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# STUDYING THE BEHAVIOUR OF LIGHTWEIGHT DEEP BEAMS WITH OPENINGS

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**Abstract:**

***In this study experimental tests were conducted to investigate the behavior of reinforced concrete deep beam with openings using lightweight concrete. The experimental program involved of testing thirteen simply supported deep beam specimens which tested under static two-point loads. Light expanding clay aggregate (LECA) was used to produce lightweight concrete. Test variables were the shape and size of openings, reinforcement around the openings, position of the openings and shear span to depth ratio. It was found that the behavior of deep beams which made of lightweight concrete is similar to that made of normal concrete. It was concluded that the ultimate load and the measured maximum deflection in beams that have circular openings are larger compared to that have rectangular openings. At the same time, the ultimate load decreased and the measured values of maximum deflection increased with increasing the size of the openings in deep beams. Also, it was found that providing steel reinforcement around the openings caused an increasing in the load capacity of the tested beams. Decreasing the shear span ratio from 0.5 to 0.4 caused an increasing in the ultimate load and the measured maximum deflection.***

**Keywords:** Deep Beams; Light Weight Concrete; LECA; Opening in Beams.

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## 1. Introduction

Reinforced concrete deep beams are practically universal structural members. It has been commonly used due to their economic efficiency and expediency. Deep beams particularized as being relatively deep and short, and having a small thickness relative to their span or depth. Generally, deep beams are those have shear span to depth ratio smaller than (1). The applications of deep beams include transfer girders, foundation walls, raft slabs, pile caps, and tanks, which often receive small loads in their own plane and transfer it to a small number of reaction points [1].

Deep beams differ from the other flexural members because they behave as two-dimensional instead of one-dimensional members and subjected to two-dimensional conditions of stresses. This variation in behavior is mainly caused from the significant effects of vertical normal stresses and shear deformations in these members [2].

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The presence of openings in beams alters the simple behavior of the beam to more complex. Due to the unforeseen changes in the beam section, opening corners will be subjected to high concentration of stress that it may cause unacceptable cracking. The reducing stiffness of the beam could cause a rise in deflections to excessive values under service load and then a considerable redistribution of internal forces and moments in a continuous beam will occur. Unless special reinforcement is provided in sufficient quantity with proper detailing, the strength and serviceability of such a beam could be affected [3].

The main use of structural lightweight concrete is to reduce the dead load of a concrete structure, which then allows the designer to reduce the size of columns, footings and other load bearing elements. Structural lightweight concrete mixtures could be designed to attain strengths values close to that of normal weight concrete. The same is true for other mechanical and durability performance requirements. Lightweight concrete gives a more efficient strength-to-weight ratio in structural members. In most cases, the higher cost of the lightweight concrete is balanced by size reduction of structural members, less reinforcement, and concrete volume, hence lower overall cost [4].

Structural lightweight concrete generally has density of (1440 to 1840 $kg/m^3$) compared to normal weight concrete (2240 to 2400 $kg/m^3$). For structural applications, the light weight concrete should have a compressive strength value at least of (17.0 MPa) [5]. Light weight concrete mixtures could be made using a lightweight coarse aggregate. In some cases, a portion or the entire fine aggregate may be a lightweight product. Lightweight aggregates that used to product structural lightweight concrete are typically expanded shale, clay or slate materials that have been fired in a rotary kiln to develop a porous structure.

Present study meant to investigate the behavior of reinforced concrete deep beam with openings using lightweight concrete. Tests were carried out on thirteen reinforced concrete deep beams with opening using light weight aggregate for this purpose. The parameters studied were; shear span to depth ratio, opening size, opening shape, opening position, reinforcement around the opening.

## 2. Literature Review

Shafigh et al, (2011) [6] studies theoretically and experimentally behaviour of 9 RC lightweight beams in flexure. The concrete made from lightweight expanded clay aggregate (LECA). In this investigation lightweight concrete had a compressive strength ranged from 37 to 62 MPa and an air-dry density of (1600 to 1850 kg/m3). Reinforced concrete beams were tested using the symmetrical two-point loads. The studied parameters were concrete strength and steel bar reinforcement. It was found after comparing flexural performance of the tested beams with the theoretical analysis, that maximum ratio of main reinforcement of the ACI code should be changed from ρma x = 0.75 ρb to ρma x = 0.6 ρb. Additionally, it was found from the values of ultimate moment and deflection of the tested beams that for making a flexural element by using LECA lightweight concrete, it is favoured to use a lighter concrete of lower compressive strength.

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Campione and Minafo (2012) [7] tested experimentally and analytically the influence of circular openings in reinforced concrete deep beams with low shear span-to-depth ratio. Twenty reinforced concrete small-scale deep beams with or without openings were tested in flexure under four-point loading. The beams had a small shear span-to-depth ratio in order to stress the shear behaviour. The specimens had different reinforcement arrangements and opening positions. The load was transmitted to the specimen with bearing plates having the same side length as the beam. Two LVDT's were arranged to record the transverse and axial strain of the theoretical struts forming in the beam. Additionally, another device was mounted to measure the middle deflection of the beam. Comparative analysis of the experimental results shows thatthe effect of the hole depends on its position in the beam and the benefit of the presence of reinforcement depends on its arrangement. An analytical model is proposed to predict the shear strength and corresponding deflection of deep beams with openings and the results are also compared with a non-linear finite element analysis showing good agreement.

