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**Behavior of reinforced concrete deep beams with openings
strengthened with steel fibers**

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Abstract

Strut-and-Tie models are effective in designing reinforced concrete structures with discontinuity regions where linear stress distribution is not valid. Deep beams are typically short girders with a large point load or multiple point loads. These point loads, in conjunction with the depth and length of the members, contribute to a member with primarily discontinuity regions. ACI 318-08 Building Code Requirements for Structural Concrete provides a method for designing deep beams using either Strut-and-Tie models (STM) or Deep Beam Method (DBM). Large openings in reinforced concrete (RC) deep beams generally interrupt the load transfer by concrete struts and cause a sharp decrease in strength and serviceability. The reinforcement detailing of these deep beams based on strut-and-tie models (STMs) can be complex and, very often, these models may not predict the failure mechanism of deep beams due to localized damages. The main objective of this paper is to study Steel Fiber Reinforced Concrete (SFRC), offered as an alternative material, to the cumbersome and iterative steps involved in strut-and-tie (STM) methodology. Additionally, a similar reinforced concrete (RC) specimen was tested under the same controlled condition designed with classical strut-and-tie model design methodology reinforced using conventional steel bars. In this investigation, three types of steel fibers, and three percentage of steel fibers, and two aspect ratios were aiming to show the effect of these parameters on the behavior of concrete deep beams.

Material testing was conducted on the materials used in the large scale specimens to ensure that the actual material mechanical properties were known for the analysis. Computer Aided Strut and Tie (CAST) software was used to quantify the experimental data obtained from the controlled conditions testing. The eight beams were compared and contrasted throughout the study to show the effect of fiber on the behavior of deep beams. This study provides information on the viability of using steel fiber reinforced concrete in complex D-regions in structural elements.

Key Words: Reinforced concrete; Deep Beam, Opening, Steel Fibers, Strut and Tie, Cracks, First crack load, Failure Load, Ultimate load, Deflection, Ductility.

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1. Introduction

Deep beams are being used in many applications in buildings and other structures. In buildings, a deep beam or transfer girder is used for architectural purposes when a lower column on the exterior façade is removed. Deep beam can be found in buildings as simply supported, continuous, and cantilever deep beam. Deep beams, sometimes the full depth of the floor-to-floor height is used to transfer the high axial forces of columns above to the supporting columns below. Foundation walls are sometimes also termed as deep beams. In highways, pile caps are classified as deep if the span-to-overall depth ratio (L/d) is greater than four. In the construction of modern buildings, many pipes and ducts are 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 soffit of the beam and for authentic reasons, are covered by suspended ceiling.

Also to transfer the high magnitude of loads collected from all the upper floors of a high-rise building, the depth of the interface beams has to be kept much higher than the conventional beams, ranging from 1 m to 4.5 m. As a result of this, L/d ratio of such beams becomes different than the conventional beam which in turn makes the load transfer mechanism through these beams altogether different. Such a beam is also referred to as a Transfer Beam.

ACI 318-08 (ACI Committee 318 2008) and ECP-203-2007[1],[2] defines a deep beam as a structural element with clear span is equal to or less than four times the overall depth, or the concentrated loads are applied within a distance equal to or less than two times the depth from the face of the support. Codes-specified empirical formulas used to design these members do not explicitly address the design of D-regions with openings. Strut-and-tie models (STMs) are extensively used for these structures with D-regions. These models idealize a deep member as a series of concrete compressive struts and steel tensile ties connected at joints (called nodes). The applied force is transferred from the loading point to supports only through the STM, and the remaining concrete between the trusses is neglected for design and strength calculation purposes.

Large openings, if located between the loading point and the support, will disrupt the flow of force transfer from the loading point to supports and usually significantly reduce the load-carrying capacity [13]. ACI 318-08 does not give any explicit guidance for designing these elements with openings. (Based on limited experimental studies [22]). Nevertheless, STMs provide flexibility to the designer to focus on safe and performance design; however, the constructability becomes a main issue due to problems with anchorage and congestion.

Steel fiber-reinforced concrete (SFRC) has gained increased popularity in construction industries in recent years. Reinforcing concrete with steel fibers has been used to reduce

conventional steel reinforcement in structural members such as slabs [1]. The construction of RC specimens can be time-consuming and labor-intensive due to the complicated detailing of reinforcing bars in contrast to the steel fibers concrete.

2. Experimental program.

2.1. Test material and material properties.

Ordinary Portland type I cement was used in the current research. Typical results of cement testing according to the manufacture specification and in accordance with ASTM C187-86, ASTM C191-82, ASTM C204-84, ASTM C150-68, and ASTM C109-88. Materials component are listed in Table1 and Table 2.

Table1. Mix-Proportions by Weight used water-cement Ratio equal (0.5).

Mix-Proportions			
Cement	Fine Aggregate	Coarse Aggregate	Water
84	126	230	42
1	1.5	2.75	0.5

Table2. Fibers-Proportions for different specimens and compressive strength MPa.

Specimen NO	Fiber Weight	Fiber Shape	Fiber Percentage	Fiber Aspect ratio	Compressive Strength (MPa)
R	-	-	-	-	37.4
RO	-	-	-	-	38.4
FO-H-1.5-50	25	EH	1.50%	50	43.9
FO-CR-1.5-50	25	CR	1.50%	50	50.9
FO-CS-1.5-50	25	CS	1.50%	50	45.1
FO-CS-2-50	35	CS	2.00%	50	41.9
FO-CS-1-50	17	CS	1.00%	50	42.2
FO-CS-1.5-40	20	CS	1.50%	40	43.1

High tensile steel 36 was provided from the national companies. Bars were round, corrugated and of 10 mm and 12 mm diameter. Tests were carried out according to E.S.S. specifications. Dolomite was used as the coarse aggregate in the mixture. The nominal maximum coarse aggregates size used for casting the concrete deep beams is of 10 mms. Natural siliceous sand was used as the fine aggregate throughout the current investigation.

2.2. Concrete mix design.

The concrete mix was designed in accordance with Egyptian standard method of concrete mix design to give an average strength of 35.0 N/mm² after 28 days. Normal Portland cement with 400 Kg/ m³ was used. Normal weight Dolomite with maximum size of 10 mm and bulk density of 1680 Kg/m³ was used as coarse aggregate. The fine aggregate was normal sand. The Mix proportions were 1: 1.5: 2.75 (Cement to sand to dolomite) with free water cement ratio of 0.50.

2.3. Design and details of the beam specimens.

The experimental program comprised casting and testing eight deep beams having the dimension of 1800*1100 mm with thickness 100 mm. Two conventionally reinforced concrete deep beams were cast and tested and used as control specimens. The test parameters were the type, percentage, and aspect ratio of the steel fiber. The current experimental program aims to investigate the effect of these test parameters on strength, stiffness, cracking behavior, ductility of transfer deep beam. A series of deep beam models (eight models) were prepared and tested at the reinforced concrete laboratory of Cairo University. Table3 shows the different types of deep beams. The reinforced concrete deep beams had original dimension of (1800*1100*100 mm). They were cured for 28 days, and then tested.

Table 3. Details of the Specimens of Series-I, II, III, IV

Test Beam Designation	Opening Size (a×b)	Effective depth (mm)	Concrete Strength			Bottom Long. Reinforcement	
			Fcu MPa	Fc' MPa	Ft MPa	Φ mm	Fy MPa
Series I Specimens							
I/R	-	1075	37.4	29.92	3.67	Φ12	488
I/RO	350×350	1075	38.4	30.72	3.71	Φ12	488
Series II Specimens							
II/FO/H/1.5/50	350×350	1075	43.9	35.12	5.33	Φ12	488
II/FO/CR/1.5/50	350×350	1075	50.9	40.72	5.33	Φ12	488
II/FO/CS/1.5/50	350×350	1075	45.1	36.08	5.33	Φ12	488
Series III Specimens							
III/FO/CS/1.0/50	350×350	1075	42.2	33.76	4.64	Φ12	488
III/FO/CS/1.5/50	350×350	1075	45.1	36.08	5.33	Φ12	488
III/FO/CS/2.0/50	350×350	1075	41.9	33.52	5.78	Φ12	488
Series IV Specimens							
IV/FO/CS/1.5/40	350×350	1075	43.1	34.48	4.93	Φ12	488
IV/FO/CS/1.5/50	350×350	1075	45.1	36.08	5.33	Φ12	488

A mathematical expression that predicts the split tensile strength of steel fiber reinforced concrete is derived by M. Musmar [28]. The suggested equation correlates the split tensile strength of steel fiber reinforced concrete with concrete compressive strength and fiber reinforcement index.

$$F_{sp} = [0.6 + 0.4(V_f \times L/d)] \times \sqrt{F_c'}$$

Eq.1

Where:-

F_{sp} is the splitting strength of fiber reinforced concrete [MPa].

