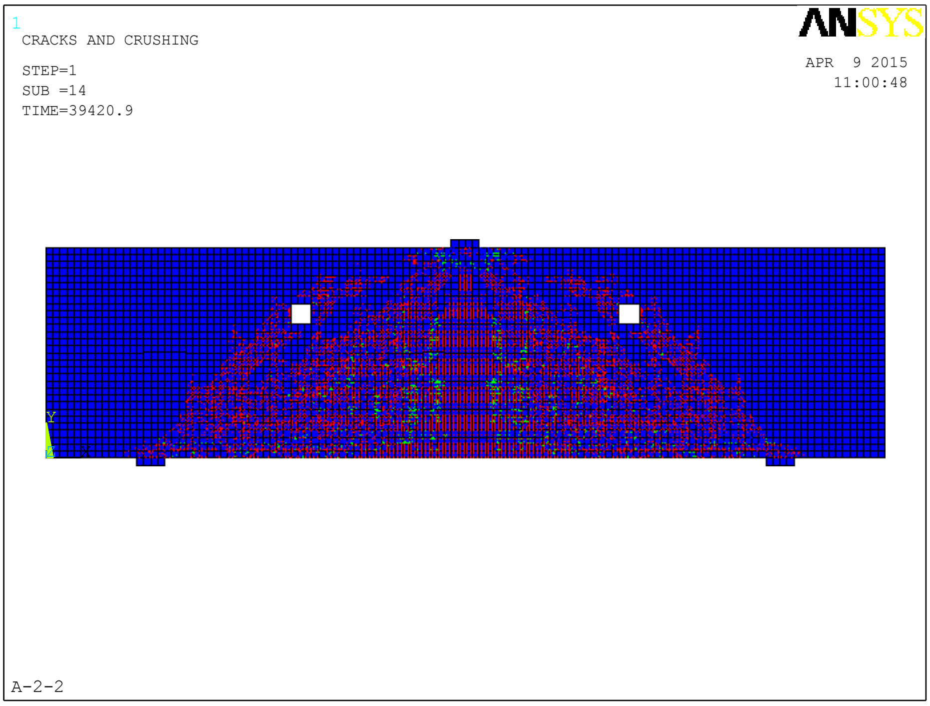


Fig. 10: Crack Pattern for Specimen (A–2–2)

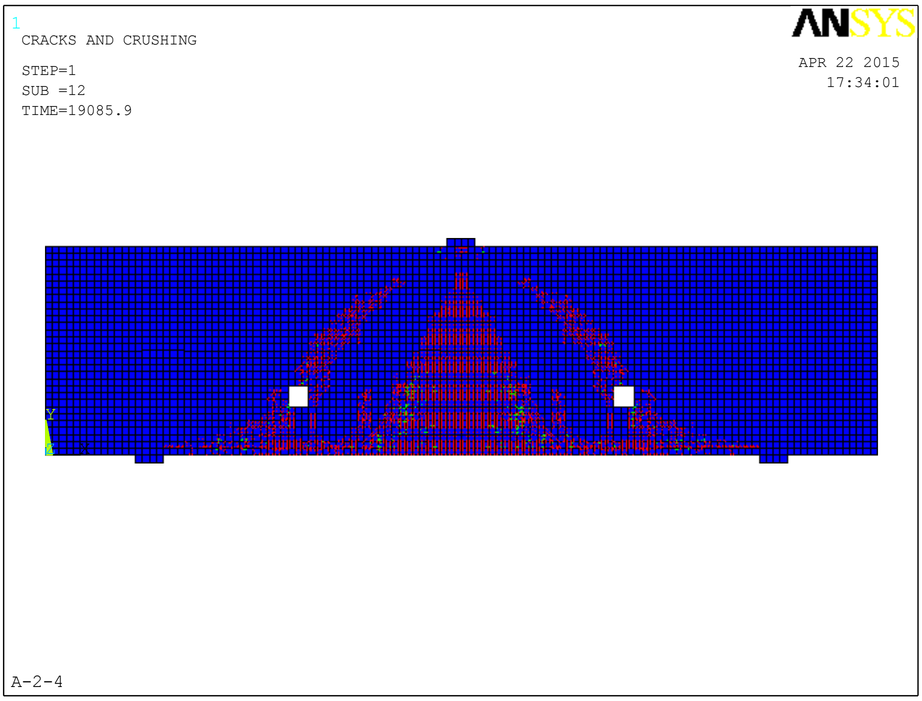


Fig. 11: Crack Pattern for Specimen (A–2–4)