Khafaga (2012) [8] tested experimentally 11 reinforced concrete beams, divided into two groups, Seven reinforced reduced-weight concrete beams and four reinforced normal-weight control beams to recover the consideration of the shear behaviour of reinforced reduced-weight concrete beams made of light-weight expanded clay aggregate LECA as a partial replacement (by volume) to the normal-weight aggregates. Variables in test were concrete weight, shear span to depth ratio, concrete grade and the quantity of stirrups. The behavior of the tested beams was analysed in terms of modes of failure, load-strains response, load-deflection response, first shear cracking loads, shear stress-shear strain relationships, ultimate carrying capacity, ductility and stiffness. The reduced-weight concrete exhibited reduction in modulus of elasticity, tensile/compressive strength ratio, and small reduction in the load carrying capacity compared with normal-weight concrete beams. The first shear cracking loads of the reduced-weight concrete beams were greater than those of the comparative normal-weight concrete beams, increasing the shear span to depth ratio decreased the cracking and ultimate loads, increasing the shear reinforcement improved the shear capacity. The experimental improvement in ultimate carrying capacity of the reduced weight concrete beams, due to the increase in the concrete grade was lower than that of the normal-weight concrete beams.

Alsaeq (2013) [9] investigated the effect of the opening shape and location on the structural behaviour of reinforced concrete deep beam with opening, while keeping the opening size unchanged. The software ANSYS 12.1 were used to handle the nonlinear finite element analysis. It was concluded that placing the opening near the upper corners of the deep beam may double the strength, and the use of a rectangular narrow opening, with the long sides in the horizontal direction, can save up to 40% of structural strength of the deep beam.

Paul and Tharu (2014) [10] reported an analytical study on deep beams designed by Strut and tie method described in ACI 318-08 using lightweight concrete, lightweight fibre added concrete and normal concrete. A nonlinear static analysis (ATENA 3D) of each beam was conducted. Characteristics recognised and arranged were maximum load, first diagonal crack, maximum crack width and maximum deflection etc. their observations for deep beam with normal concrete were that failure load and maximum deflection is greater compared to deep beams with lightweight concrete. The concrete failure load and maximum deflection were increased when fibre was added to lightweight. Cracks width are less wide for deep beam with normal concrete

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compared to lightweight concrete. Decrease in crack width can be observed when fibre is added to lightweight concrete. Deep beam with lightweight concrete had a very low cracking load compared to deep beam with fibre added lightweight concrete. Strut and tie method gave a conservative result for lightweight concrete deep beam with fibre.

Patil and Joshi (2014) [11] studied the behaviour of deep beam subjected to shear and bending stresses theoretically and experimentally. Seven simply supported rectangular deep beams were tested of constant width of 100 mm and variable lengths. The studied parameters were compressive strength of concrete and shear span to depth ratio which was taken from (1.0 to 2.67). It was fulfilled that failure of deep beams was essentially due to diagonal cracking. When span to depth ratio increases inclination of cracks decreases, the load taken at first crack in flexure is smaller than shear failure, in shear failure of deep beams the deflections are low compared to flexural failure of ordinary beams. The comparison of experimental failure load with analytical results showed that analytical results predicted higher shear capacity than experimental results

## 3. Test Program

Test program includes studying the behavior of reinforced concrete deep beams with openings using lightweight concrete by testing thirteen deep beams samples. The beams were divided into three groups; beams with circular openings, beams with rectangular openings, beams with rectangular reinforced opening.

### 3.1. Design Method

The main parameters governing the behavior of deep beams under loading are the span/depth ratio, shear span/depth ratio, slenderness (depth/thickness) ratio, main and web reinforcement, loading type, and supporting conditions [12].CIRIA GUIDE 2 used to design the tested samples of deep beams with normal and lightweight aggregate [13].

## 4. Tested Deep Beams Details

The test program consisted of two groups;

1) Control beams with lightweight concrete using of LECA named in symbol (LW).
2) Test beams consist of twelve beams; the variables were the effect of the shape of openings, the effect of the position of the openings, the effect of shear span ratio, the effect of reinforcement of steel bars around the opening, and the effect of the size of the openings.

The tested beams were of Square cross section, all beams have length of (1150 mm) and width of (100 mm) and (400 mm) depth. For all beams the clear span between the supports was 950 mm. seven from the beams have a small Square opening (100mm×100mm) in size, three with reinforcement around the openings. Three from the tested beams have circular openings of (100mm) in diameter. Two beams have bigger Square openings of (150mm×150mm); one with reinforcement around the open and the other one without, as described in Table (3.1).

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Both of the top longitudinal and bottom main reinforcement bars were 10 mm diameter, deformed steel bars extended over the entire length of the beam and anchored adequately at the ends with 900 bends equal to 200 mm. For horizontal and vertical web reinforcements, a 6 mm diameter deformed steel bars were used.

Control beam and tested beams are designed according to CIRIA guide 2 which gives 3φ10 mm for main reinforcement, ø6mm at 200mm for vertical and horizontal web reinforcement.