V_f is volumetric percentage

l and d are steel fiber length and diameter respectively.

F_c' is the cylinder strength of fiber reinforced concrete [MPa].

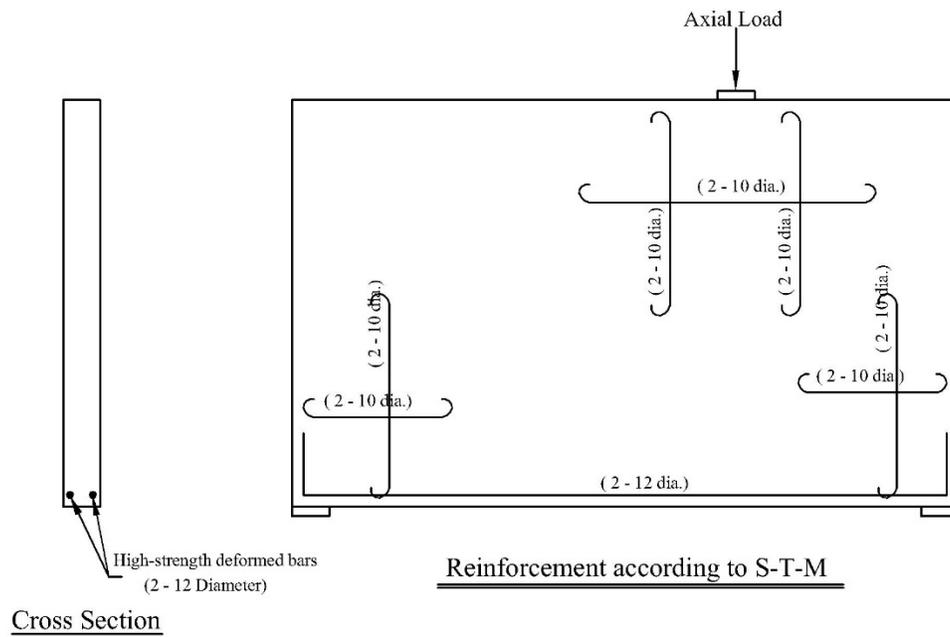
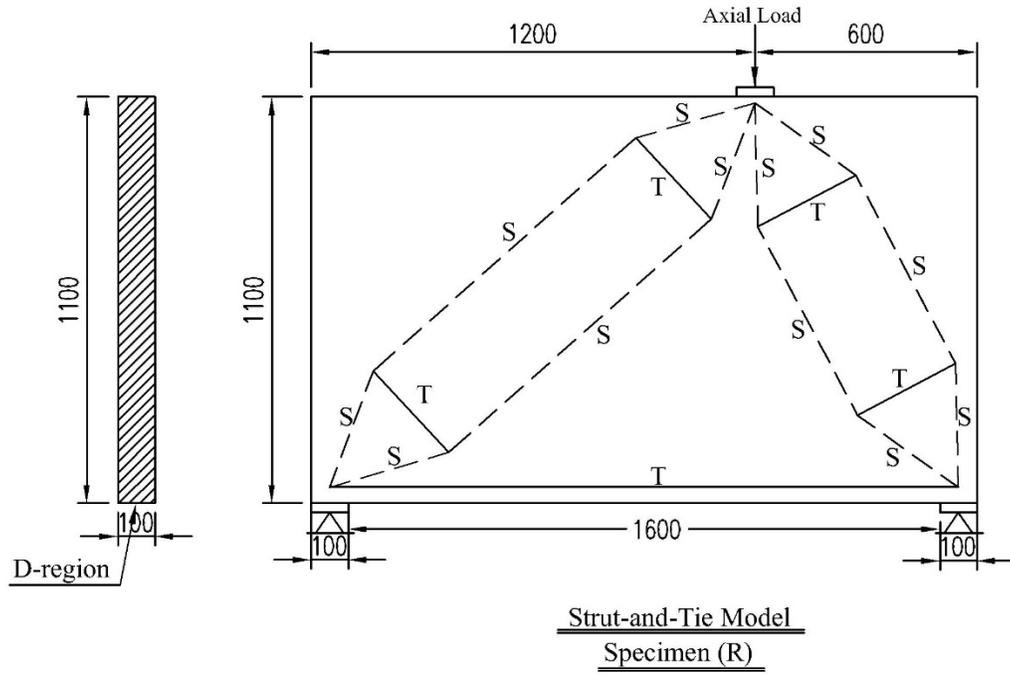
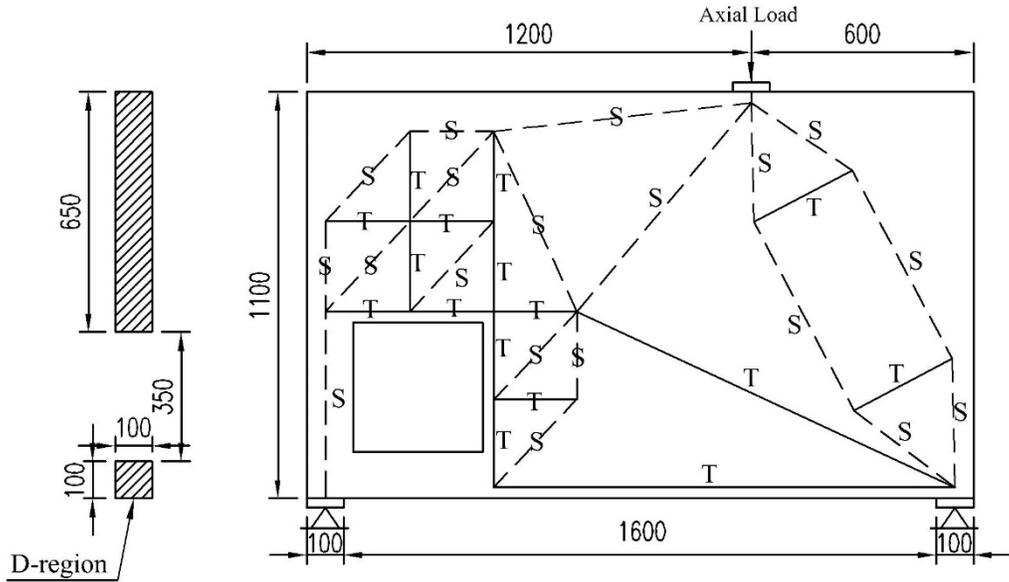
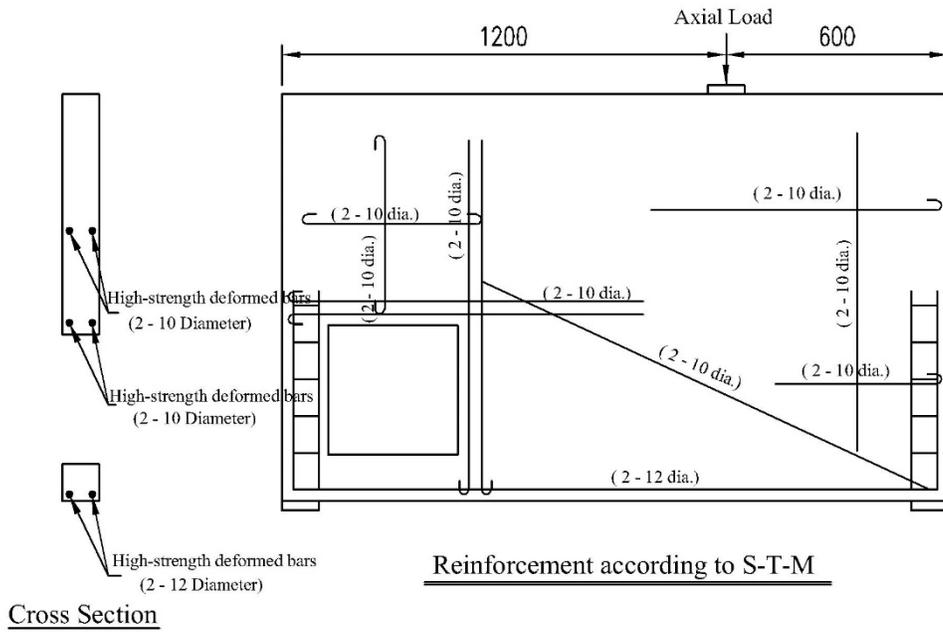


Fig. 1 Specimens (R).



