Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (40) No. (4) October, 2018

Analytical Study For Behavior Of Reinforced Light Weight Concrete Deep Beams With Web Openings

Ghada Nagah Abd Elhameed[1], Wael Montaser[2], Mohamed said[3], Amr H. Zaher[4]

[1] Ass.Lecturer, Structural Eng. Dept., Faculty of Eng., October 6 University, Giza, Egypt.
[2] Assistant Professor, Structural Eng. Dept., Faculty of Eng., October 6 University, Giza, Egypt.
[3]Associate professor, Civil Eng., Faculty of Eng., Shoubra, Benha University, Egypt.
[4]Professor, Structural Eng. Dept., Faculty of Eng., Ain Shams University, Cairo, Egypt.

ملخص البحث

تستعرض الرسالة الكمرات العميقه المصنوعه من الخرسانه خفيفه الوزن والتي يوجد بها فتحات جانبيه تحت تأثير حمل مركزي رأسي واحد وذلك باستخدام العناصر المحددة ببرنامج (ANSYS). أهم المتغيرات التى تم دراستها فى اختبار الكمرات البسيطة هى مقاس القتحات ومكان الفتحات ونوع الخرسانة و نسبة طول القص لطول الكمرة (a/d) كما تناولت الدراسة شكل الشروخ وتأثير الحملوأظهرت النتائج أن وجود فتحات جانبيه في الكمرات العميقة من الخرسانة خفيفة الوزن (ارتفاعها يساوي من 20٪ الي 40٪ من إجمالي ارتفاع الكمره، على التوالي) في مسار الحمل يؤدي إلى انخفاض في قوة القص النهائي للكمرات العميقة من الخرسانة خفيفة الوزن بنسبة حوالي من 10٪ الي 55٪ بالمقارنة مع الكمره العميقه التي ليس بها فتحات جانبية .

ABSTRACT

In order to study the shear behavior of reinforced light weight Concrete (LWC) and Normal-weight Concrete (NWC) simply supported deep beams with and without web openings an analytical program has been conducted. The results have been used to examine the applicability of the shear design requirements of three international codes (ACI 318-02, ECCS-2001, and EC-2).The behavior of the deep beam is examined by the use of finite element software ANSYS. The test program included seven reinforced concrete simply supported deep beams. The main parameters examined were the size and position of opening, the design concrete compressive strength, the magnitude of transverse reinforcement ratio and span-to-depth ratio. The results indicated that the presence of web openings (of height equal to 20% and 40 % of the total web height, respectively) in the load path leads to a reduction in the ultimate shear strength of LWC simple deep beams by about 10 and 55% when compared with a similar beam without opening.

Keywords

Light-weight concrete, Deep Beams, Shear

1. Introduction

Reinforced concrete deep beams are considered useful in tall buildings, offshore structures, long-span structures and complex foundation systems. The moment capacities of deep beams are normally adequate and are not of major concern, but the shear capacity of deep beams is very important to understand since properly designed deep beams would usually fail in shear at the ultimate limit state.Most of the current concrete researchers focus on high-performance concrete, by which is meant a cost-effective material that satisfies demanding performance requirements, including durability. Light-weight concrete (LWC) is very important to the construction industry due to its lower cost and weight. The primary advantage of using LWC is to reduce the dead load of the concrete structure, and consequently, it leads to reducing the size of columns, footings and other load bearing elements. Light-weight foamed concrete is a new kind of Lightweight concrete, which combines the advantages of normal density concrete, cellular concrete, and self-compacting concrete through partially replacing the normal weight aggregates with polystyrene foam, hence, leading to concrete unit weight reduction while maintaining adequate strength. Therefore, the latter material can be produced using standard methods familiar to the construction industry with a dry unit weight of 18.5 kN/m3, which in turn leads to deadload reduction by 15 – 20 % and the associated decrease in the structure's overall cost, hence, providing a feasible challenge to normal density concrete (NDC) with a dry unit weight of 25 kN/m3.