To stay away from local bearing failure, rubber pads were seated at loading and supporting points. Figure (1) shows an explanation about the specimen details and the variables.

Table 1: Description of Tested Deep Beams.

| **Specimen symbol** | **Shape of the opening** | **Position of the opening** | **Size of the opening** | **Reinforcement around the opening** | **a/h** |
|---|---|---|---|---|---|
| LW | - | - | - | - | 0.5 |
| LTR | Square | Top | 100mm×100mm | N/A | 0.5 |
| LMR | Square | Middle | 100mm×100mm | N/A | 0.5 |
| LBR | Square | Bottom | 100mm×100mm | N/A | 0.5 |
| LTC | Circle | Top | Dia. =100mm | N/A | 0.5 |
| LMC | Circle | Middle | Dia. =100mm | N/A | 0.5 |
| LBC | Circle | Bottom | Dia. =100mm | N/A | 0.5 |
| LTRR | Square | Top | 100mm×100mm | Applicable | 0.5 |
| LMRR | Square | Middle | 100mm×100mm | Applicable | 0.5 |
| LBRR | Square | Bottom | 100mm×100mm | Applicable | 0.5 |
| LBRRB | Square | Bottom | 150mm×150mm | Applicable | 0.5 |
| LBRB | Square | Bottom | 150mm×150mm | N/A | 0.5 |
| LBRD | Square | Bottom | 100mm×100mm | N/A | 0.4 |

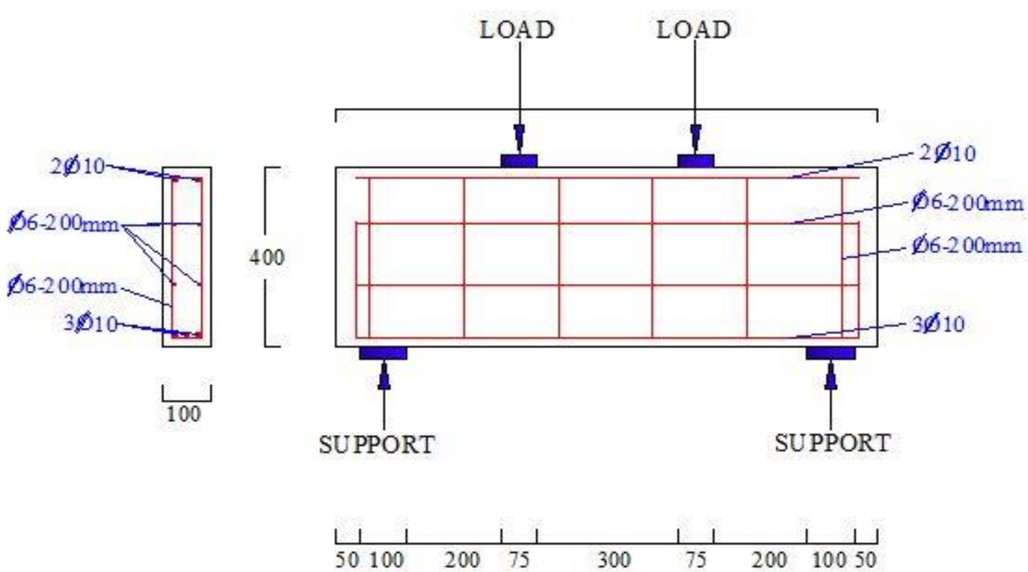


Figure 1: LW Beam.

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## 5. Lightweight Concrete Mixes

In the investigational program a series of trial mixes cast and tested before choosing which mixes were to used; the purpose was to get mixes that satisfy structural lightweight concrete requirements (density between 1440-1840 kg/m$^3$ and compressive strength not less than 17.5MPa).

Mix (M1): The ratios of all material took from previous researches (used only LECA as coarse aggregate without normal weight aggregate).

Mix (M2): Decrease fine aggregate content and replace 15% of coarse aggregate volume with normal weight gravel and 85% LECA content and water ratio.

Mix (M3): Same mix (M2), increase gravel volume to 25% and decrease LECA volume to 75% of coarse aggregate volume.

For each mix three concrete cubes were cast and tested to obtain the density and compressive strength.

Mix (M1) used to cast all lightweight concrete deep beams because it is the only one that satisfied the requirements.
The quantities of materials required for one cubic meter of concrete for all trial mixes in addition to the densities and compressive strength are given in Table (2).

Table 2: Properties of trail mixes.

| **Mix No.** | **Cement(kg/m)** | **Water (kg/m)** | **Fine Agg. (kg/m)** | **Course Agg. (kg)** | | **Density (kg/m$^3$)** | **Compressive strength (MPa)** |
|---|---|---|---|---|---|---|---|
| | | | | **Gravel (kg/m)** | **LECA (kg/m)** | | |
| M1 | 350 | 160 | 630 | - | 340 | 1820 | 26.170 |
| M2 | 400 | 170 | 600 | 230 | 270 | 2149 | 29.839 |
| M3 | 400 | 170 | 600 | 380 | 240 | 2188 | 28.208 |

## 6. Fabrication and Casting of Deep Beams

### 6.1. Fabrication and Gathering of The Reinforcement and Timber Forms

The main, horizontal and vertical web bars were assembled by steel wires manually and then using plastic spacers to maintain the concrete cover and secure the position of reinforcement in designated location.

