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Structural Behavior of Reinforced Concrete Deep Beams with Inclined Circular Holes

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ABSTRACT

The loads in the deep beams are transmitted diagonally from the load area to the support area by means of the strut and the tie. It is characterized by having a small span to depth ratio. which causes the distribution of stresses to be non-linear within the beam, which motivates researchers to study the effect of the placing of longitudinal hollows and the extent to which these holes affect the behavior and distribution of stresses for these types of beams. In addition to the advantages added by longitudinal hollow to the beam such as reducing weight and passing various electrical and mechanical services...etc. This study investigated the effect of making longitudinal circular holes (with a diameter of 50mm) with a slope on the structural behavior of three deep beams with a solid sample as a reference where the slope used was 0%, 4.3%, and 7.8%. The results showed that making holes reduces the load capacity of the deep beam, a decrease in the failure load was observed by 7.56%, 8.96%, and 11.2% for hollow beams with a slope of 0%, 4.3%, and 7.8%, respectively. Also, the appearance of flexural cracking increased by 2.66%, 2.66%, and 6.66%.and 2.14%, 3.52%, and 7.14%, respectively, for shear cracks. While the effect was small for the neutral axis location as well as for the vertical deflection.

1. Introduction

Reinforced concrete deep beams are structural members that are It is characterized by a great depth compared to their extension and less width than the other two dimensions. It also has a high moment of inertia because its depth is large, which increases its rigidity [1-3]. In such types of beams, the stress distribution is non-linear and shear failure is the dominant feature [4-5]. These structural members are among the most common in the wake of the great development in modern construction and have many uses such as bent caps in bridges, pile caps in foundations, bunkers, and other applications [3], [5-12]. And the use of longitudinal holes in beams has become one of the trends and requirements at the present time because of its importance in reducing the weight of these beams and thus reducing the amount of CO_2 emission due to the decrease in the amount of concrete used. These hollows are placed in a tension zone and zone with less stress so that they do not significantly affect the structural behavior of these beams. The presence of these openings in the beams has many advantages such as passing many electrical services, communications, water, and sewage pipes…etc. [13-16]. Recently, there have been efforts to study the behavior of concrete beams with longitudinal openings as follows Murtada and Yahyia [17] investigated the structural behavior of shallow self-compacting beams when the diameter of the holes was changed, and it was found that the ultimate load decreases with the increase in the diameter of the holes. Muhanad

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and Saad [18] Hadi et al. [19] They found that circular holes are better than rectangular when used in deep beams to make longitudinal holes. Haider and Mortada [20] find that parabola shapes are better than round when used in the longitudinal holes of the T-beams. It also showed the effect of changing the depth of the holes on the behavior of these beams.Balaji and Vetturayasudharsanan [21] The effect of the presence of plastic and steel pipes on the behavior of the rectangular beams was examined and it was found that the steel pipes increase the efficiency of the hollow beam compared to the solid sample. There are also many other studies, most of which focus on shallow beams and study the shape, depth, and diameter of the cavities. And the extent of their influence on the shear behavior and flexural behavior of these bundles [22–36]. Therefore, there is a lack of studies for hollow deep beams in general, and there is no study in all the literature that investigated the effect of having longitudinal gaps with a slope in all types of RC beams in particular. It is possible to take advantage of the slope hollows in the sewage works, as well as transfer the level of different services from one level to another.].

2. Methodology

2.1. Specimens description

The experimental work of this study includes four reinforced concrete deep beams all with the same reinforcement and dimensions (length 1400 mm, width 150 mm, and the total depth of 320 mm) and a clear span of 1060 mm, a shear span of 375 mm as shown in Figure (1). The reference sample is solid without hollows by which the neutral axis and the places of least stress were determined by placing a number of strain gauges. The other three beams contain a longitudinal circular hole with different slopes for each sample, the first sample contains a single circular hole with zero slopes. The second and third samples contain circular holes with a slope of 4.3% and 7.8%, respectively. as shown in figure (2). Table (1) shows the details of the beams.

Table 1: Beams details

Beam designation	Reduction in vol. of beams %	Description
DB1	/	Reference beam
DB2	4.1	hollow deep beam with 0% slope.
DB3	4.1	hollow deep beam with 4.3% slope.
DB4	4.1	hollow deep beam with 7.8% slope.