Moussa, A., et al [3] tested eleven deep beams. Which was constructed and tested experimentally to establish the effect of the presence of the openings on the behavior of deep beam as well as the nature and magnitude of stress distribution. Test results showed that increasing the size of the opening leads to increase in the top deflections. Moving the opening up wards lead to an increase in the top deflection and decrease in the bottom one due to the deviation of arch action. For solid beams and beams that have openings not intercepting the load path. The shear capacity predicted by both Egyptian and ACI codes are quite close. Haque, M., et al [4] conducted a photo elastic investigation of the stress distribution in deep beams with and without web openings. The general form of stress diffusion has been established and the critical zones have been identified. The critical tensile and shear stresses have been evaluated and their sensitivity to various span-to-depth ratios and opening positions along the span has been established. Based on stress flow pattern and contour lines of principal tensile stresses, failure mechanisms have been predicted and recommendations have beenmade for the design of reinforced concrete deep beams.

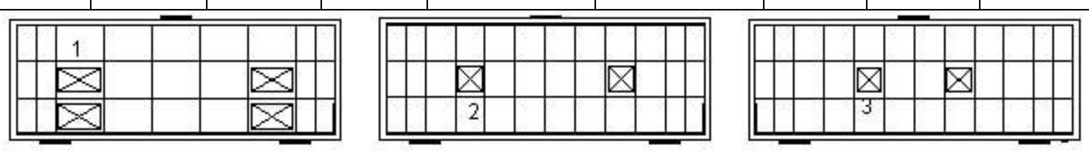
Danile F. Jensen [5] studied Reliability Analysis for Shear in Lightweight Reinforced Concrete Bridges Using Shear Beam Database (2014). The objective of this study is to analyze and calibrate the reliability indices for shear in reinforced concrete bridge girders. Existing statistical models are based on limited experimental data from only a few research tests. These existing models show that our current procedures for analysis are about 10-15% less conservative for lightweight concrete compared to an analysis for normal weight concrete. Accurate load models are used to find shear and moment envelopes of loads applied to bridges. The analysis is based on different span lengths, span number, and girder dimensions. Design calculations are performed using design values and loads calculated from load models. Different strength of concrete is also used to compare the reliabilities of various parameters. Results show that when using a professional factor of 1.0 and variability of 0.0 and a resistance factor of 0.8 can be applied to the AASHTO design equation for shear in reinforced concrete. C. H. Huang, L. H. Chen, Y. C. Kan, C. H. Wu and T. Yen [6] studied the shear behavior of full size reinforced lightweight concrete beam (2011). This study presents the results of experimental investigations on three lightweight aggregate concrete (LWAC) beams and three normal weight concrete (NWC) beams were designed and cast for shear investigation by conducting center load bending test. Test results showed that the shear failure modes of LWAC beams are similar to NWC beam, including shear-compression failure and shear-tension failure.

2. FINITE ELEMENT MODELING

The Analytical study included seven reinforced concrete simply supported deep beams with and without web openings and constructed from Normal and light weight Concrete. The beams were tested under the effect of one concentrated load. All tested specimens had same geometry and main longitudinal top and bottom reinforcement. The beams were divided into three groups as shown in Table 1. All the tested deep beams had the same rectangular cross-section of 80 mm wide and 400 mm total height as shown in Fig.1 through Fig.2.

