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The Effect of Web Opening in the Shear Span on the Ultimate load of RC Deep Beams

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Abstract

Deep beams with rectangular (R) and T- cross sections that have web openings are widely used in concrete structural field for servicing purposes. This situation should be treated with special care depending on the type of the load subjected and the location of the opening. This study is aimed to investigate the ultimate load; carrying capacity of indirectly loaded deep reinforced concrete (RC) beams through an experimental and analytical program. The experimental work has two parts of specimens, where the six deep beams have ratio of shear span- to- effective depth (a/d) is 1.0 have been consider. The first part consists of two deep beams with rectangular and T- cross sections, which formed without web opening, with vertical web reinforcement. The second part consists of four deep rectangular and T-beam cross sections in which, all beams have openings in the shear span, with deferent reinforcement arrangements. The behavior of deep beams was observed, cracking and ultimate loads. The experimental results indicate that the web opening in the shear span of the beams shows a significant reduction in the ultimate load capacity. For predicting the ultimate load carrying capacity for deep beams with opening, Eq. of Kong & Sharp (1977) used. Comparison between experimental finding and numerical results showed a good agreement with experimental results of ultimate load capacity of beams with opening.

Keywords: Deep beams, D-region, Loading conditions, Web opening, Indirected loading.

Introduction

Reinforced concrete beams are commonly classified as deep and shallow beams according to their shear span-to-depth ratios as defined by park [1] or clear span to overall depth as defined by ACI code 14[2] . The deep beam is a structural element loaded as a simple beam in which a significant amount of the load is carried to the supports by a compression force combining the load and the reaction (arch action mechanism). As a result, the distribution of strain is no longer considered linear so it is well known that the classical elastic theory of bending is not appropriate to such problems as deep beams and shear deformations of such beam become important in comparison with pure flexure. In the shallow beam the load is carried by a beam action and distribution of strain is linear across the section. ACI code 14[2] classifies the deep beams as D-regions and shallow beams as B- regions.

Deep Beams with Opening

In the last years, various methods of constructions and many researches have been done on the opening in the web region of the deep beam which is sometimes provided for important civil services and convenience like electricity, air conditioning and computer networks. Fig.1 shows a deep beam with a web opening in a building. Sometimes openings are made by core boring technique and it may be necessary to determine the mechanical properties of the concrete in the existing structures.In such conditions, it is extremely significant to know the behavior of such beams. If openings layout in the stress path connect the loading and supporting points, it is observable that the load path changes and the shear capacity of the element are reduced. The stress pattern is nonlinear and differs considerably from that derived by Bernoulli and Navier [3]. However, studies on indirect loading deep beams with web openings are very limited and no national code even provides any guidance for the design of deep beams with web openings. Therefore, there is a definite need for an understanding of the behavior in particular and strength of deep beams with openings in the web.

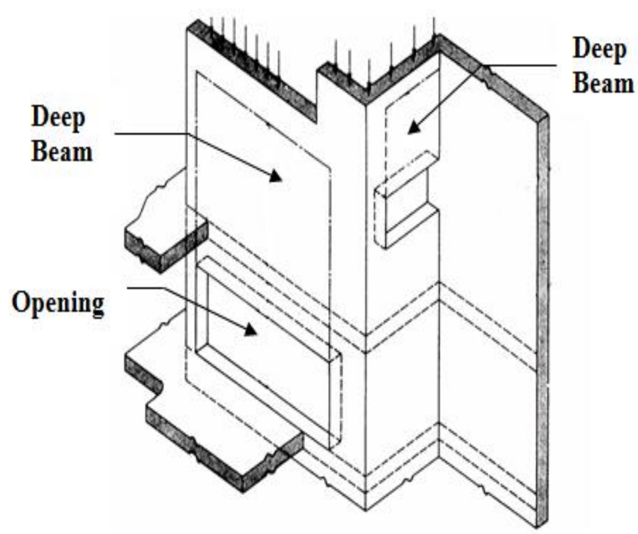
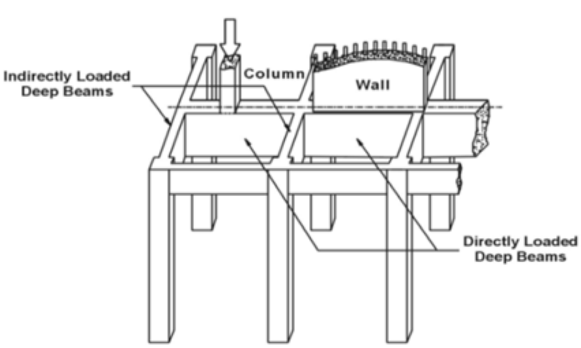