Timber forms with plywood face were used in casting beams, the interior faces of forms were coated with oil prior to casting and before the reinforcement cage was placed in position, plastic spacers were used to maintain the concrete covers.

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### 6.2. Casting of Deep Beams

Tilting drum mixer was used; the interior surface of the mixer drum was cleaned and moistened before use. LECA used in saturated surface dry (SSD) condition so it covered with water for 1 day before mixing. The water in the mix was computed as if LECA were non-absorbent. The dry ingredients were added in the following order, all the fine aggregate, all the cement, and lastly the coarse aggregate. Then mixing was started and with the water added. The period of mixing was about three minutes so that a homogenous mix was obtained. After the mixing process was completed, concrete was poured in the forms and then compacted by means of Poker vibrator to ensure the proper placement and consolidation of the concrete in and around the reinforcement cage, the top surface of concrete was finished level after casting was completed using hand trowel. The beams were cured for seven day after casting using damp canvas.

## 7. Instrumentation and Procedure

Before the test all the beams were painted white to make easy tracing the crack patterns. The positions of the (Demountable Mechanical) DEMEC points were marked and DEMEC were attached using an epoxy resign. Concrete strains measured at sections of maximum and minimum bending moment and along the load path between the load points and supports were measured by DEMEC mechanical strain gauge with gauge length of 50 mm and accuracy of 20 micro strains as showed in Fig. (2). The mid-span deflection of each beam was measured by using dial gauge with magnetic base. The accuracy of the dial gauge was (0.01 mm). Width of concrete cracks were monitored using hand microscope of accuracy (0.02mm per division). The beams were tested at age of 28 days. The supports were of the roller type. The bottom spreader consisted of one universal steel (I section) beams with depth of (350mm) while the upper spreader consisted of one (I section) beam with a depth (120 mm).

Torsee's Universal Testing Machine with a capacity of 2000kN was used to apply the load. The beam was loaded from top at the center of the top spreader. Load was applied in increments. At each load increment (0.5 ton), the total applied load on the beam, mid-span deflection, concrete strain in six positions, and crack width for the main inclined crack were measured and recorded in a prepared paper. The cracks were then plotted and marked with a coloured pencil.

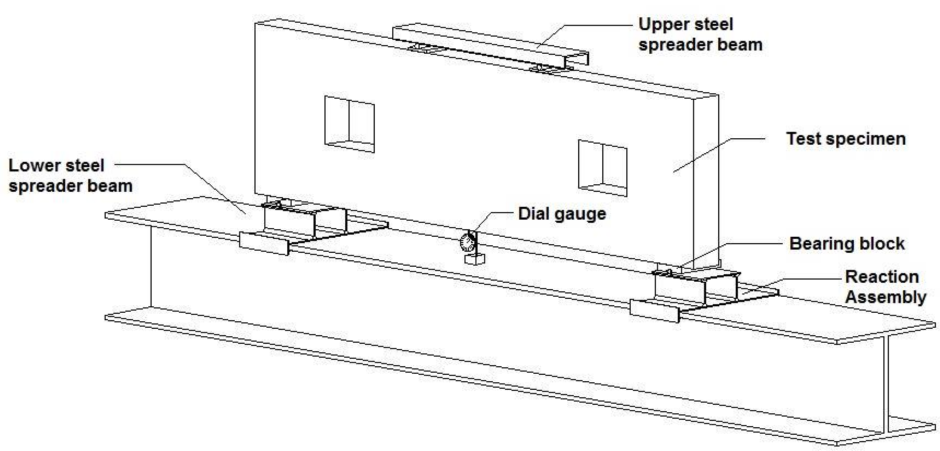


Figure 2: Set of the specimen on testing machine.

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The test was terminated when the total load on the specimens started to drop off. The total time to failure in a test for each beep beam was approximately one hour.

## 8. Beams Under Loading Behavior

In the test, all beams failed by shear and local failure due to crushing of concrete over the supports or under the loading points occurs. End anchorage of the bottom steel bars functionally very well and did not affect the failure mode of beam in the entire beam tested. The first crack observed was shear-flexure crack, and then inclined cracks at about mid-height of the beam in the middle of both shear spans were observed. As the load increased one inclined crack became more prominent than the others, and propagated towards the loads and support points, eventually this crack caused the shear failure of the beam.

The load against mid-span deflection curves for the experimented beams are shown in Figs. (3 to 7).From these curves, it could be noticed that a change in slope of the curves occurred after the appearance of inclined cracking, because the formation of first main inclined crack reduced beam stiffness and as a result increased the deflection.

Loads-shear strain plots for all deep beams are shown in Figs. (8 and 9) for all specimens, it was observed that shear strain before first diagonal cracking was very small and increased rapidly after diagonal crack developing.