Table 1 Designation of analytical testing groups

Beam	Shear span to depth ratio (a/d)	Section b*t (mm)	Span (mm)	Upper Longitudinal Bars	Lower Longitudinal Bars	Stirrups		Opening Notation
						s (mm)	dv (mm)	
DLOH1	0.97	80*400	800	2Ø10	4Ø16	100	6	---
DLOH2	0.97	80*400	800	2Ø10	4Ø16	100	6	1A13
DLOH3	0.97	80*400	800	2Ø10	4Ø16	100	6	1A12
DLOH4	0.97	80*400	800	2Ø10	4Ø16	100	6	2A12
DLOH5	0.97	80*400	800	2Ø10	4Ø16	160	6	1B22
DLOH6	0.97	80*400	800	2Ø10	4Ø16	160	6	2B22
DLOH7	0.97	80*400	800	2Ø10	4Ø16	160	6	2B21



Location OfOpenings

the first part refers to the number of openings in the shear span (1 or 2); the second part indicated the size of opening (A= width* height=80*80 mm and B=140*80 mm); the third part referred to the web reinforcement arrangement (1 for Sv =100 mm and 2 for Sv=160 mm) and the fourth part referred to the location of the openings (location 1, 2 and 3).

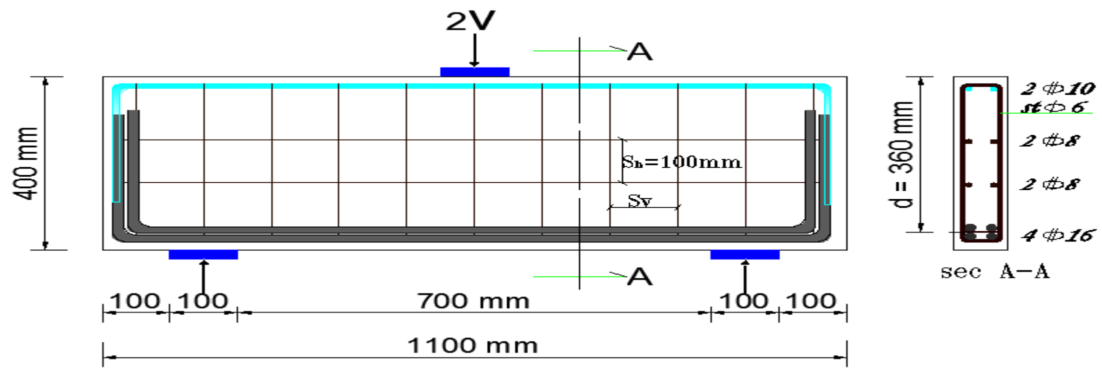


Fig.1 reinforcement Details

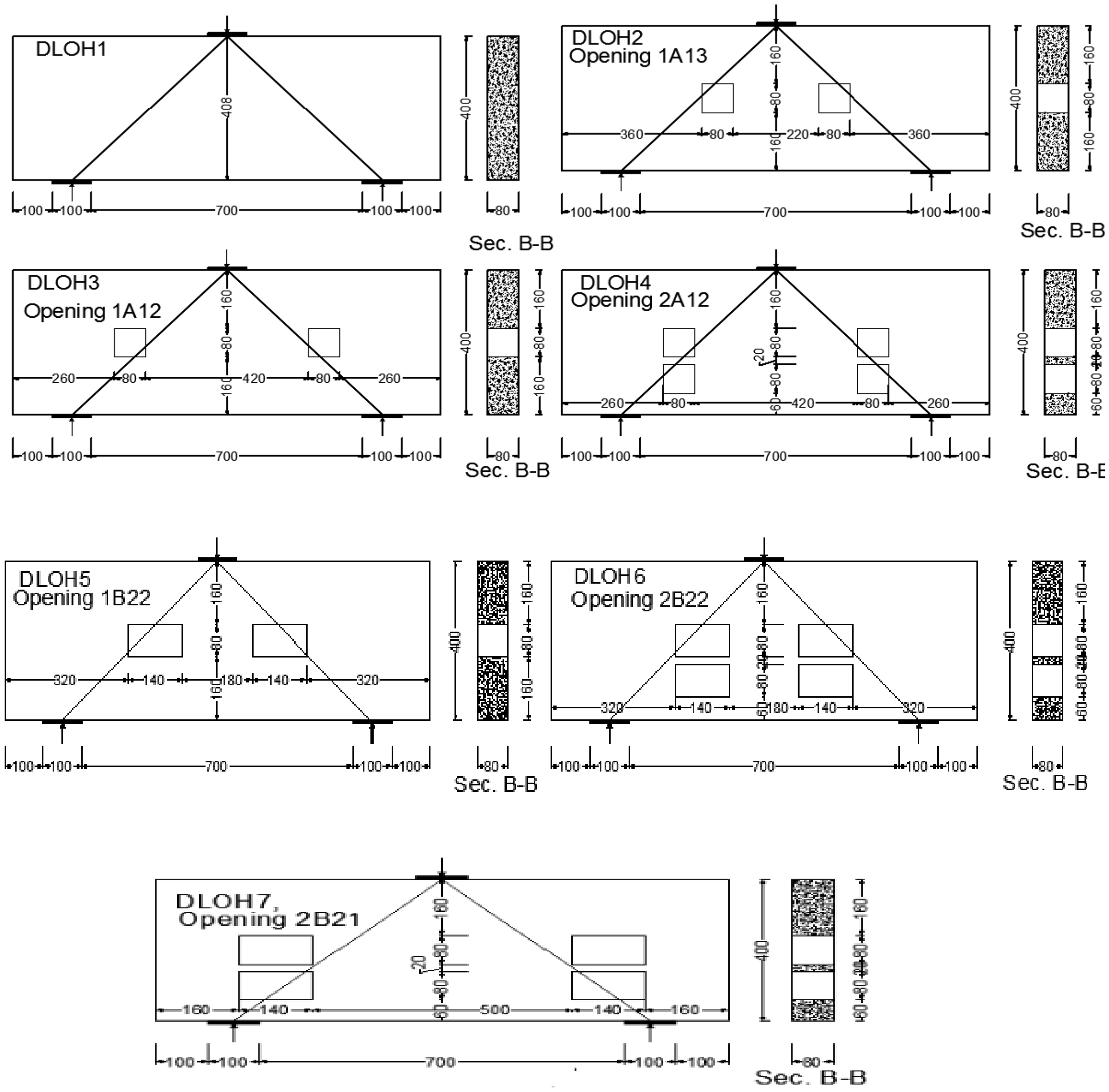


Fig.2 Show size and location of openings

2.1 Material properties and constitutive models

Concrete and steel are the two main materials used in the numerical analysis of the deep beam in which their properties and constitutive models are presented below:

2.1.1 Concrete

The concrete solid element (SOLID65 in ANSYS computer program is used to model the three-dimensional behavior of concrete). The solid element is capable of cracking in tension and crushing in compression. The element is defined by eight nodes having three translational degrees of freedom (x, y, and z) at each node. The equivalent stress-strain curves for concrete used in FEM in this study to model concrete, is illustrated in figure (4). The main parameters for the curve are the concrete compressive strengthfcu, and the modulus of elasticity of concrete, Ec. For undetermined data, The concrete compressive strength of LWC (fcu) is 30Mpa, The concrete compressive strength of NWC (fcu) is 25 Mpa[7] and the modulus of elasticity (Ec) of LWC is 15000MPa and the modulus of elasticity of NWC is 22000 MPa ,Poisson's ratio of 0.2was used for all beams. The concrete material properties are numbered as a material number (1)