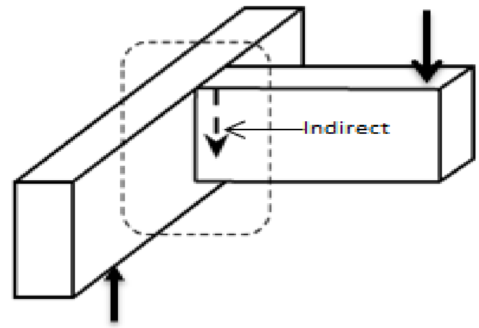
Fig. 1 Deep Beam as a Part of other Buildings

Loading and Supporting Conditions

Simply supported deep beams can be classified according to loading and supporting conditions into directly loaded deep beams (forces are applied to the top or compression face of the beam and reactions are acted underside the face of the beam) and indirectly loaded deep beams (loads are applied via shear to the sides of the members) [4]. The latter type has an indirect load which acts on the sides of the member and applying away from the centroid as shown in Fig. 2 (a, b) [5]. Indirectly loaded rectangular and flanged deep beams have a lower shear strength than the directly loaded deep rectangular beams this has been attributed to the less effect of the tied arch action in indirectly loaded R.C deep beams[6]. To improve the ultimate load of indirectly loaded deep beams, Paul [7] concludes that a sufficient hanger or suspension reinforcement at the position of the load and a good anchoring in the compression zone should be provided.



(a)



(b)

Fig. 2 Directly or Indirectly Loaded Deep Beams.

Significance of the Study

In spite of wide use of deep beams in construction projects, particularly those with web openings, attempts to evaluate the ultimate strength of deep beams are still limited and uncertain on the understanding of the behavior and the failure mechanism of indirectly loaded concrete deep beams, due to the recent development of construction material and construction technique**.** The Study of the effect of indirectly loading conditions on the behavior of deep beams with web openings and in various amounts of web reinforcement is thus necessary. The experiments were conducted according to the standard procedure provided by BS 1881: part 116 [8] and ASTM [9] for the compressive strength of concrete beams and ASTM [10] for splitting tensile Strength.

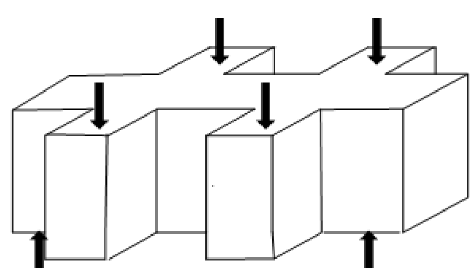
Aim and Objectives

The aim of this study is to practically investigate the structural behavior of rectangular and flanged deep beams that have opening under indirect loading. This will be achieved through the following objectives:

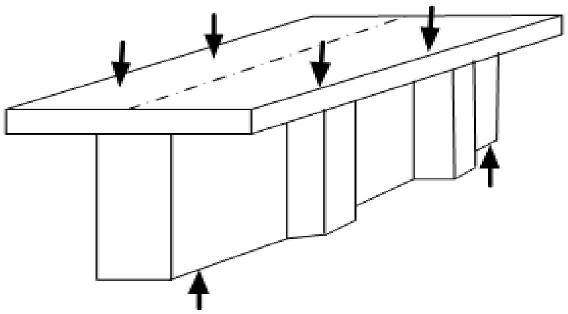
1. Studying the behavior of indirect loading reinforced concrete deep beams failing in shear with web opening in the shear span of the beam, by testing six deep beams with different types of beam's cross section (T-beams & Rectangular beams), different web reinforcement. Then, the obtained results would be analyzed and harmonized in such a way that the main aim of the research is achieved by using the theoretical Equation.
2. Comparing the experimental results and the empirical formula in order to establish a more advanced theory in the field of deep beams behavior which will add to the literature.
3. Examine some engineering properties of the deep beams when subjected to severe conditions of loading.