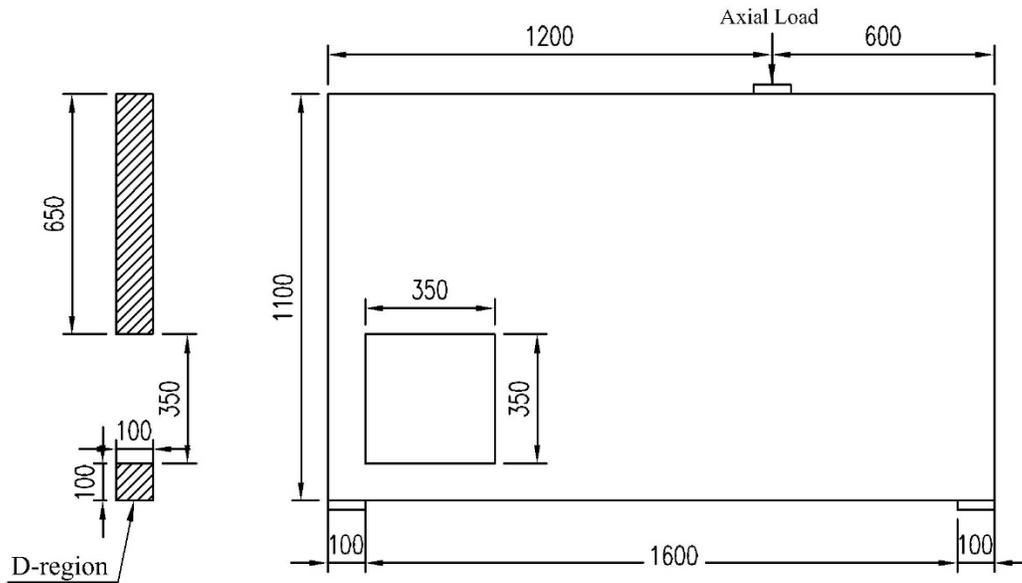
Strut-and-Tie Model
Specimen (RO)



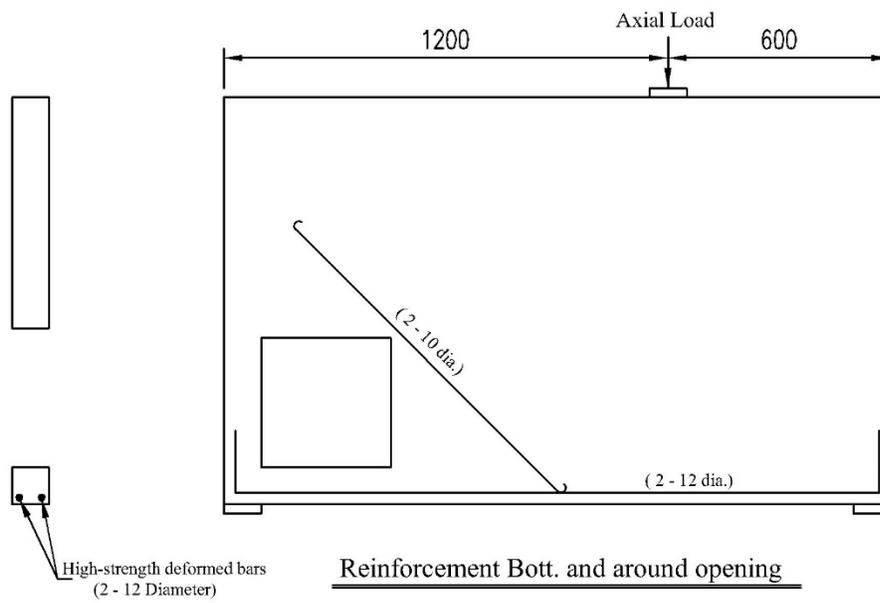
Reinforcement according to S-T-M

Cross Section

Fig. 2 Specimens (RO).



Fibers specimens geometry



Reinforcement Bott. and around opening

Fig. 3 Typical for steel fiber specimens.

Series II, series III, and series IV specimens are beams with steel fiber reinforcement. Series II consist of three beams with varying shapes. End hooked and crimped (segment and rounded) are used. Series III consist of three beams with different volumetric fraction percentages. Percentage 1.0 %, 1.5 %, and 2.0% are used. Series IV consist of two beams with two different aspect ratios. Aspect ratios 40 and 50 are used. Constant percentage of horizontal steel in the bottom fibers of beam and parallel to open diagonal. Figs.1, 2, 3 showing layout of reinforcement distributed on beams depth.

2.4. Specimen identification.

This paper addresses the effect of the various influencing parameters of using different types of steel fibers with different percentages and aspect ratios in reinforcing deep beams and the effect on D-regions. Also, to study the comparison between using reinforced steel bars and various types of steel fibers. The second is to examine the viability of installing large opening interrupting the load path on the load carrying capacity of reinforced concrete transfer (deep) beams. In the beam notations under Table 3.

In series I beam specimens, the series number is given first, followed by beam type. For example, Beam I-RO refers to a specimen in series I and R refers to reinforced concrete and O refer to existence of opening in beam.

For series II beam specimens, the series number is given first; followed by beam type, followed by volumetric percentage and then by (a/d) aspect ratio. For example, Beam II-FO-H-1.5-50 refers to a specimen in series II, followed by FO fiber reinforced concrete and the beam containing opening, then fiber shape where H means end hooked steel fiber. Then 1.50% is the volumetric percentage with a/d-ratio of 50.

For series III beam specimens, the series number is given first; followed by beam type; followed by volumetric percentage and then by (a/d) aspect ratio. For example, Beam III-FO-CS-1-50 refers to a specimen in series III, followed by FO fiber reinforced concrete and the beam containing opening, then fiber shape CS mean crimped segment, then 1% volumetric percentage with a/d-ratio of 50.

For series IV beam specimens, the series number is given first; followed by beam type, followed by volumetric percentage and then by a/d-ratio. For example, Beam IV-FO-CS-1.5-40 refers to a specimen in series IV, followed by FO fiber reinforced concrete and the beam containing opening, then fiber shape CS mean crimped segment, then 1.50% volumetric percentage with a/d-ratio of 40.

3. Test procedure.

3.1. Test setup and loading apparatuses.

All beam specimens were tested under three-point loading test set-up (1-active, 2-passive) as shown in Fig. 4. Point-Load was kept constant for all the specimens at 550 mm from center line of right support. The load was transferred from loading frame to the specimens through a proving ring by hydraulic jack placed on the top of specimens. Loading was stopped at 10 KN intervals to document crack propagation and width. Cracks were drawn on the back face in blue, red, and black in the front face to distinguish the sides.