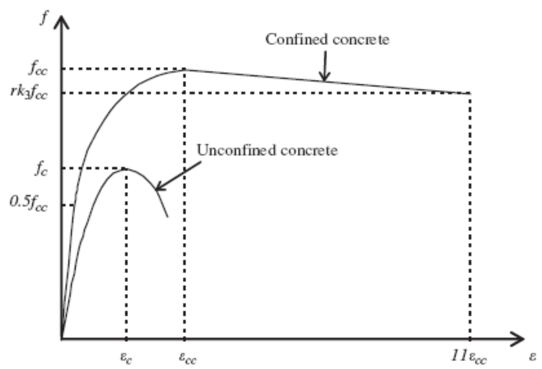


Fig.3: Equivalent stress-strain curves for concrete

2.1.2 Steel

In the present research, modeling of steel was performed as an elastic-perfectly plastic material in both tension and compression. The material behavior provided by ANSYS using plastic option allows non- linear stress-strain curve to be defined. Strain-hardening stress-strain curve is used to describe the behavior of the steel for modeling the steel tube and the end plate as shown in figure (4). The main parameters for the curve are steel yield strength, Fy, steel ultimate strength, Fu, modulus of elasticity of steel, Es, which is taken equal to 210000 MPa, and Poisson's ratio, γ_s, which is taken equal to 0.3.

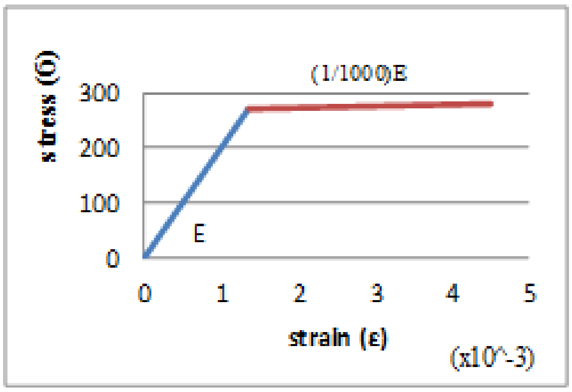


Fig.4: Stress-strain curve of steel used in the present research

2. Analytical Results

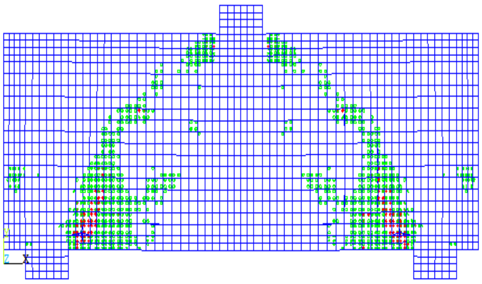
The seven tested models behaved in a different manner and the following remarks were noticed:

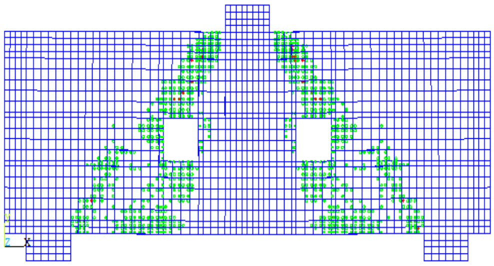
Crack Pattern and Failure Mode of Tested Beams

At the end of testing each deep beam, the marked crack pattern was used to provide necessary information required for defining the failure mechanism of each specimen.Fig.5 shows the failure mode of all the tested specimens.For all specimens the flexural cracks initiated on the tension side at the middle of the beam span, the cracks propagated upward with the increase of load. For solid beam the first diagonal crack suddenly developed at mid depth within the shear span. Diagonal cracks were observed parallel to the compression strut and propagated towards the loading region and supports.For the beams with small opening size the increase in the applied load, shear diagonal cracks began to appear and extend from the support plates to the edges of the openings.For the tested deep beams with large openings, diagonal cracks were the first and initiated at opening corners and propagated with the load increase towards loading zone and supports.With increasing the load; more diagonal cracks appeared parallel to the strut, passing through the opening corners and propagated in both directions towards the loading region and the supporting plates.Table 2 shows cracking and failure loads for all tested beams.

Table 2cracking and failure loads for all tested beams.