Table 3: Experimental deflections at service load

| **Beam Symbol** | **Deflection at mid-beam at 65% of ultimate load for LW beam (mm)** | **Difference percentage with LW beam** |
|---|---|---|
| LW | 2.59 | - |
| LTR | 1.85 | -28.60% |
| LMR | 1.87 | -27.80% |
| LBR | 2.53 | -2.30% |
| LTC | 2.15 | -17.00% |
| LMC | 3.40 | 31.30% |
| LBC | 4.00 | 54.40% |
| LTRR | 3.80 | 46.70% |
| LMRR | 2.05 | -20.80% |
| LBRR | 1.83 | -29.30% |
| LBRD | 3.12 | 20.50% |
| LBRB | 5.80 | 123.90% |
| LBRRB | 2.98 | 15.10% |

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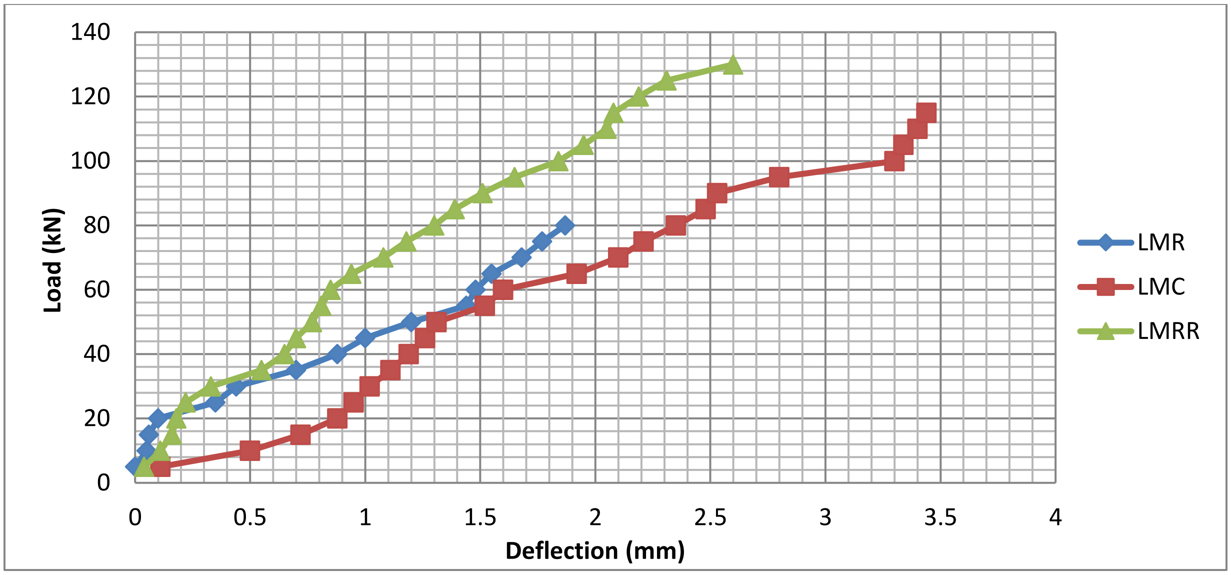


Figure 3: Load versus deflection for middle opening beams in mid-span.

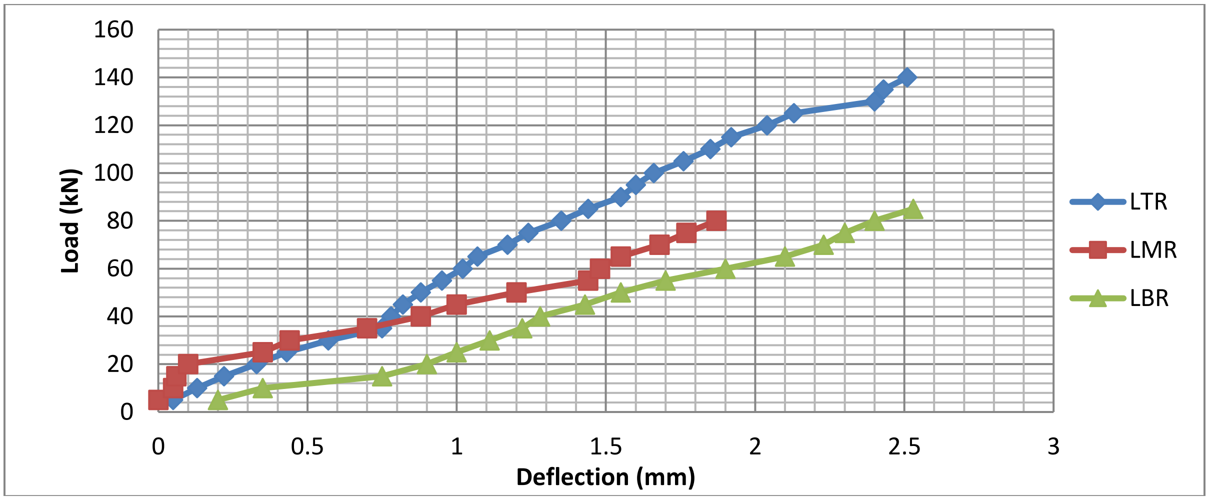


Figure 4: Comparison between rectangular opening position for mid-span deflection.