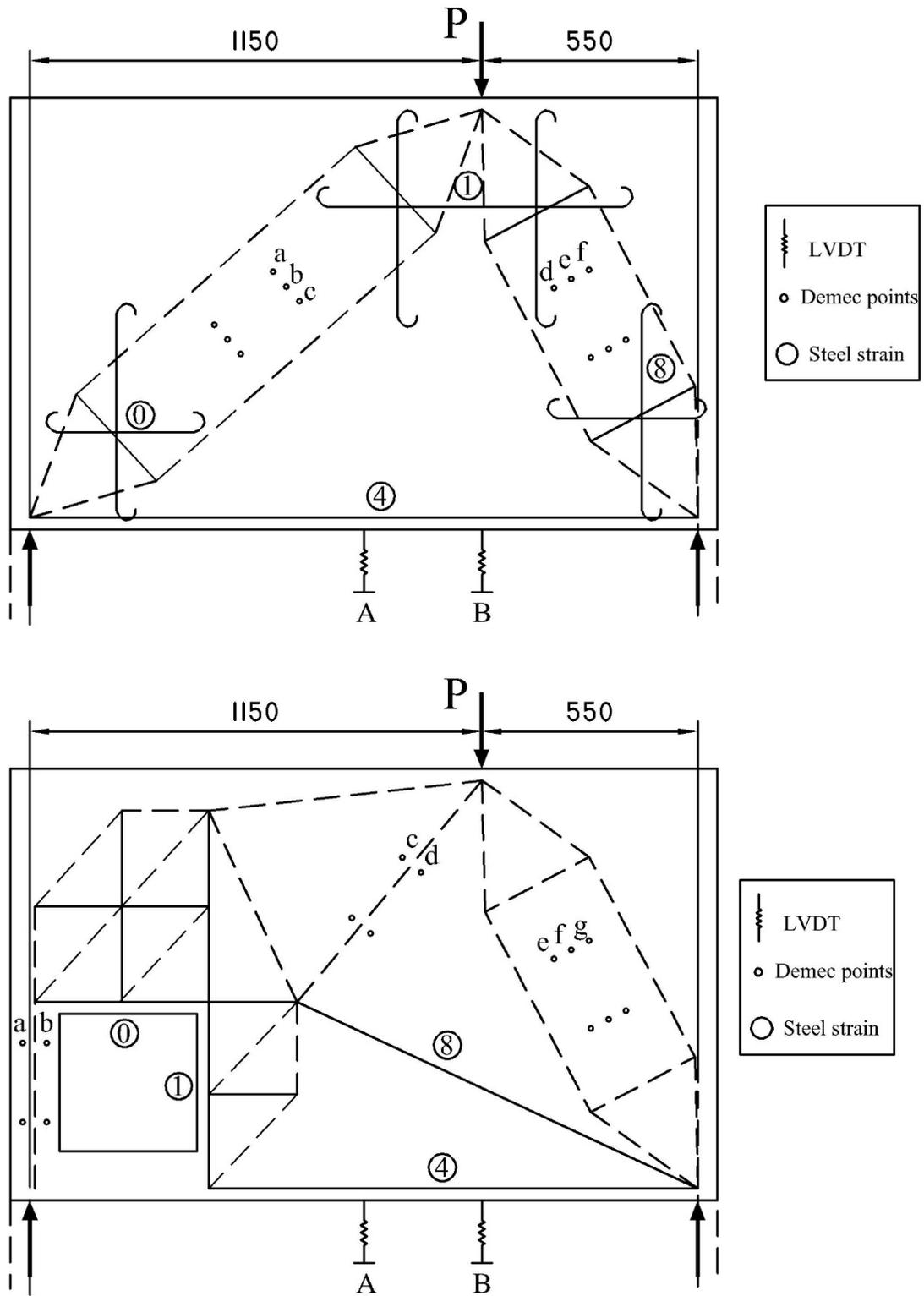


Fig.4 Three point loading test set-up.

After 28-days curing period, the beam specimens were removed from the curing tank and both sides of the beam were white-washed to aid observations of the crack development during testing. Load was applied gradually with the help of a jack and the deflection of proving LVDT was recorded to find the failure load.

3.2. Test results and discussion.

The results obtained from the experimental investigation are tabulated in Table 4. From the results obtained, the effect of various parameters on shear strength of concrete are analyzed and discussed as follows.

Table 4. Test results of Series I, II, III, and IV.

Test Beam Designation	L/d ratio	Concrete Strength		Bottom Long. Reinf	P _{cracking} KN	P _{failure} KN	Mode of Failure
		F _{cu} MPa	F _{c'} MPa	Dia (Φ)			
Series I Specimens							
I/R	1.63	37.4	29.92	Φ12	260	370	concrete crushing
I/RO	1.63	38.4	30.72	Φ12	160	340	Flexural diagonal-splitting
II/FO/H/1.5/50	1.63	43.9	35.12	Φ12	250	500	Flexural diagonal-splitting
II/FO/CR/1.5/50	1.63	50.9	40.72	Φ12	240	430	concrete crushing
II/FO/CS/1.5/50	1.63	45.1	36.08	Φ12	250	420	Flexural diagonal-splitting
III/FO/CS/1.0/50	1.63	42.2	33.76	Φ12	170	350	Flexural diagonal-splitting
III/FO/CS/1.5/50	1.63	45.1	36.08	Φ12	250	420	Flexural diagonal-splitting
III/FO/CS/2.0/50	1.63	41.9	33.52	Φ12	170	400	Flexural diagonal-splitting
IV/FO/CS/1.5/40	1.63	43.1	34.48	Φ12	200	365	Flexural diagonal-splitting
IV/FO/CS/1.5/50	1.63	45.1	36.08	Φ12	250	420	Flexural diagonal-splitting

3.3. Mode of failure.

The failure modes of the specimens are indicated in the Table 4. Two types of failure modes are identified flexural diagonal splitting and concrete compressive crushing. The flexural diagonal-splitting failure, characterized as direct tension failure, is a ductile failure. This is ductile mode of failure in which the beam deflects at the center and no explosive sound was heard at the time of failure. Concrete compressive crushing failure, characterized as direct compressive failure, is a brittle failure, sudden and hence

treacherous. A critical diagonal strut joining the loading point at the top and support point at bottom is developed. In the compressive mode of failure, after the appearance of the inclined crack at support, the concrete portion of concrete separated and the beam finally fails. This mode of failure is equally a brittle mode of failure.

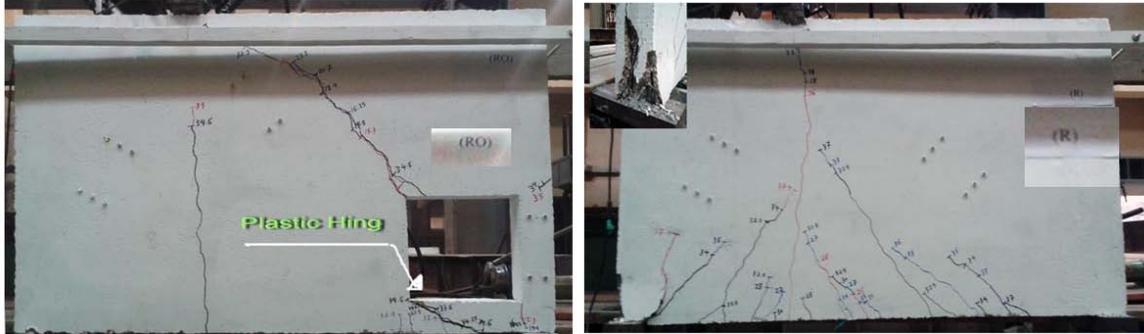


Fig. 5 Crack pattern for series-I.