Experimental Program

The experimental Investigation focuses on preparing the specimens that will failed in shear, as a result of the indirect loading. The experimental work was carried out in the Laboratory in the school of civil engineering and mechanics, Huazhong University of science and technology, Wuhan, china. The beams consisted of two groups of different sections and with the same shear span to effective depth ratio (a/d). The beams had T (tee)-and R (rectangular) cross sections with an indirect loading as illustrated in the Fig.3 (a ,b). The concentrated load is transferred via shear from the central intersecting beams to the main beam which is the supported at the bottom face of the main beam. Bearing plates were provided to prevent the crushing of the concrete at the loading and supporting area.



(a) Indirect loading Rectangular beam (IR)



(b) Indirect loading T- beam (IT)

Fig. 3 Indirectly Loading Deep Beams

Material Properties

1. Concrete

A local ready-mix concrete provider batched the normal strength concrete for all beams with the same designer mix, which was cast using a normal strength concrete mix formula. All mixes were designed to give the compressive strength of 23.5 Mpa at the age of 28 days and slump of about 120mm. The maximum aggregate size was 20 mm. According to BS 1881: parts 116 [8] three concrete cubes specimens, (150*150*150) mm, were cast at the same time with the deep beam specimens and cured for 28 days to get the average compressive strength of the concrete.

A tilting drum mixer was used. Its interior surface was cleaned before use. BS 1881:Part125 [11]. The dry ingredients were added in the following order, about one-half of the coarse aggregate, all the fine aggregate, all the cement and finally the remaining part of the coarse aggregate. Then the water was added and the mixing was started. The period of mixing ranged from two to three minutes so that a homogeneous mix was obtained.

2. Steel reinforcement

All tested deep beams were reinforced with four (16mm) diameter deformed steel bars with yield strength of 330 MPa as tension reinforcement. The bars are anchored beyond the supports with a sufficient length and the ends bent with a 90˚ to prevent anchorage zone failure. The reinforcement bars satisfied the minimum tension steel requirement specified by the ACI 318. The compression reinforcement is two (12mm) diameter deformed steel bars. Shear reinforcement is (10mm) plane round steel bars and hanger stirrups of (12mm) diameter. Bearing plates that are (100mm) wide, (20mm) thick and (150mm) long are positioned at the supporting points. Plates as which are (150mm) long, (75mm) wide and (20mm) thick are positioned at the loading points. To monitor the strain in the steel reinforcement, strain gauges type (Bx 120-50AA) attached on the surface of steel reinforcement. Fig. 4 showed the typical installation of a strain gauge onto the steel reinforcement.

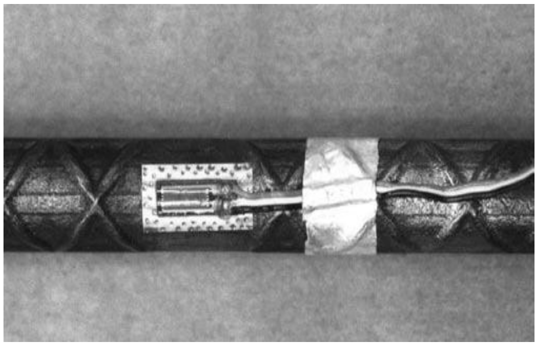


Fig. 4 Steel Strain Gauge Insulation on the Surface of Steel Bar

Geometrical Properties

1. Nomenclature for Tested beams

To understand the deep beams design, a nomenclature system is given below:

As an example, the characteristics of **ITVHO** means:

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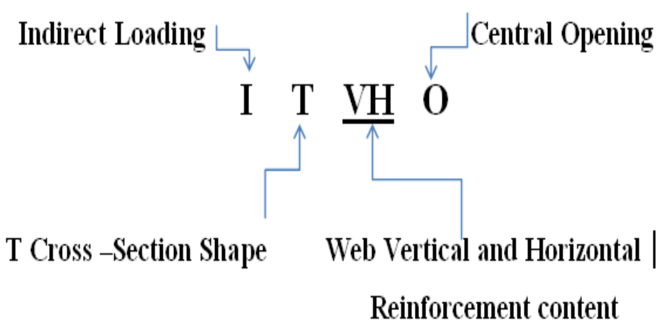