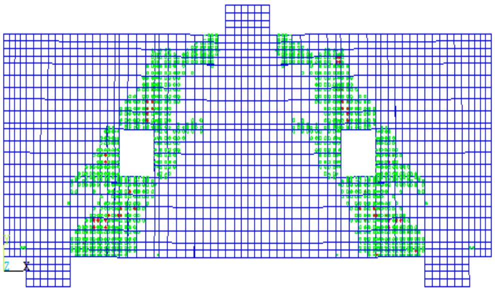
Specimen	DLOH1	DLOH2	DLOH3	DLOH4	DLOH5	DLOH6	DLOH7
Failure load (KN)	185	170	155	117	120	73.5	75
Cracking load (KN)	90	75	70	55	50	35	40

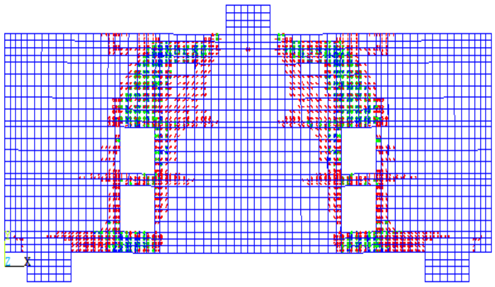




Beam DLOH2

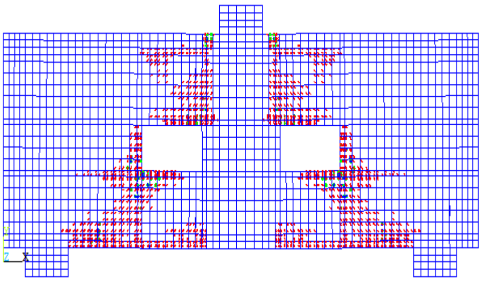
Beam DLOH1.

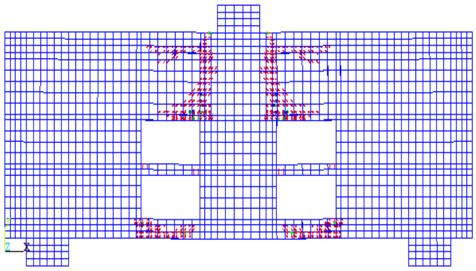




Beam DLOH4

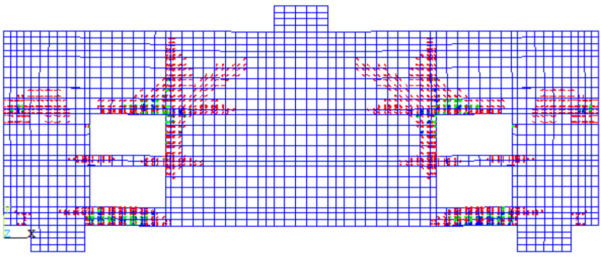
Beam DLOH3





Beam DLOH6

Beam DLOH5



Beam DLOH7

Fig. 5:Failure modes of tested beams

The following points can be made: -

1-The effect of opening size on the failure load for beams (DLOH3, DLOH5), (DLOH4, DLOH6), (DLOH3, DLOH4) and (DLOH5, DLOH6) on the failure loads compared with that of the solid beam DLOH1. It may be noted that, the failure load of DLOH3 and DLOH5 were 0.83and 0.64of that of beam DLOH1, respectively. The failure load of DLOH4 and DLOH6 with respect to the solid deep beam DLOH1were 0.63 and 0.39, respectively. The failure load of DLOH3 and DLOH4 with respect to the solid deep beam DLOH1were 0.83 and 0.63, respectively. The failure load of DLOH5 and DLOH6 with respect to the solid deep beam DLOH1were 0.64 and 0.39, respectively.

2-The effect of opening location on the failure load for beams (DLOH2, DLOH3)and (DLOH6, DLOH7) on the failure loads compared with that of the solid beam DLOH1. It may be noted that, the failure load of DLOH2 and DLOH3 were 0.91 and 0.83 of that of beam DLOH1, respectively. The failure load of DLOH7 and DLOH6 with respect to the solid deep beam DLOH1were 0.41 and 0.39, respectively.