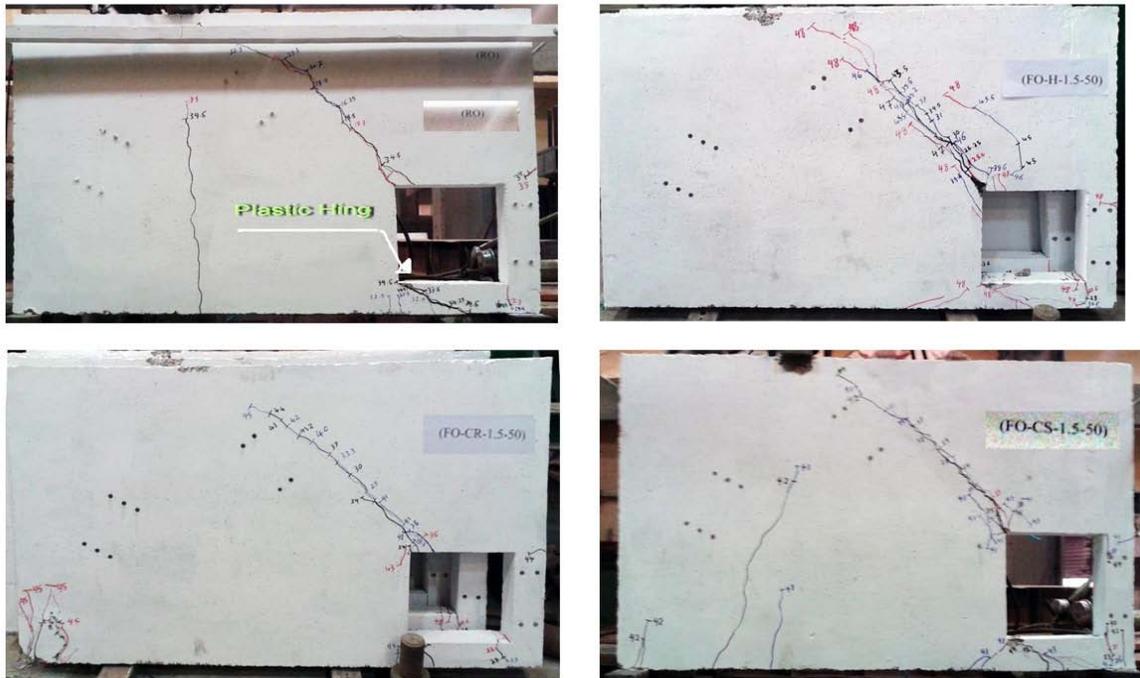


Fig. 6 Crack pattern for series-II.

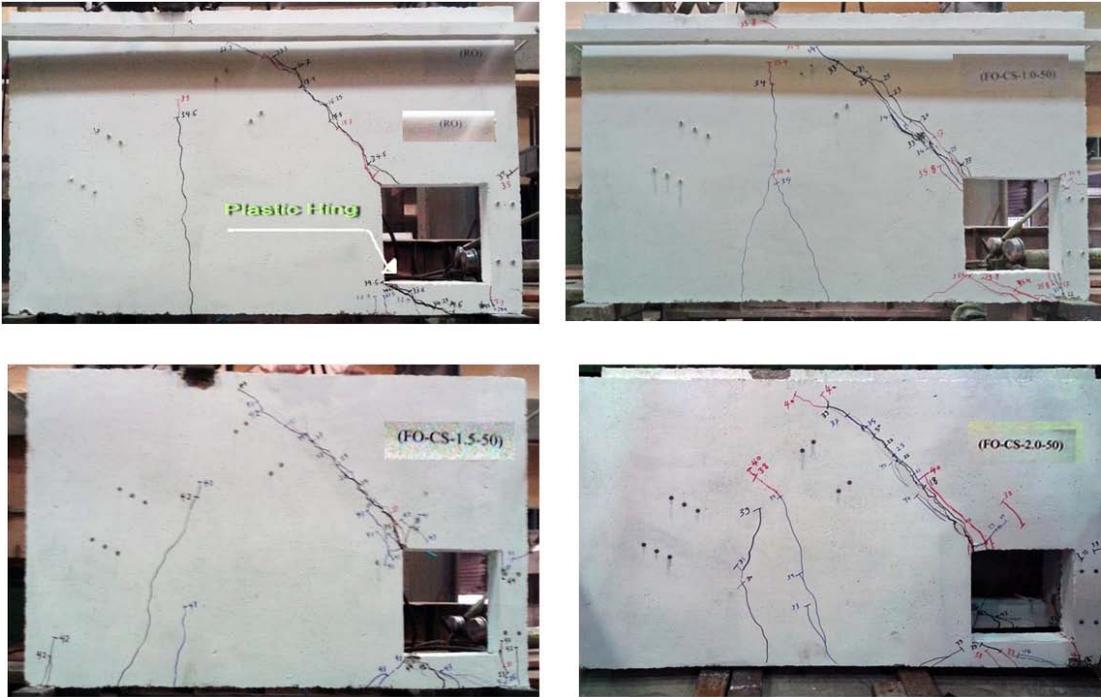


Fig. 7 Crack pattern for series-III.

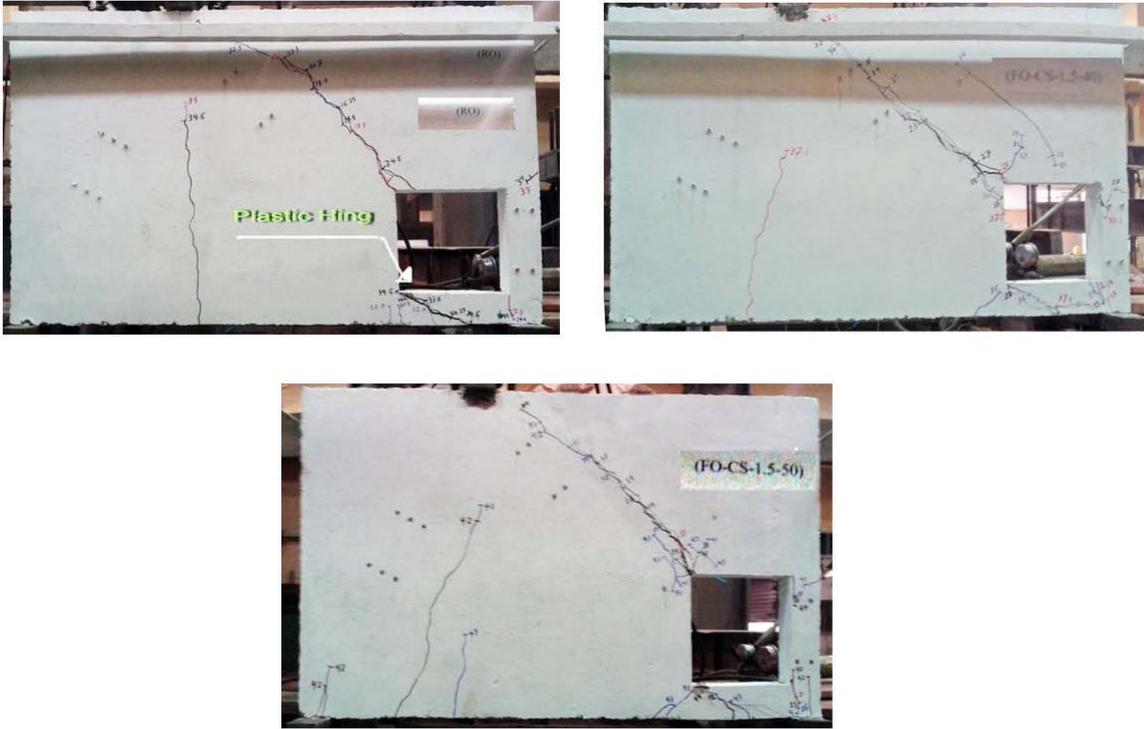


Fig. 8 Crack pattern for series-IV.

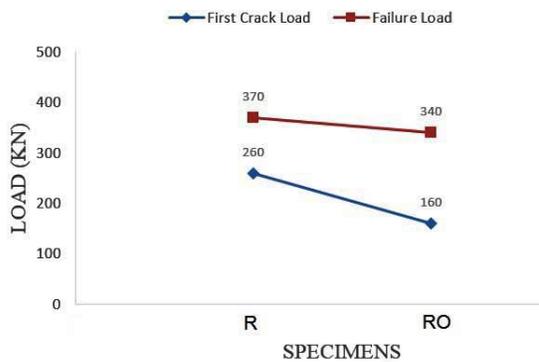
3.4.Failure strength.

For series I as shown in Fig 5. Installing openings in transfer deep beam decreases first crack load as expected. It decreased from 260 KN to 160 KN which decreases about 62.5% of that obtained in case of beam without opening. Behavior of deep beam with opening in failure wasn't predicted as good behavior for beam with opening due to plastic hinge around opening with increase beam capacity in failure load and little decrease in load due to installing opening from 370 KN to 340 KN which decrease about 8 % from beam with opening.