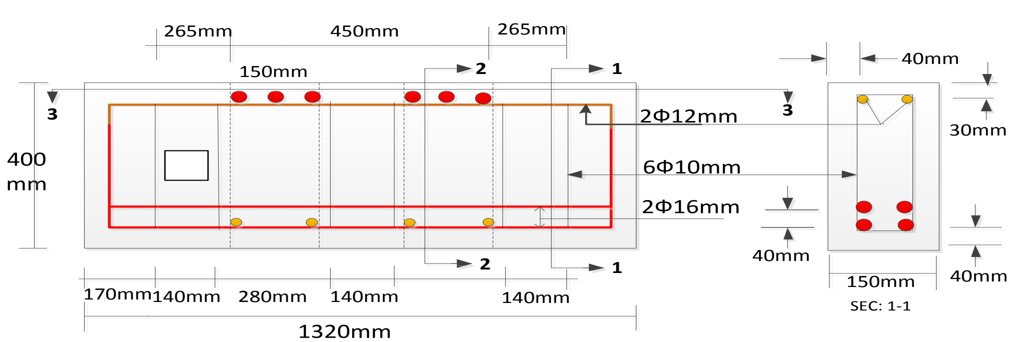
I stands for the loading and supporting conditions which are used for the experimental investigation where **I** and **D** represent the indirectly and directly loading. **T** represents the shape of specimen's cross sections with **T**& **R** as Tee and Rectangle shapes. **VH** represents the web reinforcement in which **V** or **VH** are vertical or vertical and horizontal shear reinforcement. The fourth character refers to the locations of web opening in which **O, O**2 represent the central and shear span opening respectively.

2. Details of Tested Beams

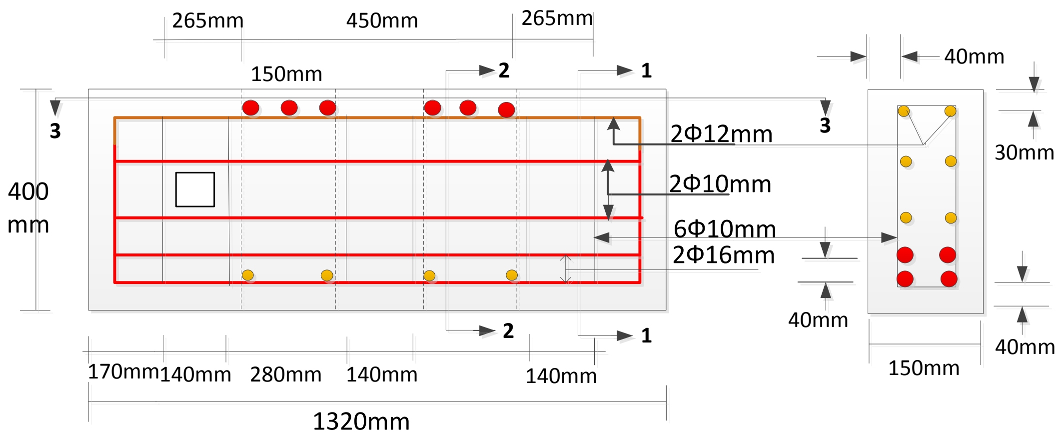
The present program involves casting and testing six deep beams. The tested beams were divided into two groups of T&R cross sections. All beams have Shear Span/effective depth ratios (a/d) =1, a Total length (L) of (1320mm), an overall depth (h) of (400mm) and a web thickness (W_b) of (150mm). The beams have two central intersecting members of the same an overall depth, (150mm) in width and (450mm) in length. The details and dimensions of the beams are shown in Figs. 5 & 6 and Table 1. The first group consists of two beams of rectangular cross sections subjected to the indirect loading. The second group consists of two beams of T-cross sections that have a flange width of (450mm) and flange depth of (75mm). All beams have a web opening of (100*100mm) and are subjected to the indirect loading. All beams have single span with clear span (L_e) of (980 mm) and in various amounts of shear reinforcement. The notations of each tested specimen were described by characters as shown in Table 1. The beams were designed to fail in shear and to satisfy this type of failure suitable tension reinforcement was provided to avoid the flexural failure. The main reinforcement was (16mm) diameter deformed steel bars are extended over the entire length of the beam and anchored adequately at the ends to avoid the anchorage failure. Round bars of (10mm) diameter are used for the web and flange reinforcement. Deformed bars of (12mm) diameter is used for the hanger reinforcement. Deformed bars of (12mm) diameter are used for compression reinforcement. To overcome local failure due to crushing, bearing plates (150*75*20mm) are seated at loading points and (150*100*20mm) bearing plates are seated at reaction points.