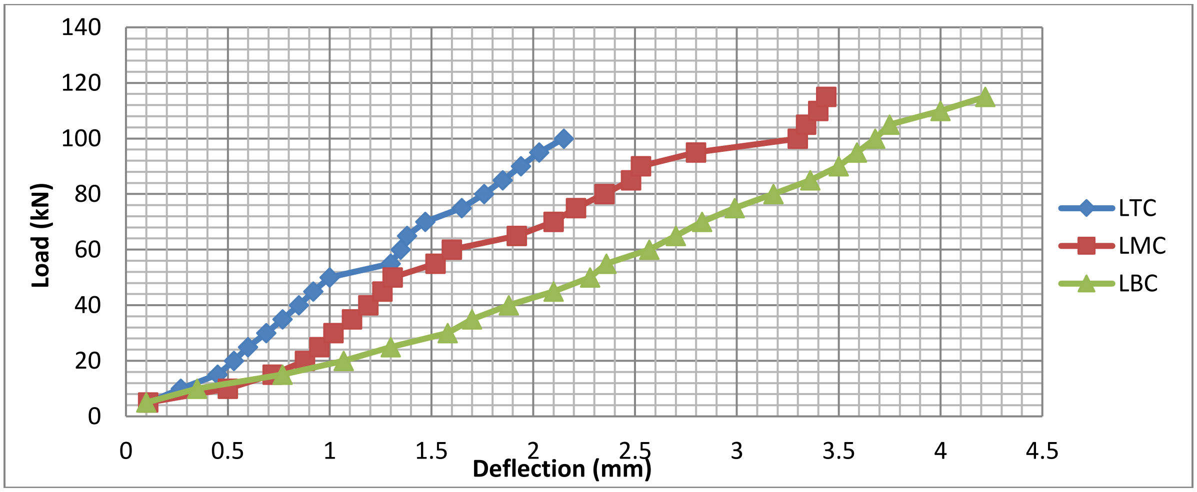


Figure 5: Comparison between circular opening position for mid-span deflection.

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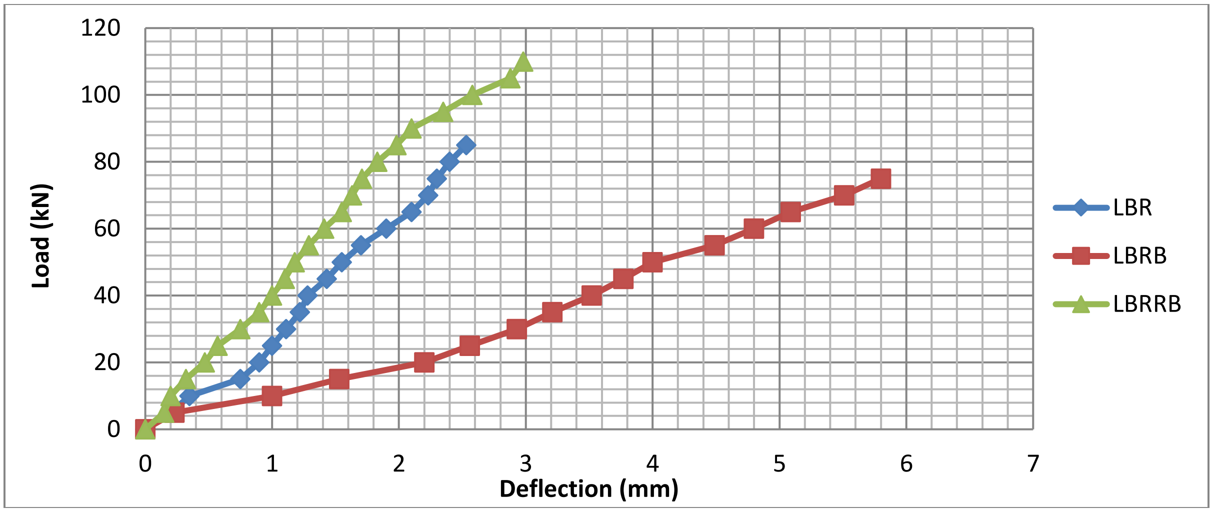

Figure 6: Comparison between bottoms rectangular opening for mid-span deflection.