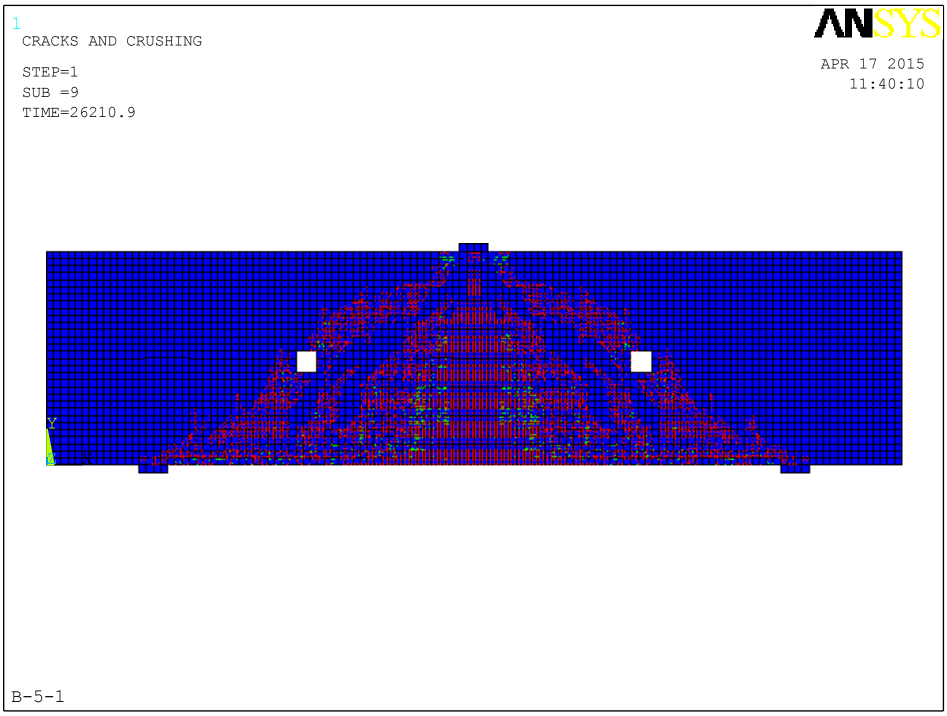


Fig. 12: Crack Pattern for Specimen (B–5–1)

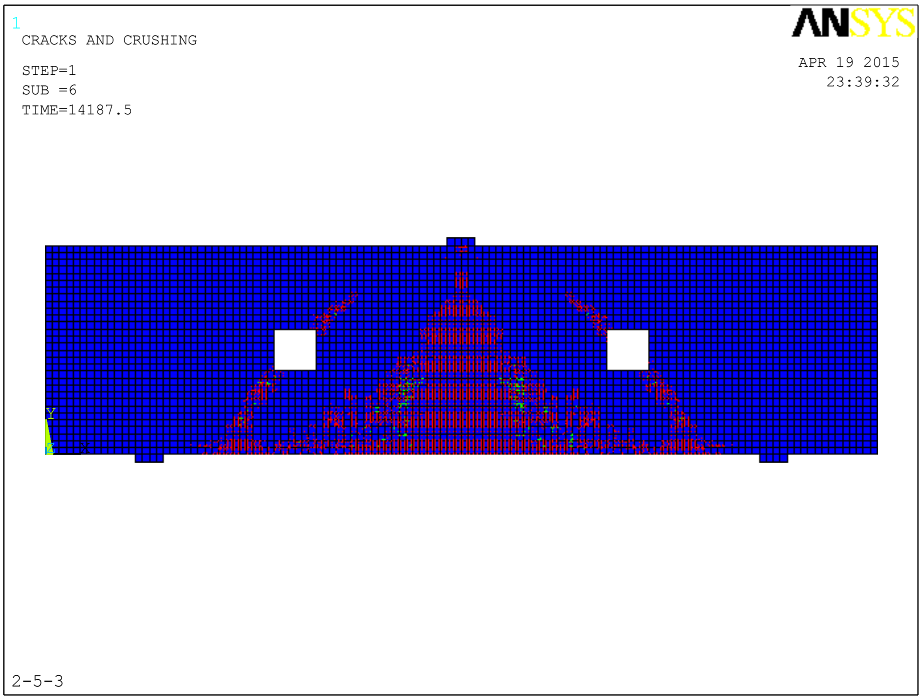


Fig. 13: Crack Pattern for Specimen (B–5–3)