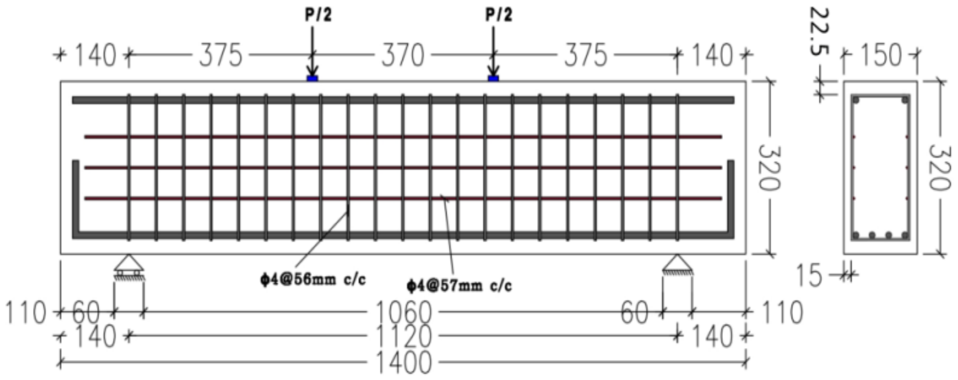


Figure 1. Beam dimensions and reinforcement

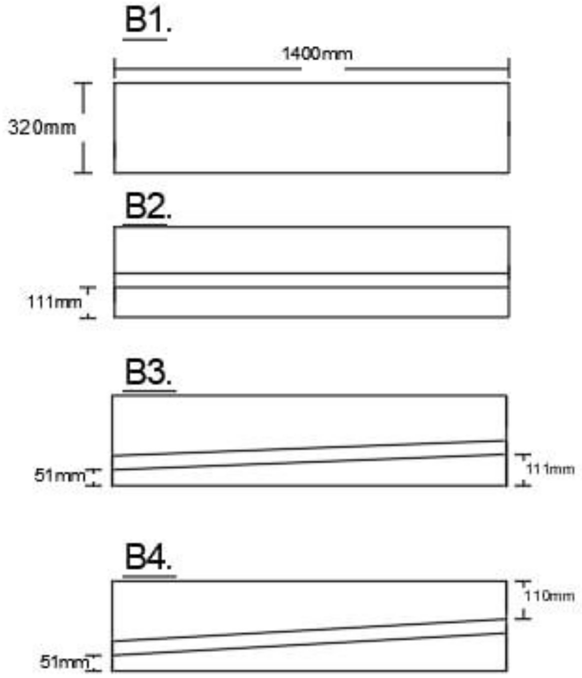


Figure 2. Detail of the inclined hole in the beams (Distances from the edge of the pipes)

2.2. Materials

Normal concrete was used in this study and the properties of this concrete and the reinforcement used were clarified.

2.2.1 Cement

For the formation of normal concrete, Portland cement of the brand Tasluja of the first type was used, whose physical and chemical properties are in accordance with Iraqi Standard No. 5, 1984.[37].

2.2.2. Fine aggregates

The use of fine aggregates whose physical properties comply with the Iraqi specification No. 45 of 1984 [38], which was taken from Al-Sidr Suburb in Diyala Governorate, Iraq.

2.2.3. Coarse aggregates

In this study, coarse aggregates brought from the Al-Sidr suburb with a maximum of 10 mm were used, as their classification, in addition to their physical properties, is located within the boundaries of the second region in the Iraqi specification No. 45, 1984 [38].

2.2.4. Water

The traditional tap water was used throughout the present study for concrete mixing and curing purposes.

2.2.5. Steel reinforcement

A 12 mm diameter deformed bar was used in the tensile and compression zone, to strengthen the main bending with yielding stress (fy) of 550 MPa.and deformed bars with a diameter of 4 mm were used for the purpose of enhancing the vertical and horizontal shear with yielding stress (fy) of 340 MPa.These bars were tested at the laboratory of construction materials/college of Engineering / University of Diyala according to ASTM A615/A 615M, 2009[32] [39].

2.2.6. The recycled plastic pipes

To create longitudinal holes, 1.5 mm thick and 50 mm diameter recycled pipes were used, which are inert and do not react with concrete mix materials and/or reinforcing bars.

2.3. Concrete mixture

After conducting several trail mixes for normal concrete, the required compressive strength (27 MPa in 28 days) was obtained. Table No. (2) Shows the normal concrete mix components and their quantities per cubic meter.