Table 1: Detail of the Tested Beams

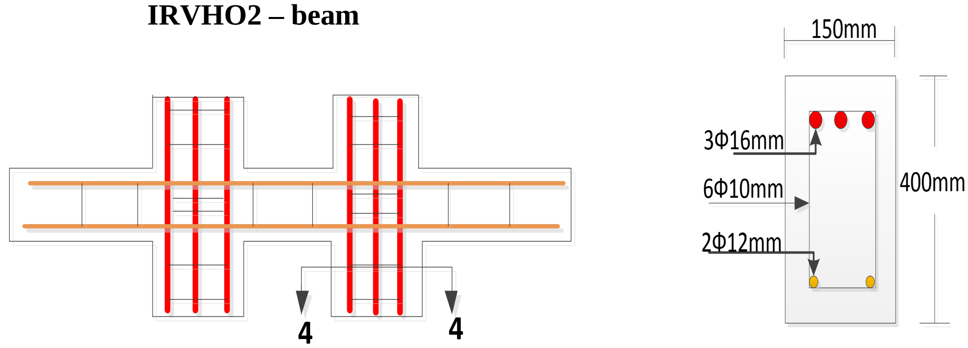
Beam No.	a/d	L_n/h	f_{cu} N/mm^2	f'_c N/mm^2	f_t N/mm^2
Rectangular Beams					
IRV	1.0	2.45	28.5	22.8	2.25
IRVO2	1.0	2.45	29.4	23.5	2.35
IRVHO2	1.0	2.45	29.4	23.5	2.35
Tee Beams					
ITV	1.0	2.45	28.5	22.8	2.25
ITVO2	1.0	2.45	33.6	26.9	2.65
ITVHO2	1.0	2.45	33.6	26.9	2.65