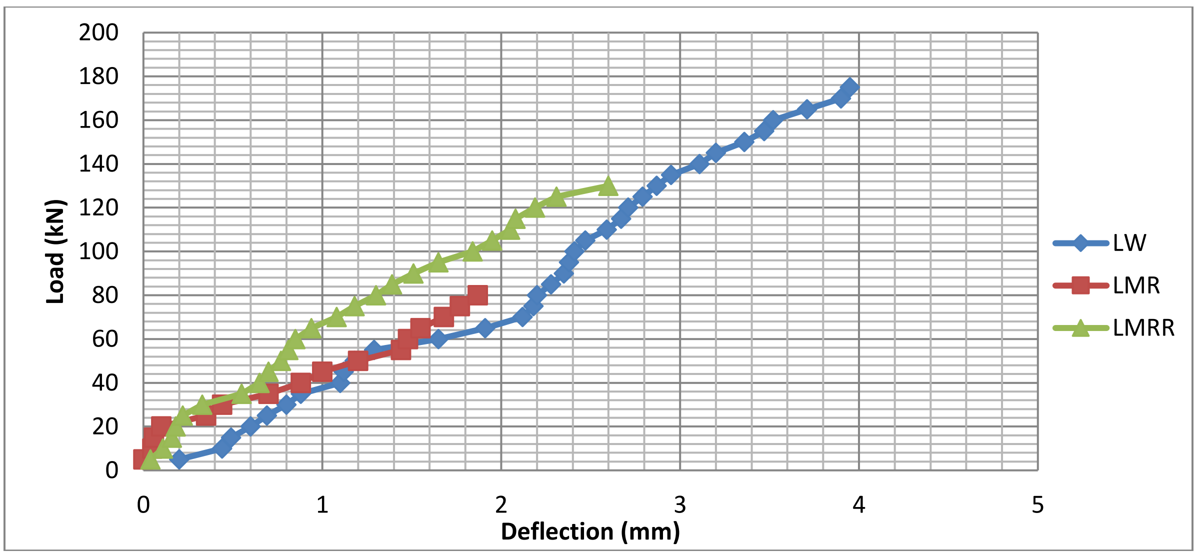

Figure 7: Comparison between middle rectangular opining for mid-span deflection.

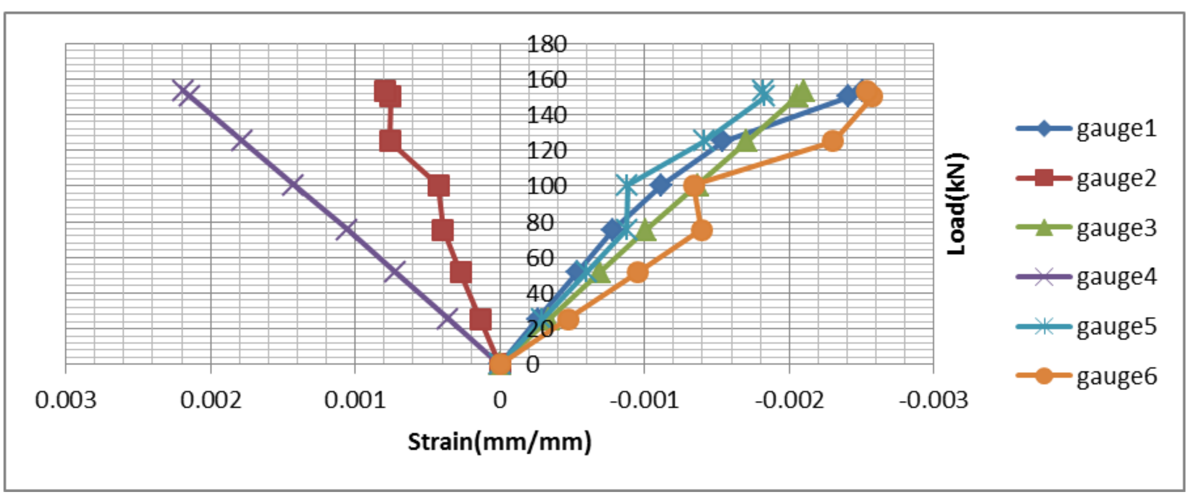

Figure 8: Load versus shear and compression strains at beam LW.

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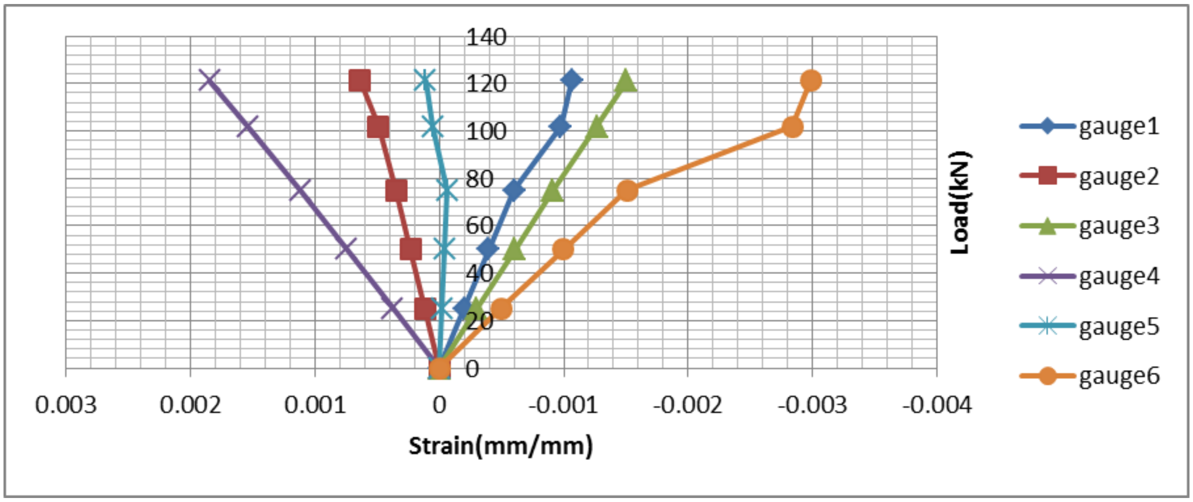
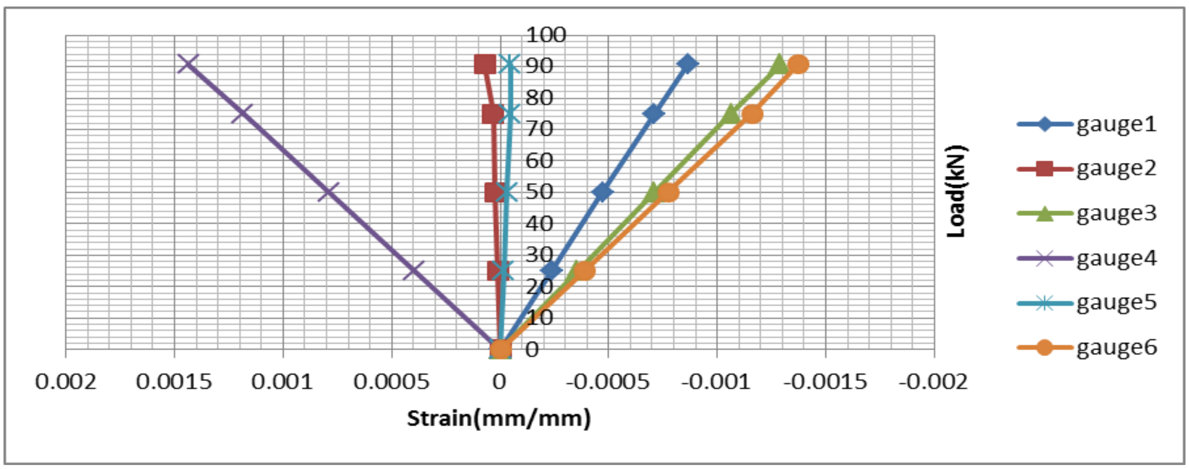