Table 2:

Materials	Cement kg/m^3	Sand kg/m^3	Gravel kg/m^3	Water kg/m^3
Quantities	400	750	780	240

2.4. Mechanical Properties of Hardened Concrete

Table 3: Lists mechanical properties of the hardened concrete

Property	f'c	Modulus of rupture (*fr*)	Splitting strength (*fct*)	Modulus of elasticity
Average value	27.5 MPa	3.65 MPa	3.445MPa	24425 MPa

2.5. Testing of the beam specimens

The four samples were tested by applying a four-point load as shown in Figure (3) using a global hydraulic testing machine with a capacity of 600 kN in the Civil Engineering Laboratory at Diyala University. The linear variable deflection transducer (LVDT) sensor was installed in the middle of the beams to measure the vertical deflection. Also, to find out the neutral axis and the potential for least stress, stress gauges (PFL-10-11) were used.

Figure 3. Test setup of the beams

4. Results and discussion

4.1. Testing of the beam specimens

All four samples failed shear failure as shown in Figure (5) and from the results of the examination presented in Table (4) that making a slope in the longitudinal hollow has a small effect on the rate of acceleration of the emergence of bending and shear cracks. It accelerated the occurrence of cracking flexural by 2.66%, 2.66% and 6.66% at slope 0%, 4.3% and 7.8%, respectively. and 2.14%, 3.52% and 7.14%, respectively, for shear cracks. It was noticed that the final load of the deep beams decreased with an increase in inclination at varying rates of 7.56%, 8.96% and 11.20%, respectively. This can be explained that at a slope of 4.3%, the slope of the hollow was from the zone below the neutral axis to the tensile zone close to the bottom reinforcement, which is the greatest tensile stress. The inclination of 7.8%, represents the transfer of a service level from an area located above the neutral axis within the zone of least stress to the tensile region close to the tensile reinforcement, so despite the presence of the slope in the zone of least compression stress, it caused a slight decrease in the failure load.

Table 4: First crack load, and ultimate strength result values of the tested beams

Beam designation	**Reduction in vol. of beams %**	**Cracking Flexural load Pcr (kN)**	**Decrease in Cracking Flexural load%**	**Cracking shear load Pcr(kN)**	**Decrease in Cracking shear load%**	**Ultimate load Pu (kN)**	**Decrease in Pu %**
Reference (B1)	/	75	/	140	/	357	/
HDB0%S (B2)	4.1	73	2.66	137	2.14	330	7.56
HDB4.3%S(B3)	4.1	73	2.66	135	3.57	325	8.96
HDB7.85S (B4)	4.1	70	6.66	130	7.14	317	11.2