IRVO2 – beam



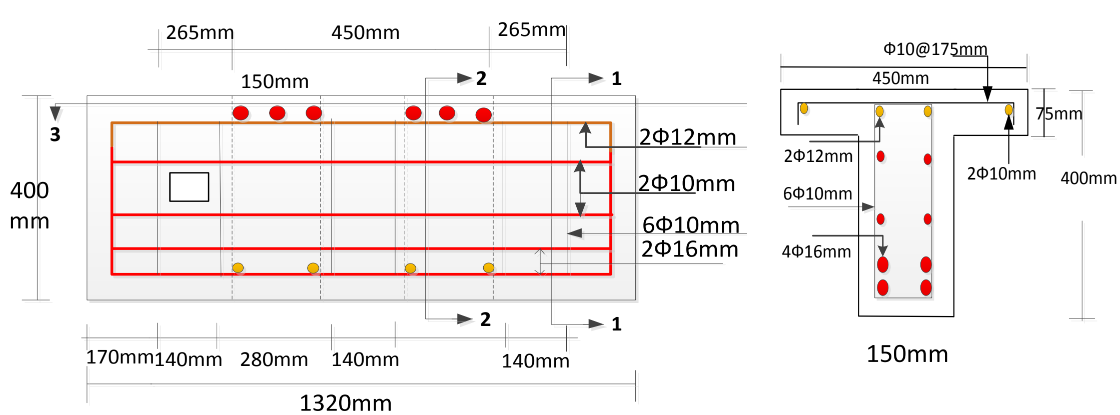
IRVHO2 – beam



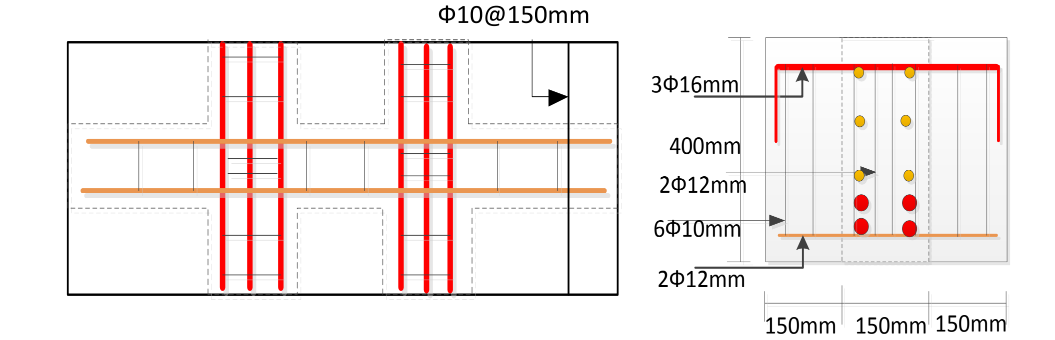
SEC (3-3)

SEC (4-4)

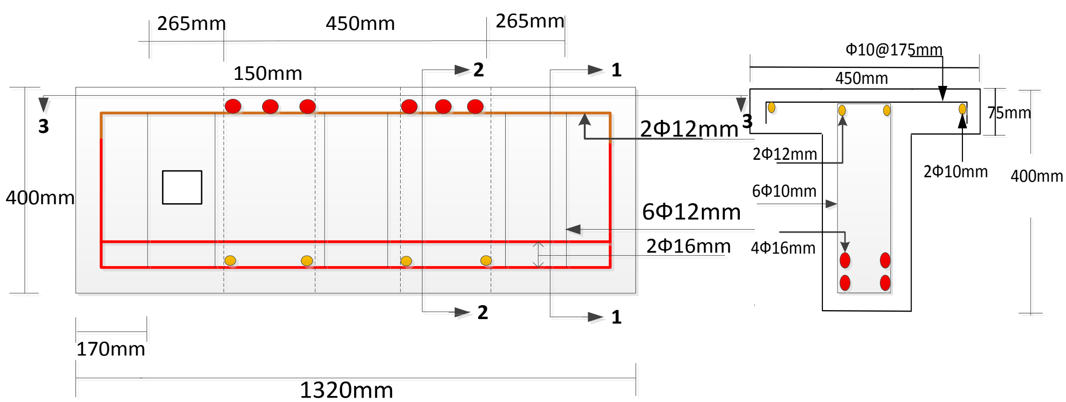
Fig. 5 Details of Indirectly Loading R-Deep Beams



ITVHO2-beam



SEC: (3-3) **SEC: (2-2)**



ITVO2 - beam

Fig. 6 Details of Indirectly loading T-Deep Beams

Instrumentation of Testing Beams

Wood molds were used in the fabrication of the beams. The inside surfaces of the molds were coated in thin oil layers before the reinforcement cage was placed in its position. The concrete mix was placed in three approximately equal layers and each layer was compacted by means of poker vibrator, the top surface of the beam was finishing level. The beams were moist cured by water for seven days under damp canvas and then stored in suitable laboratory conditions.

Fig. 7 shows the casting process.

Fig. 7 The casting process.

The widths of concrete cracks were monitored using a digital measuring instrument as clear in Figs. 8 which showed the test arrangement and setup. A Universal Testing hydraulic jack with a capacity of 1000kN was used to apply the load At each load increment, the total load applied to the beam mid-span deflection, concrete strain, steel strain, and crack width was measured. The cracks were then plotted and marked

Fig. 8 Test Setup

Fig. 9 Digital Crack widths measuring

Figs. 9 to 15 show the tested beams. Table 2 shows the test results

Fig. 10 IRV Beam

Fig. 11 IRVO2 Beam

Fig. 12 IRVHO2 Beam

Table 2: Test results of tested beams

Beam No.	Span Load (kN)		P_{cr}/P_u	$\frac{P_U - P_{cr}}{P_{cr}} \times 100$ Reserve Strength
	Inclined Cracking P_{cr}	Ultimate P_u		
IRV	210	555	0.48	164
IRVO2	160	450	0.355	181
IRVHO2	265	450	0.58	69.8
ITV	200	640	0.31	220
ITVO2	200	480	0.4	140
ITVHO2	200	510	0.39	155