Deflections

During testing of each beam, the deflection at mid-span was measured at the end of each load increment. The measured load-deflection curves are shown in Fig.6. From the figure, the following points are made:

1-The mid-span deflection curves of LWC deep beams with and without web openings are reported here. In early stages of loading, the beams behaved in a truly elastic manner. At higher levels of loading, beams with large web openings exhibited the highest deflection among all beams of the same level of loading. Beams with small web openings showed load deflection behavior very similar to that of the solid beam.

2- The effect of the opening located on the mid span deflection. The load deflection curves of beams DLOH2 and BLW3 it can be noted that moving the opening towards the beam center reduces the deflection. On the other hand, the load deflection curves for the beams DLOH6 and DLOH7, beams, indicates that moving the opening towards the mid shear span increases this deflection.

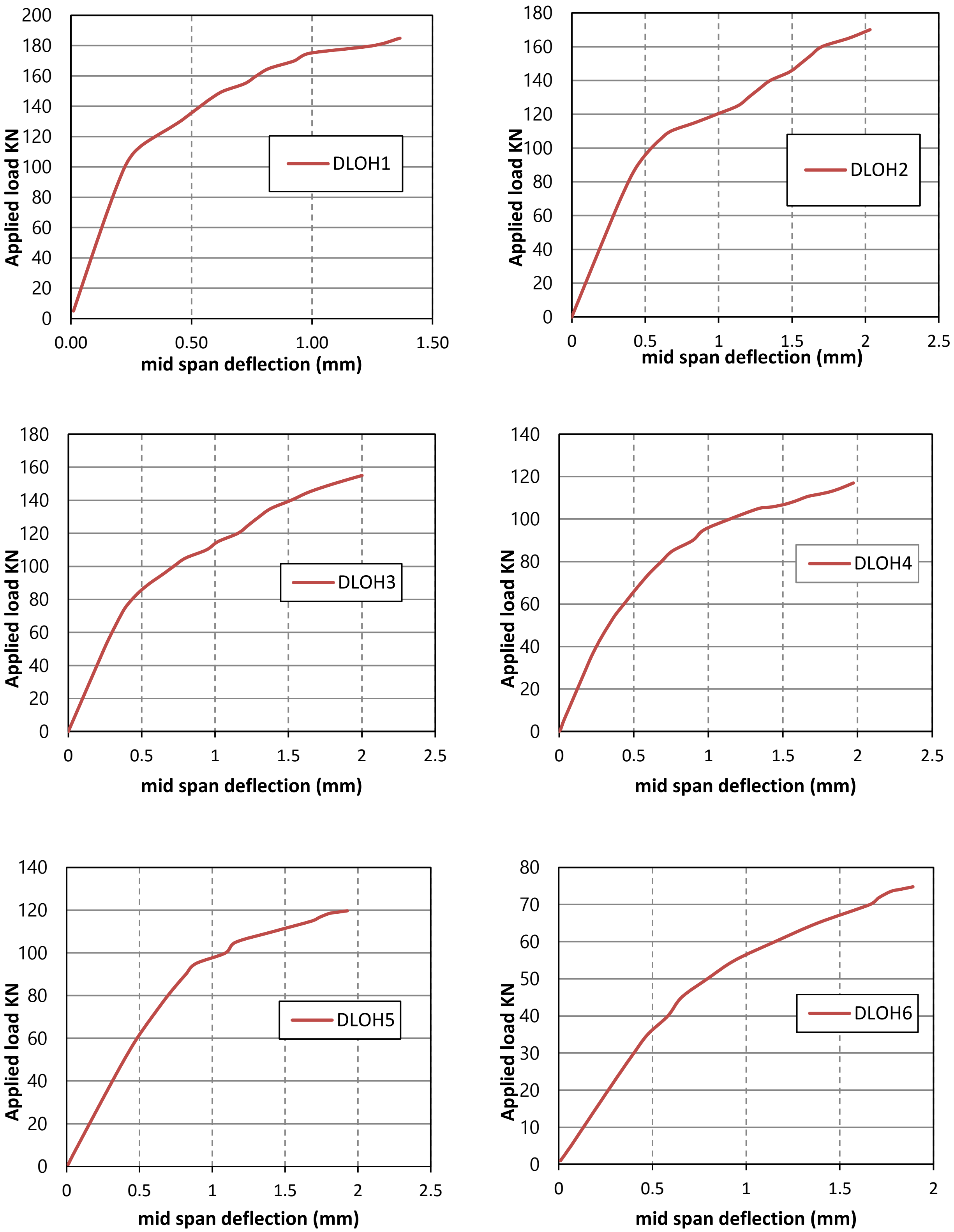


Fig. 6: Load-deflection curve from Finite element results

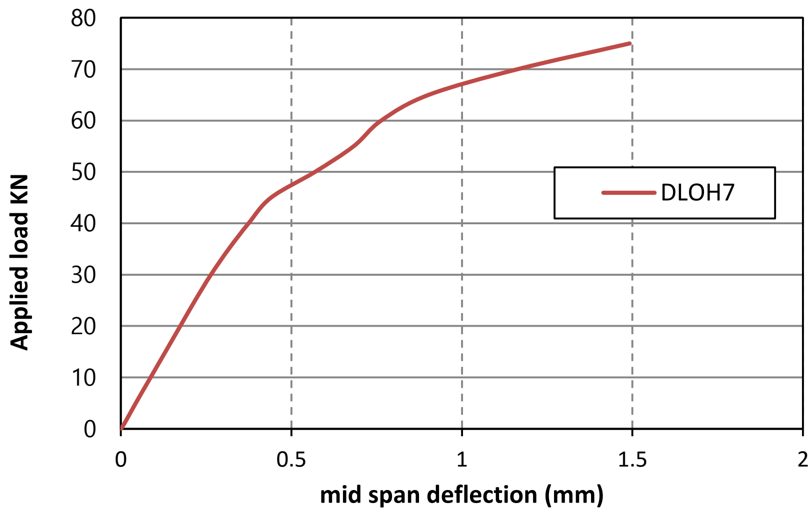


Fig. 6: Load-deflection curve from Finite element results

3. CONCLUSIONS

1- The presence of web openings (of height equals to 20% and 40 %, respectively, of the total web height) on the load path leads to a reduction in the ultimate shear strength of LWC deep beams by about 28% and 46.5%, respectively, when compared with the similar beam without openings.