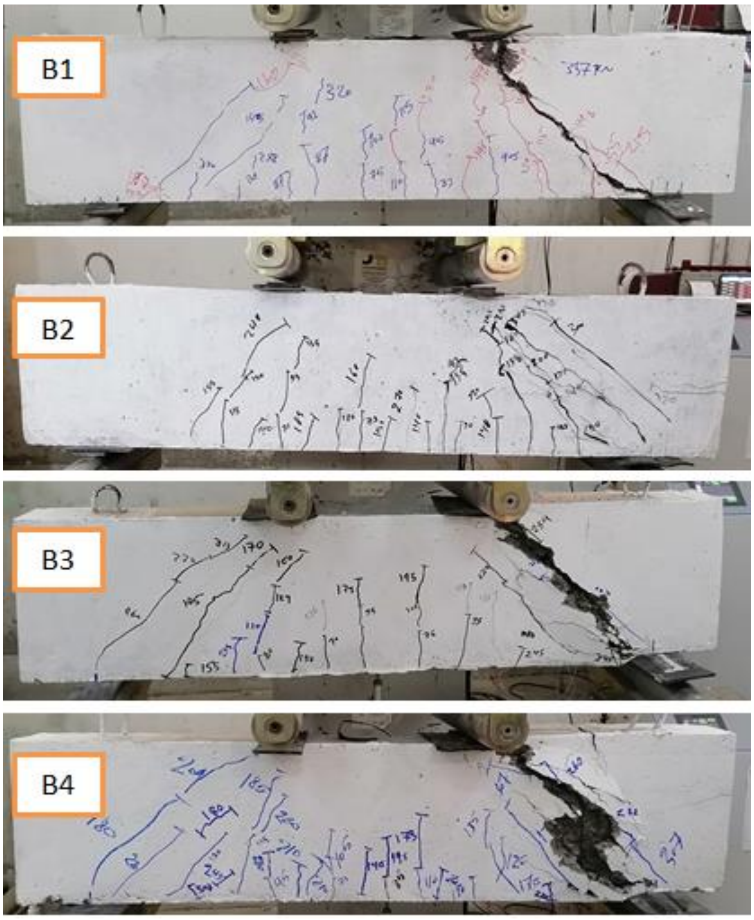


Figure 4. Test setup of the beams

4.2. Load-Deflection Relationship

From table (4) Figure (4) it is noted that making a hollow in the deep beam increases the vertical deflection by 13.125% compared to the deflection of the solid deep beam. Making a hole with a slope has almost the same effect on the vertical deflection of the beam compared to the hollow beam at 21.198 and 21.294 percent at the inclination of 4.3% and 7.8%, respectively. The stiffness factor of the hollow deep beams also decreased by 19.7% and 28.26% to 30.11% for the same bundles, respectively, when compared with the solid sample.

where $stiffness\ factor = \frac{P}{\Delta}$

Table 5: The load – deflection results

Beam designation	Reduction in vol. of beams %	Ultimate load Pu (kN)	Ultimate deflection Δu (mm)	Increase in Δu %	decrease in stiffness factor%
DB1	/	357	5.851	/	/
DB2	4.1	330	6.735	13.125	19.7
DB3	4.1	325	7.425	21.198	28.26
DB4	4.1	317	7.434	21.294	30.11

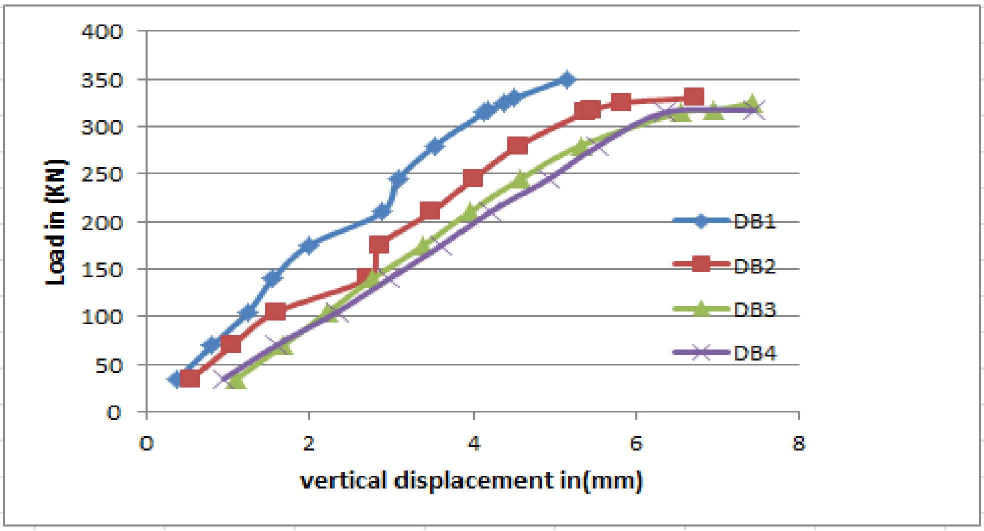
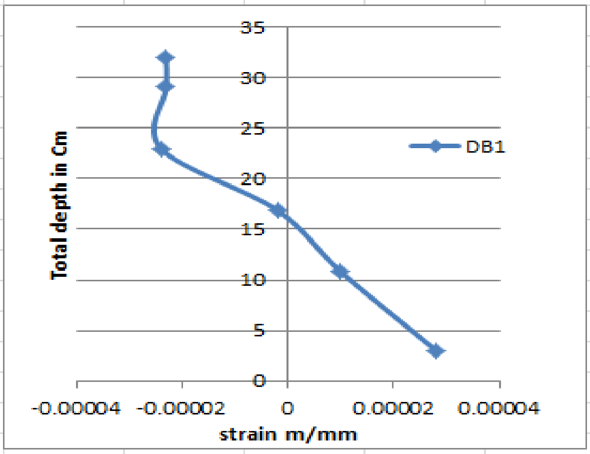