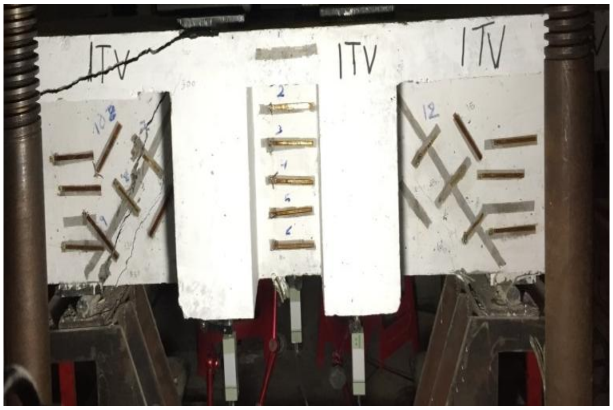


Fig. 13 ITV Beam

Fig. 14 ITVO2 Beam

Fig. 15 ITVHO2

Comparison of Tested Beams Results with Kong &sharp Eq.

Kong & Sharp (1977) [12] tested 32 deep beams, of a wider range covering the ratio of shear span-to-depth, web reinforcement arrangements, and ratios of clear shear span-to-depth. The study proposed that the ultimate shear strength of deep beams with web openings could be calculated using the structural idealizations shown in Fig. 16, which clarifies that the load applied is transported to the support by a lower path and partly by a higher path.

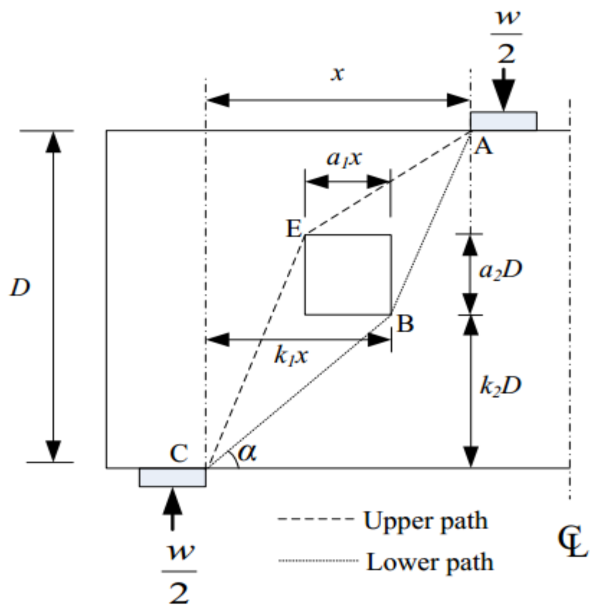


Fig. 16 Load-Transmission Paths

y_1 is the depth in which a typical bar reinforcement crosses the strut (upper path) EA or(lower path) CB, α is the angle between the bar and strut either EA or CB see Fig. 16, and λ is the empirical coefficient which is 1.5 for web reinforcement bar and 1.0 for main tension bars.

The Eq. below was used to predict the shear strength of beams with opening in the shear span.

$$Q_{ult} = c_1[1-0.35\frac{k_1 x_e}{k_2 D}] f_1 b k_2 D + \sum \lambda A c_2 \frac{Y}{D} \sin^2 \alpha$$

Where:

C_1 is the coefficient taken as 1.35 and C_2 is the coefficient taken as 300N/mm^2. Y is the depth of a typical reinforcing steel bar that crosses the strut EA (upper path) or CB (lower path); α is an angle between the typical bar and either strut EA or CB as seen in Fig. 16 and λ is an empirical coefficient taken as 1.5 for the main longitudinal bars and 1.0 for the web reinforcement bar. D is the overall depth of the beam and A is the typical area of the steel bar.

The first term of the Eq. is an expression of the ultimate load of the lower path and the second term characterizes the contribution of the reinforcement to the shear strength capacity of the beam. The Eq. becomes more conservative when the opening is relocated nearer to the supports because a lower path of the load becomes weaker. The ratio of the measured values from the experiment and the calculated values using this Eq. were estimated.

Table 3 and fig. 17 show the comparisons of experimental results and the equation of Kong and Sharp predicting results.