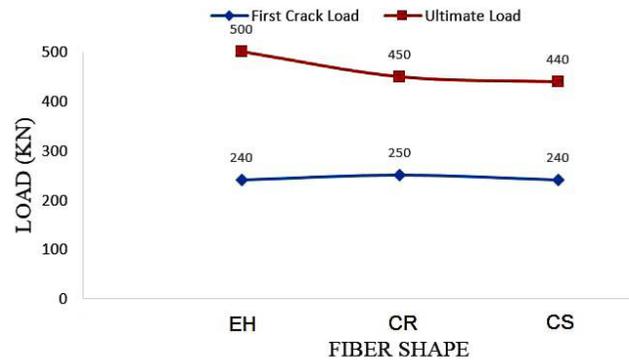
For series II as shown in Fig 6 strengthening deep beams with steel fiber increase both; first crack and failure load. Rounded fibers as end hooked and crimped rounded have good behavior in concrete as they are more workable than segment fiber. End hooked fiber gave the highest value in ultimate load which reached to 500 KN and is more ductile than the other beams.

For series III as shown in Fig 7 which show different percentages of segment crimped steel fiber. The best percentage for traditional concrete is 1.5 % which give the highest results compared to other percentages in first crack and failure load. [Percentage 1.00% was little percentage].Decrease in loads for beam with percentage 2.00% due to honeycomb for concrete.

For series IV as shown in Fig 8 which show different aspect ratios of segment crimped steel fiber. The best aspect ratio for traditional concrete was L/d=50 which gives the highest values in first crack load and failure load. Beam load carrying capacity is increased with this aspect ratio than L/d=40.



Series I



Series II

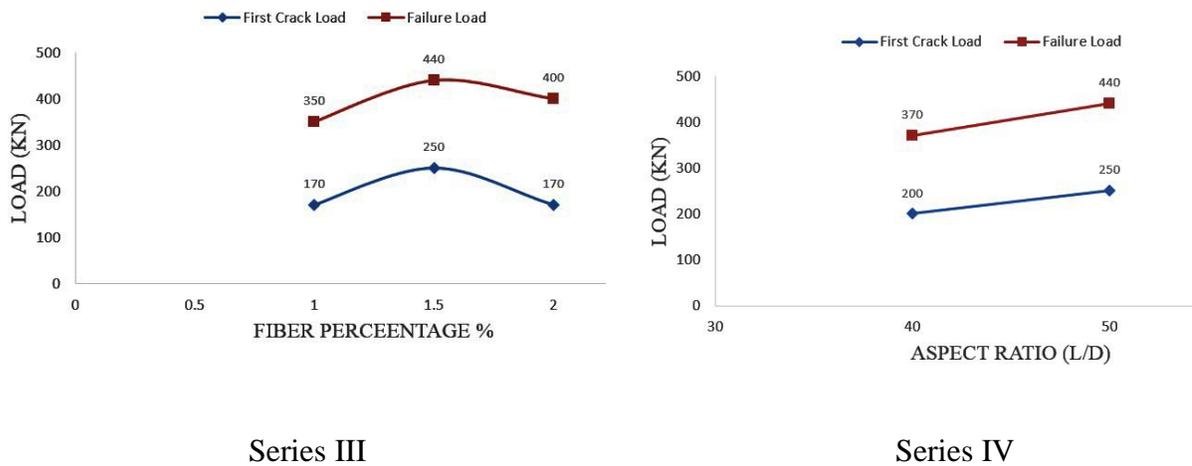


Fig. 9 Cracking and failure loads for different specimens

3.5. General behavior.

The general behavior of all the specimens was quite similar. First, the fine flexural cracks were initiated in the pure bending region and with further increase of load, new flexural-shear cracks formed around the opening and subsequently, curved toward the loading points. Failure in these specimens was always flexural failure and in diagonal tension, shortly after diagonal cracks around opening appeared. Fig 9 shows results of first crack load and failure load which were obtained from experimented beams for different series.

3.6. Effect of installing opening.

The opening geometry may be considered one of the important parameters affecting both cracking and failure load. Table 4 presents the measured failure load of the transfer beams. [Tension steel is provided at the bottom of beams (Series-I specimens)]. A significant decrease in the carrying load capacity for beam with opening. Presence of opening that disrupt load flow to the support decrease the first crack load about 40 % and decrease the ultimate load about 10 % from control specimen (RO). A ductile plastic mechanism was developed after the formation of several plastic hinges in Specimen RO. Steel cages increased node capacity for beam RO in series-I.

3.7. Effect of steel fiber shape.

In the Series II beam specimens, a constant percentage of steel fibers equal (1.50%) and aspect ratio equal (50) is distributed across the depth of beams and varying fiber shapes are used one for each of the three beams. From the experimental results it can be seen that rounded fiber is better than segment in concrete mixes. End hooked steel fiber improved

the first crack load about 60%, and improved the failure load capacity about 32% from control specimen (RO). The construction of RC specimens can be time-consuming and labor-intensive due to the complicated detailing of reinforcing bars in contrast to the steel fibers specimens.

3.8.Effect of steel fiber percentage.

In the Series III beam specimens, crimped segment steel fibers with aspect ratio equal 50 were used and distributed across the depth of three beams. Three fiber percentage ($\rho_v = 1.00\%$, 1.50% , and 2.00%). A ductile plastic mechanism developed after the formation of several plastic hinges in specimens containing opening. Using a steel fiber percentage 1.5% improve the first crack load about 40% , and improve the failure load capacity about 60% . Increasing the percentage of fibers further to 2% decreased the first crack load and ultimate load due to the formation of concrete Honeycomb. In general, according to the results obtained the percentage of steel fiber in concrete of 1.50% led to the best results.

3.9.Effect of steel fiber aspect ratio.

In the Series IV beam specimens, crimped segment steel fibers with percentage 1.50% were used and distributed across the depth of two beams. Two aspect ratios ($a/d = 40$ and 50). Fibers aspect ratio $L/d=50$ increase the first crack load about 56% and failure load about 30% , and steel fibers with aspect ratio $L/d=40$ increase first crack load about 25% and ultimate load about 5% . [Behavior of specimen with aspect ratio 50 is better in crack behavior than aspect ratio 40 .]

4. Modelling specimen's results.

The design of concrete structure by using the strut-and tie model approach usually involves the estimation of initial size, developing an appropriate strut-and tie model and dimensioning struts, ties and nodal zones. Developing an appropriate strut-and-tie model for a concrete structure with complex geometry and loading conditions is the most challenging task in the design process. Afterwards, dimensioning the strut-and-tie model is straightforward according to codes of practice. (CAST) a computer analysis program for strut-and-tie modeling and get forces in strut-and-tie. This program give reasonable results in case of opening without opening and need to make modification for deep beam contains steel fibers.

4.1. Modeling of specimen R

By using BESO2D program the optimum topology is obtained. The beam is modeled by four-node plane stress element. The material Young's modulus $E = 200$ GPa and poisson ratio $\nu = 0.15$ are input into the program. The results from analysis as show in Fig. 10 that indicate the load path through deep beam.

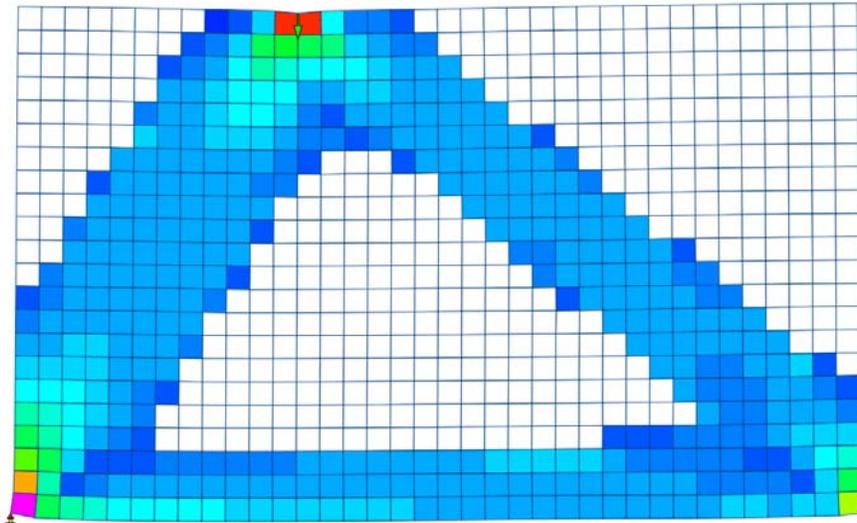


Fig.10 Final topology after 41 iteration for specimen R

Starting with the results of topology optimization obtained from BESO2D and by assuming that the struts and ties are centerline of assumed topology and suggest truss by C-A-S-T program is solved. Fig.11 and Fig.12 show the forces results obtained from CAST by solving the suggested truss at service and ultimate load capacity.