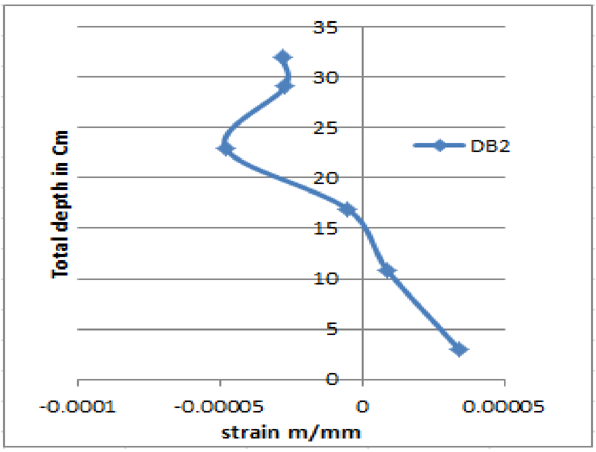
Figure 5. Load – mid span deflection curves

4.3. Total Depth-Strain relationship

The distribution of stresses is non-linear in deep beams, which makes it difficult to determine the neutral axis of the beam, as well as to know the locations of the maximum and minimum stresses. Therefore, the strain gauge was placed vertically inside each beam to monitor the change in the distribution of stresses and the location of the neutral axis, in addition to knowing the optimal places to clarify the longitudinal holes inside the deep beam

Initially, the neutral axis was set at an initial load value (10 kN). As shown in Figure (5), the position of the neutral axis is the same for all four beams, as they came as 160 mm, 150 mm, 150 mm and 155 mm measured from the bottom edge of the beam for DB1, DB2, DB3, and DB4 beams respectively. The location of the neutral axis at the failure load was also determined for each beam as follows; 220 mm, 215 mm, 220 mm and 230 mm for samples DB1, DB2, DB3 and DB4 respectively. as shown in Figure (6).