Table 3: Comparison the Experimental results of Deep Beams with opening with Kong & Sharp Equations results.

Beams	Exp. P_u (kN)	Kong &sharp. Pu (kN)	P_u Equ/ P_uExp.
IRVO2	450	418.5	0.93
IRVHO2	450	453.6	1.0
ITVO2	470	418.5	0.89
ITVHO2	510	453.6	0.89

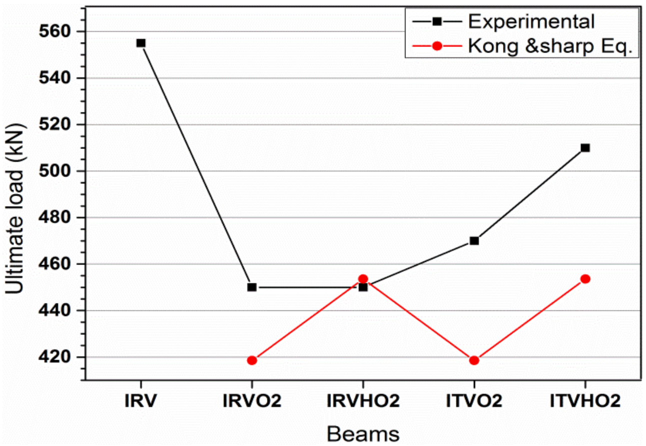


Fig. 17 Eexperimental and Eq. of Kong and sharp predicted results.

Conclusions

The prediction of the ultimate load of beams with openings in the shear span is very important for controling the safety use of deep beam structures especiaily with vertical and horizontal web reinforcement .

1- Web openings lead to decrease in the ultimate and cracking load.
2- The beams become stronger with the use of horizontal and vertical web reinforcement and the ultimate and cracking load improve.
3- Indirect load T- beams with openings show higher ultimate load than indirect load rectangular beams with openings.
4- The equation of Kong and Sharp is very convenient to predict the ultimate load of indirect load deep beams with openings in the shear span.

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تاثير وجود فتحة في فضاء القص على الحمل الاقصى للعتبات الكونكريتية المسلحة العميقة

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الخلاصة:

انتشر استخدام العتبات العميقة ذات المقطع المستطيل والمقطع بشكل حرف (T) والتي تحتوي على فتحه (للاغراض الخدمية) بشكل واسع في المنشات الكونكريتية. مثل هذه الحالة يجب ا لتعامل معها بشكل خاص يعتمد على نوع الاحمال المسلطه على العتبات وعلى مواقع الفتحات.

هذه الدراسة تهدف الى تحري مقدار الحمل الاقصى الذي تتحمله العتبات الكونكريتيه المسلحة العميقه , من خلال اجراء عدد من الفحوصات المختبرية واجراء حسابات تحليليه للمقارنه. يتضمن البرنامج العملي فحص ستة نماذج تكون نسبة فضاء القص الى العمق الفعال لها (a/d) تساوي 1 وتم تقسيم النماذج الى مجموعتين : الاولى, تم فحص نموذجين احدهما ذو مقطع عرضي مستطيل والاخر ذو مقطع عرضي بشكل حرف (T) ويحتوي النموذجان على حديد تسليح لمقاومة قوى القص عمودي فقط. النموذجين بدون فتحات. الثاني, تم فحص اربعة نماذج تحتوي عل فتحات في فضاء القص. اثنان من النماذج ذات مقطع مستطيل واثنان ذات مقطع بشكل حرف (T). وتحتوي على حديد تسليح لمقاومة قوى القص عمودي وافقي.

اثناء عملية الفحص تم تسجيل حمل التشقق, والحمل الاقصى. نتائج الفحص اظهرت نقصان كبير في الحمل الاقصى الذي يتحمله العتب للنماذج التي تحتوي على فتحات.

تم استخدام معادلة الباحثين كونك و شارب لحساب الحمل الاقصى الذي تتحمله النماذج ذات الفتحات, وبمقارنة نتائج الحسابات النظريه مع نتائج الفحص العملي وجد انها مقبولة جدا .

الكلمات المفتاحية: العتبات العميقة, منطقة- D, شروط التحميل, فتحة الجذع, التحميل غير المباشر.