**(a)LTR**




**(b)LMR**

Figure 9: Load versus shear and compression strains at beams(a) LTR beam, (b) LMR beam

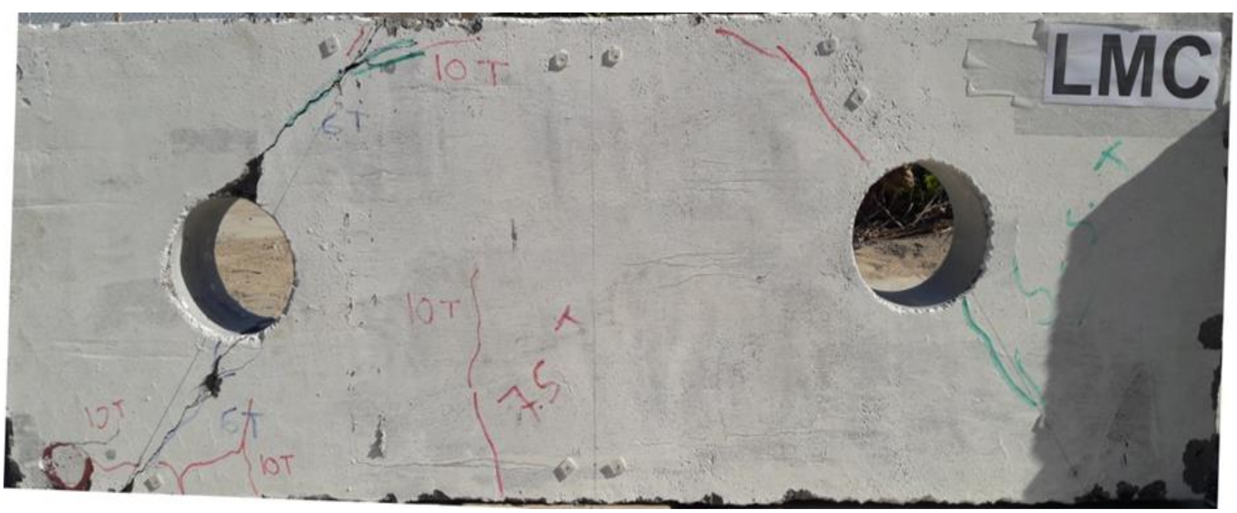



Figure 10: Beam (LMC) after test

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## 9. Conclusions from Experimental Tests

The most important conclusions can be illustrated from the test results are;

1) The general behaviour of deep beams under loading, regular of cracks, and failure mode of lightweight concrete are very much similar to those of normal weight concrete which is the crack pattern is a function of simple strut between loads and supports.
2) The use of circular openings instead of rectangular increases the ultimate load by 10% and maximum deflection by 42%.
3) When the openings position in the mid height of deep beam, a decrease in maximum deflection occurs by 22% and increased ultimate load by 3% comparison with bottom position.
4) Large openings (125% larger) decreased ultimate load by (11.7%) comparison with smaller openings, and increased maximum deflection by (129%) when the open with no steel reinforcement. When steel reinforcement provided it decreased ultimate load by (4.3%) and increased maximum deflection by (59%).
5) Providing steel bars reinforcement around the small openings increases ultimate load by (35%) and for large opening by (46%).
6) The best position of openings is at the top to the outside from action line.
7) In general, the primary cause of failure was diagonal cracking.
8) The maximum deflection occurs when use the large openings and it is larger by (46%) compared to beams without openings.

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