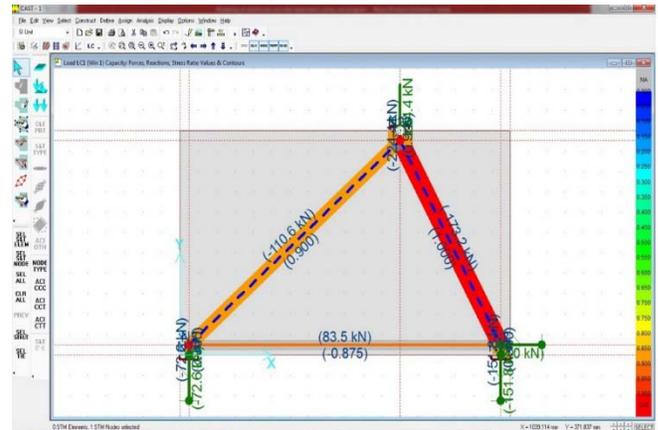
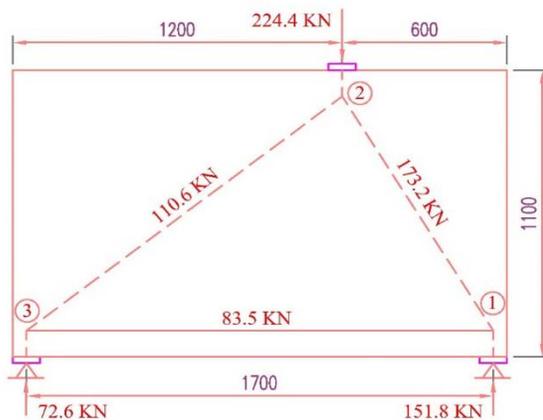


Fig.11 Computer analysis result program at service load (C-A-S-T) for specimen (R) using strength reduction factor = 0.75

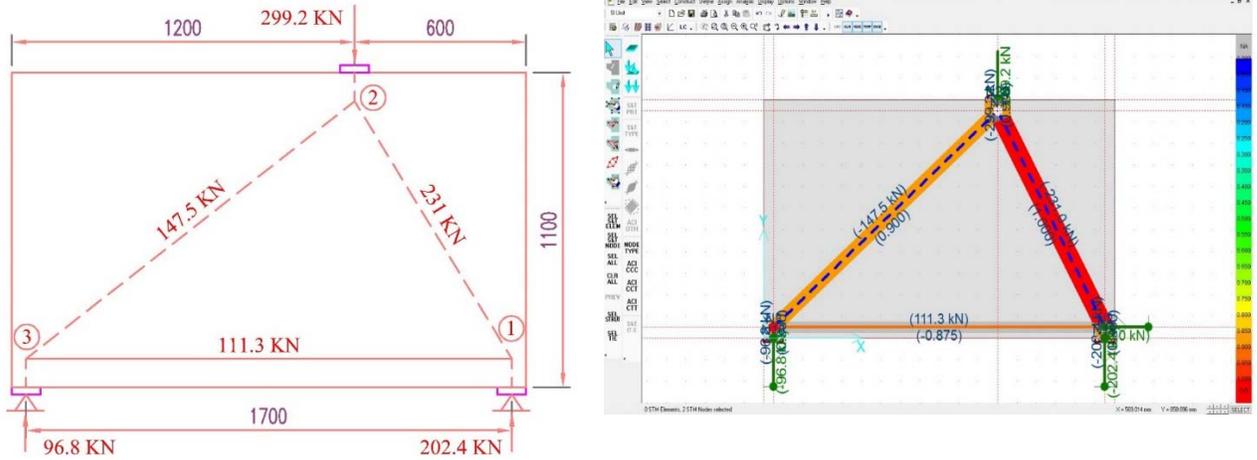


Fig.12 Computer analysis result program at service load (C-A-S-T) for specimen (R) using strength reduction factor of unity

According to ACI Section A.3.3, a low-efficiency factor β_s of 0.63 was used for bottle-shaped struts to reflect the fact that no cracking-controlled reinforcement was used. An efficiency factor of 0.85 was conservatively used for the prismatic struts at the supports. Strength reduction factor of unity is used to get the ultimate load capacity of deep beam.

$$F_{cu} = R * \beta_s * F_c'' \quad \beta_s = 0.63 \quad \text{For Bottle shape} \quad \text{Eq.3}$$

$$F_{cu} = R * \beta_s * F_c'' \quad \beta_s = 0.85 \quad \text{For Prismatic shape} \quad \text{Eq.4}$$

Where: - R: strength reduction factor - β_s : depend on strut type
 - F_c'' : cylinder compressive strength

4.2. Modeling of specimen RO

By using BESO2D program getting the optimum topology. The beam is modeled by four-node plane stress element. The material Young's modulus $E = 200$ GPa and poisson ratio $\nu = 0.15$. The results from analysis show in fig.13 that indicate the load path through deep beam.

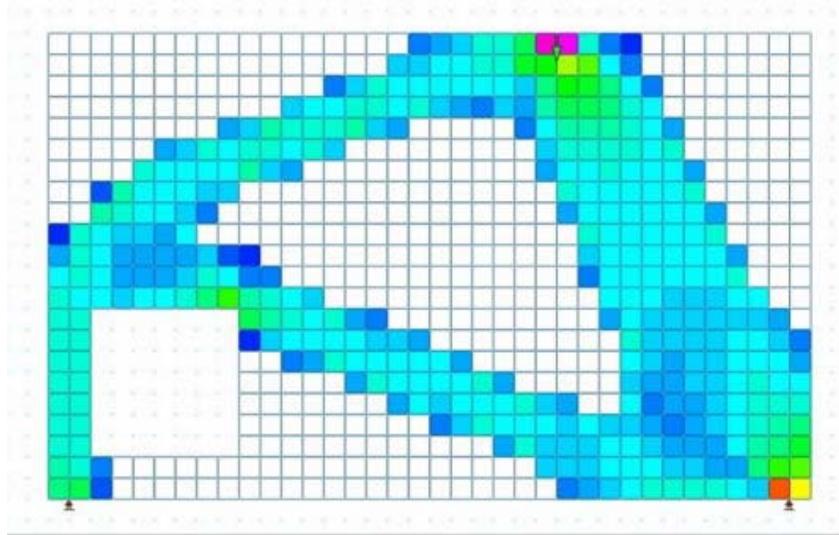


Fig. 13 Final topology after 41 iteration for specimen RO

Starting with the results of topology optimization obtained from BESO2D results by assuming that the struts and ties are centerline of assumed topology and solve the suggest truss by C-A-S-T program. Fig.14 and Fig.15 shows the forces results obtained from cast by solving the suggested truss at service and ultimate load capacity.