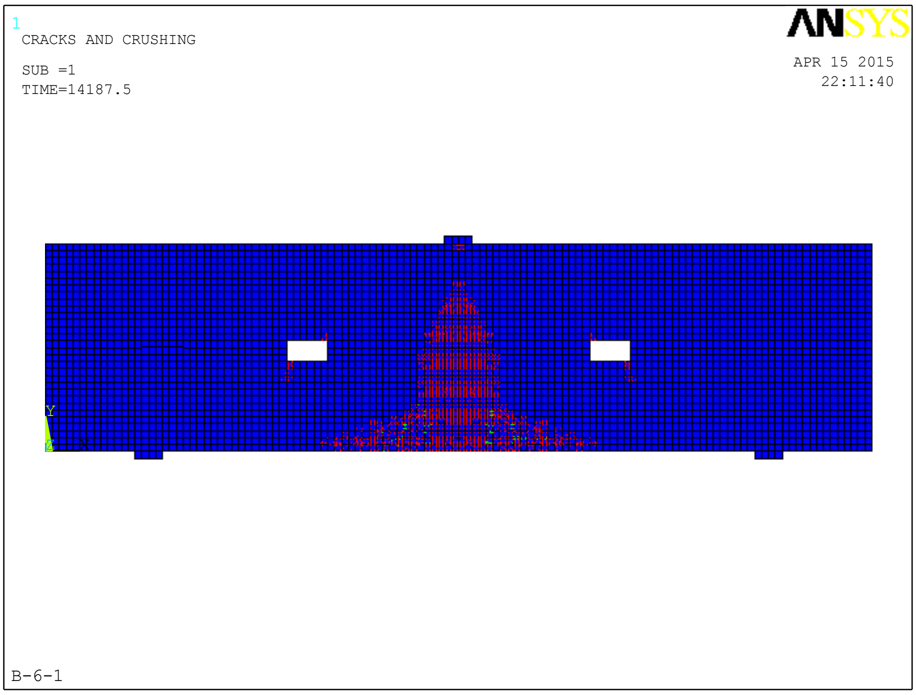


Fig. 14: Crack Pattern for Specimen (B–6–1)

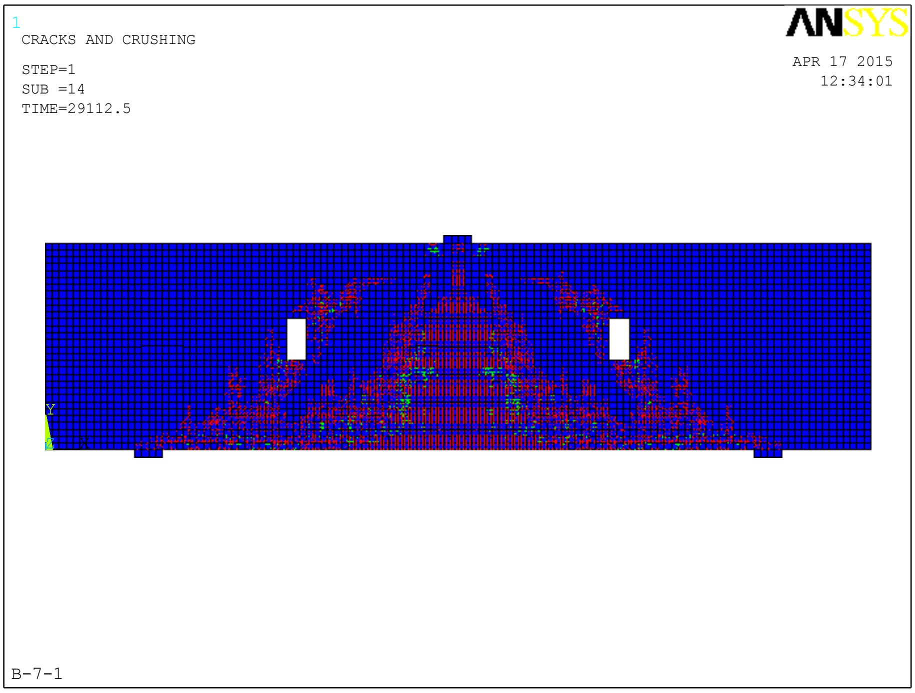


Fig. 15: Crack Pattern for Specimen (B–7–1)