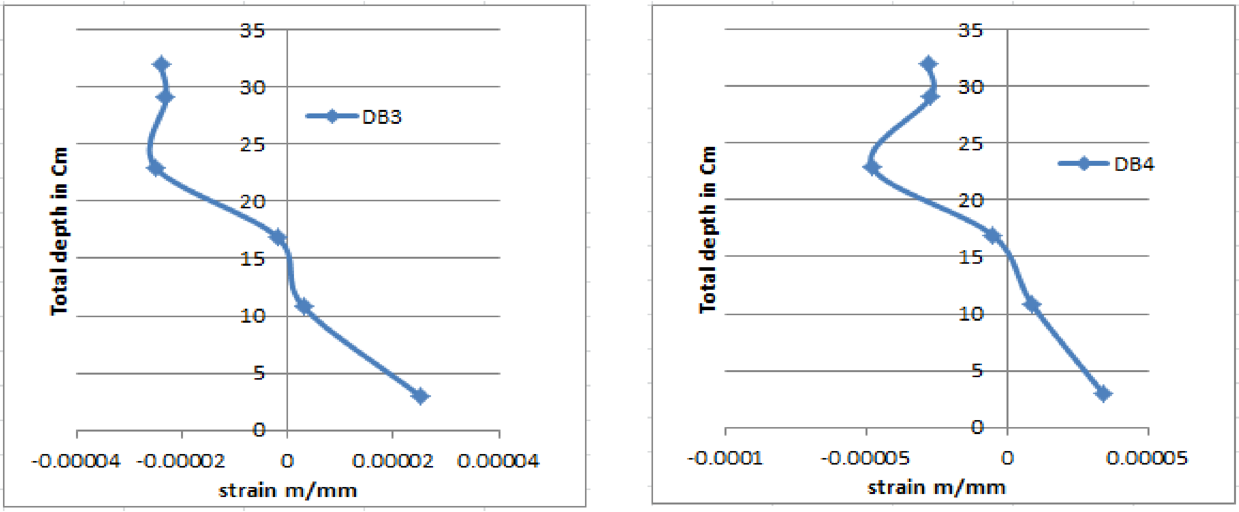


Figure 6. The position of the neutral axis at a load of 10 kN

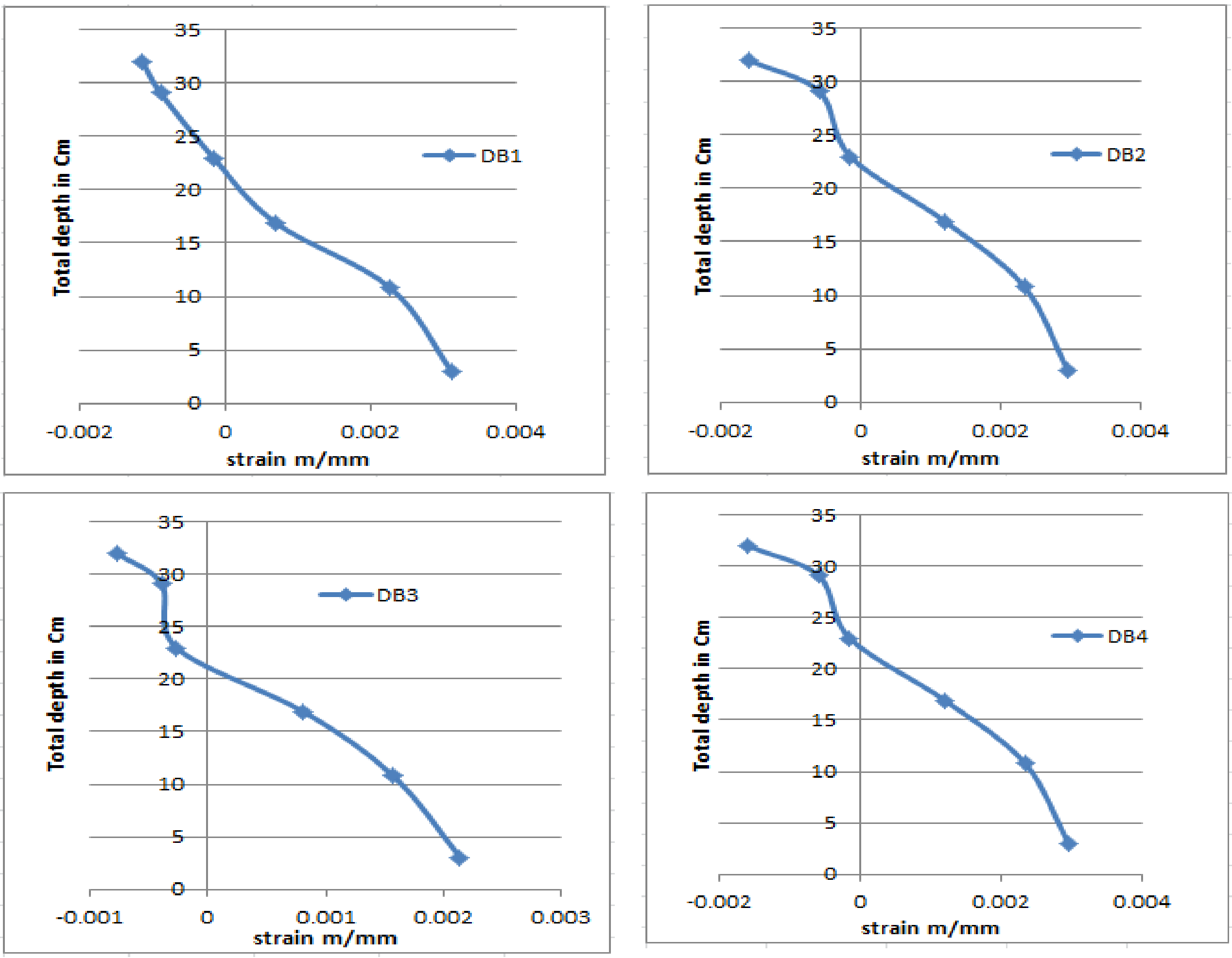


Figure 7. The position of the neutral axle at the failure load

5. Conclusion

The following are the most important conclusions reached in this study:

1. In general, the presence of longitudinal holes in the deep beams reduces the effectiveness of the strut and tie method.

2. The reduction in shear and flexural fracture load is small compared to the reference beam of the zero-slope beam. Because at the inclination of 3.4% and 7.8%, a small part of the hollow is within the zone of extreme tensile close to the reinforcement which is more susceptible to cracking than the rest of the areas.
3. The decrease in the final load increases with the increase in the slope of the longitudinal hole. The depression is more when one of the nozzles of the holes is in the area of compression because the action of concrete is more in compression rather than tensile.
4. The rigidity of the deep beams is affected by the presence of longitudinal hollows, as their stiffness decreases and the amount of vertical deflection of the beams increases due to the decrease in the moment of inertia of the hollow beams.
5. The effect on the stiffness and the vertical deflection of the deep beams is small when changing the inclination of the longitudinal holes of the beams when compared to the zero-slope beam since the size of the concrete reduction is constant for all beams.
6. The position of the neutral axis for all samples is almost the same at the initial load (10 kN) and the same at the failure load of each beam, with a different distribution of stresses.
7. When transferring the level of the service holes (sanitary, electrical, mechanical, etc.) within the tension zone or from the compression zone to the tension zone affects the failure load of the deep beams, while its effect on the crack load and the deflection load is very small.

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