2- When an opening exists near the support region of LWC deep beam, it leads to early cracking and a reduction in the strength and stiffness of the beam.

3- Openings in the shear span of deep beams reduced the shear strength compared to that of the solid deep beam.

4. REFERENCES

1.ACI Committee. (1963). Building code requirements for reinforced concrete (ACI 318-63). American Concrete Institute. Ministry of Housing, Utilities and Urban Communities,

2.“Egyptian Code for Design and Construction of Reinforced Concrete Structures (ECCS 203-2007),” Cairo, 2007.

3. Moussa, A., Mahmoud, A., Abdel- Fattah , W., and Abu- Elmagd, S., “Behavior of R.C. Deep Beams with and without Openings, ” Proceedings of the 5th Alexandria International Conference on Structural and Geotechnical Engineering, Structural Engineering Department, Faculty of Engineering, Alexandria University, 20-22 December2003, pp. CR185-CR202.

4. Haque, M., Rasheeduzzafar, and Al- Tayyib, A.H., “Stress Distribution in Deep Beams with Web Openings,” Journal of Structural Engineering, V.112, No. 5, July 1986, pp. 1147-1165.

5. Danile F. Jensen Reliability Analysis for Shear in Lightweight Reinforced Concrete Bridges Using Shear Beam Database, Utah State University,2014

6. pp. 1147-1165. C. H. Huang, L. H. Chen, Y. C. Kan, C. H. Wu and T. Yen Shear behavior of full size reinforced lightweight concrete beam. Dahan Institute of Technology, Hualien, Taiwan. 2011.