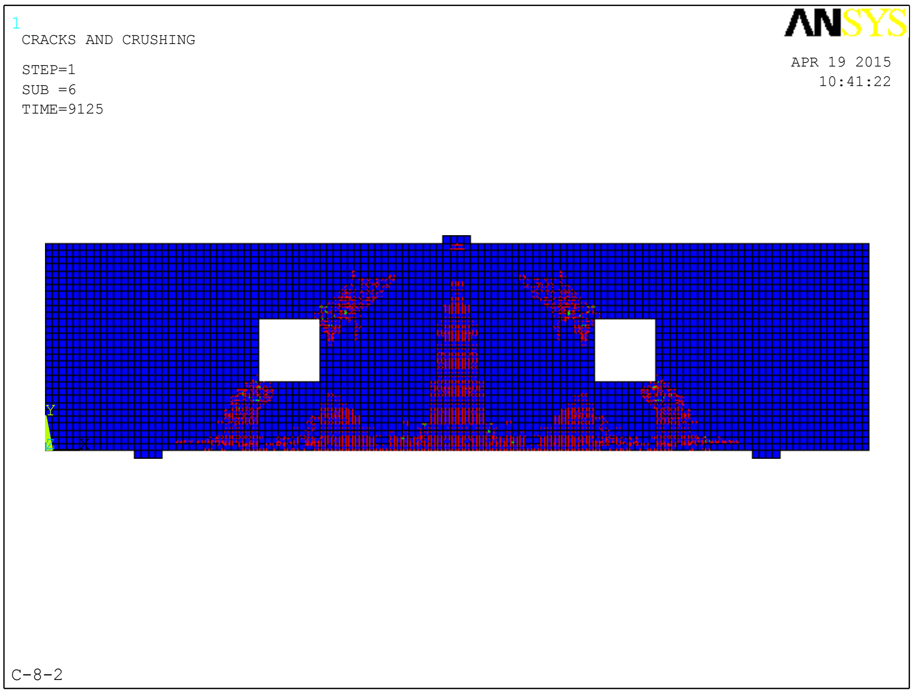


Fig. 16: Crack Pattern for Specimen (C–8–2)

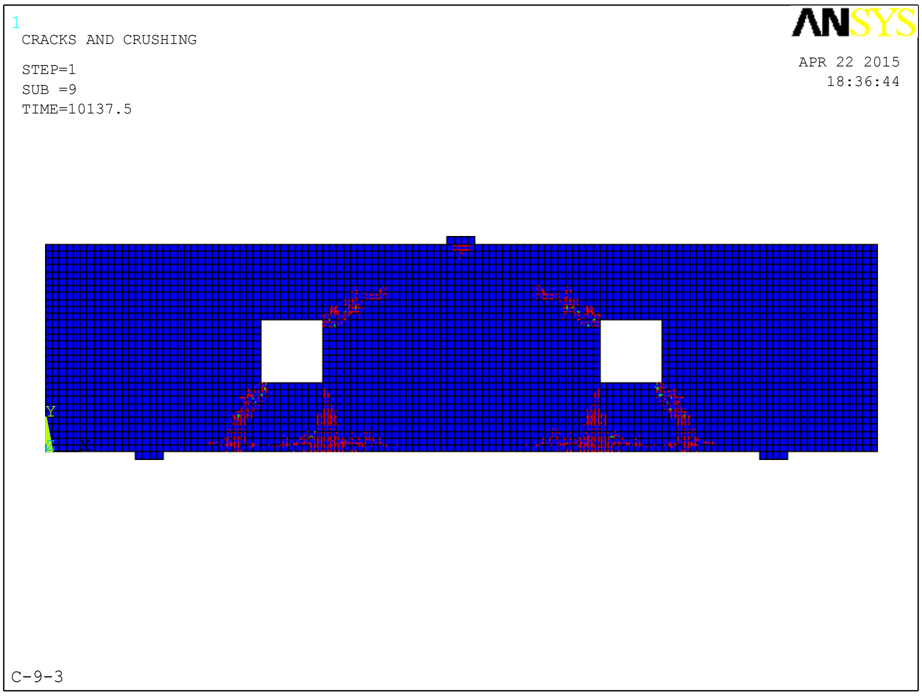


Fig. 17: Crack Pattern for Specimen (C–9–3)

V. CONCLUSIONS

According to present studies, the following conclusions can be get out:

1. As much more area of opening inside the central zone increases, the failure load decreases.
2. The best opening locations for constant square area (10 % x 10 %) is along the perpendicular direction to the diagonal strut, and 20 % upward the central zone.
3. The best opening size for square openings is (10 % x 10 %).
4. Failure load in normal strength concrete deep beams is smaller than high strength concrete deep beams, while deflection in normal strength concrete deep beams is larger than high strength concrete deep beams.

5. Beams with normal strength concrete are more ductile than beams with high strength concrete.
6. Cracks taken the strut and tie triangular shape, extents from supports to load plate, concentrated around openings corner and there are no cracks at the two zones after the supports.
7. Stresses at mid – span increases linearly till it reached to first crack, then it increases non – linear taken the shape of parabola till it reached to failure where maximum stress found.
8. At corners of openings the stress began from zero, reaches to maximum value at first crack then it returned to zero at failure.
9. Stresses decreases as the size of opening increases.

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