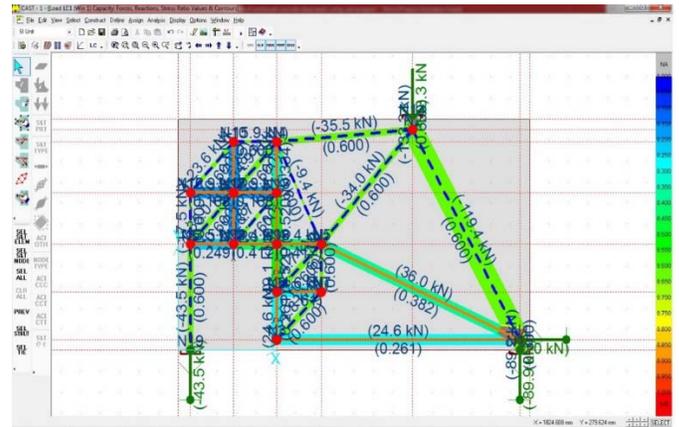
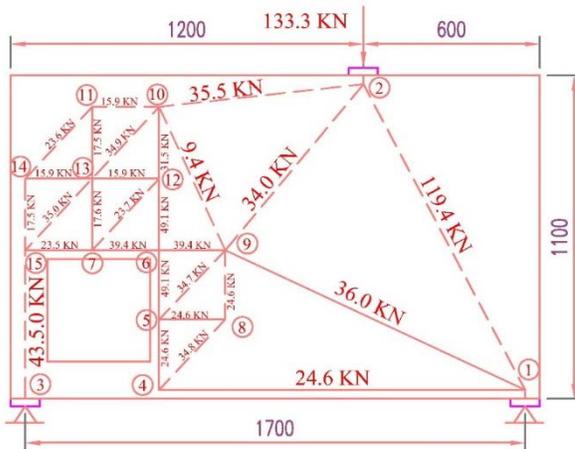
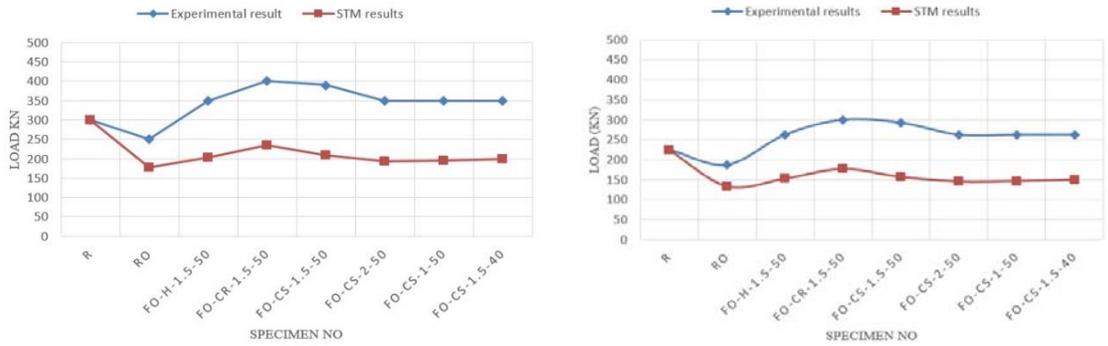


Fig. 14 Computer analysis result program at service load (C-A-S-T) for specimen (RO) using strength reduction factor = 0.75



(B) Ultimate loads

(A) Service loads

Fig.16 Summary of analysis and experimental testing

5. Conclusions

The reinforcement detailing of concrete members based on STMs can be quite complicated and, very often, these models cannot predict the failure mechanism due to localized damages. Also, the actual stress fields in such members are typically very different from those predicted by STMs, as indicated by many experimental investigations. Based on the experimental and analytical studies on transfer (deep) beams in high-rise building, using steel fibers in deep beams improve its capacity for cracking and failure load and improve its ductility. Using rounded steel fiber was better than segment fiber which is workable in concrete matrix and flexibility for mix with concrete. Generally steel fiber is a better material for deep beam which increase capacity of beam and improve crack propagation. End hooked steel fibers with aspect ratio 50 and percentage 1.5% gives good behavior than other parameter.

Based on the study, designing by ACI code for deep beams (Transfer beams), it is concluded ACI gives some useful guidelines for design procedures but warns that there is no experimental evidence to substantiate these procedures. Design by Cast program gives accurate results for deep beams without openings than beam with openings.

References

- [1] A. C. Institute, Building Code Requirements For Structural Concrete .manual of concrete practice, USA, Michigan: ACI Committee 318-08, 2008, pp. 379-393.
- [2] Egyptian Code for design and Constuction of reinforced concrete structural, ECP 203-2007 ed., Egypt, 2007, pp. 6/115-6/124.
- [3] Morsch,E, Concrete-steel Construction., New Yorj: MCGrow-Hill, 1909.
- [4] R. Hibbeler, Mechanics of materials, 6, Ed., Prentice Hall, 2005, p. 123.
- [5] AASHO, AASHTO LRFD Bridge design Specifications, 1 ed., USA, Washington: American Assosiation of state Highway and Trasportation officials, 1994.

- [6] B. T.Martin, Verification and Implementation of Strut-and-Tie Model in LRFD Bridge Design Specifications, university of Nevada Reno, Novamner,2007.
- [7] Mitchell, D., Collins, M. P., Bhide, S. B., and Rabbat B. G, "AASHTO LRFD Strut-and-Tie," *Portland Cement Association*,, p. 60pp, 2004.
- [8] Brown, M. D., Bayrak, O, "Minimum Transverse Reinforcement for Bottle-Shaped Struts," *ACI Structural Journal*, vol. 103, pp. 813-821, 2006.
- [9] L. Ahmed, "Analysis and Design of Connected Variable Sections Column," MTC, Cairo, 2012.
- [10] M. Emam, Concrete, Mansoura-Egypt: Civil Engineering department-Faculty of Engineering-Mansoura University.
- [11] D. Dean, "Steel Fiber Reinforced Concrete," Faculty of Civil Engineering - university of Technology, Ho Chi Minh City.
- [12] C. A. FLORES, Performance of Large Scale Steel Fiber Reinforced Concrete Deep Beam with Single Opening Under Monotonic Loading, Arlington: University of Texas, August 2009.
- [13] R. Sahoo, Carlos A. Flores, and Shih-Ho Chao, "Behavior of Steel Fiber-Reinforced Concrete Deep Beams with Large Opening," *ACI*, pp. 193-204, April 2012.
- [14] S.-H. Chao, T. Pareek, and D.R. Sahoo, Effect of Fiber Reinforced Concrete in Members with Highly Complex Stress Fields, USA: Department of Civil Engineering, University of Texas at Arlington, 2012.
- [15] N. V. Chanh, "Steel Fiber Reinforced concrete," University of Technology, Ho Chi Minh City.
- [16] Vinu R. Patel, I. I. Pandya, "Ultimate shear strength of Fibrous moderate deep beams," *IJASER*, vol. 1, pp. 138-145, 2.012.
- [17] Strength and Behavior of High Strength Concrete Deep Beam with Web Openings, Australia: Griffith University, February,2011.
- [18] E. Skibbe, "Acomparision of design using Strut-and-Tie Modelling and deep beam method for transfer girder building," B.S, Kansas State University, U.S.A, 2010.
- [19] al, Hai H. Dinh et, "Shear Behavior of Steel Fiber-Reinforced Concrete Beams without Stirrup Reinforcement," *ACI*, U.S.A, 2010.
- [20] al, S.K. Madan et, "Steel Fibers as Replacement of Web Reinforcement for RCC Deep Beams in Shear," *AJCE*, vol. 8, pp. 479-489, 2007.
- [21] R. Londhe, "Shear Strength Analysis and Prediction of Reinforced Concrete Transfer Beams in High-Rise Buildings," *Structural Engineering and Mechanics*, Vols. Vol. 37, No. 1, pp. 39-59, 2011.
- [22] B. a. Morrison, "Factors Affecting Strength of Elements Designed Using Strut-and-Tie Models," *ACI Structual Journal*, vol. vol 104, pp. pp 267-277, 2007.

- [23] Chao, D. R. Sahoo and S.-H., Use of Steel Fiber Reinforced Concrete for Enhanced Performance of Deep Beams with Large Openings, USA: ASCE, 2010.
- [24] S.K. Madan, G. Rajesh Kumar and S.P. Singh, "Steel Fiber as Replacement of Web Reinforcement for RCC Deep Beam in Shear," *Asian Journal of Civil Engineering*, Vols. VOL. 8, NO. 5, pp. 479-489, 2007.
- [25] et.al, S.Ahmed, "Design and Evaluation of the Shear Strength of Deep Beams By Strut-and-Tie Model (STM)," *IJST*, vol. Vol.35, pp. 1-13, 2011.
- [26] Egyptian Standard Specifications, concrete-aggregate from natural sources, No.1109-1971 ed.
- [27] Kuchma, Ten Tjhin & Daniel, Acomplete Finite Element Analysis System (CAST), 2004.
- [28] M. Musmar, "Tensile Strength of Steel Fiber," *Contemporary Engineering Sciences*, vol. 6, pp. 225-237, 2013.