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# Parameters Affecting Load Capacity of Reinforced Self-Compacted Concrete Deep Beams

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***Abstract :*** **This paper studies the behavior of self compacted concrete (SCC) deep beam and the parameters affecting the ultimate capacity. Eighteen specimens represented by ANSYS 11 program to study the effect of several variables like the percentage of shear span to effective depth ratio (a/d), areas of the web openings, web openings shape, concrete compressive strength (f'c), horizontal stirrups and vertical stirrups on the ultimate capacity of SCC deep beams. The finite element model uses Solid65 to model the SCC deep beams and link180 to model steel reinforcement. All beams are simply supported and tested under two concentrated point loads. All beams have the same dimensions and reinforcement. They have an overall length of 1200 mm, a height of 440 mm and a width of 110 mm. Conclusions showed that reducing the shear span to effective depth ratio (a/d) from 1.2 to 0.8 leads to an increase in ultimate capacity by 20%. The deep beams ultimate capacity increases by 9% after reducing the size of the square opening by 30.5%. The circular openings are recommended more than other web openings shape.**

***Keywords: - Deep Beams, Shear Span To Effective Depth Ratio (A/D), Web Openings, Self-Compacted Concrete, Horizontal And Vertical Reinforcement, Finite Element.***

## I. INTRODUCTION

Deep beams are recognized by comparatively small values of span-to-depth ratio. As per code provisions given by American Concrete Institute (ACI 318-11) a beam shall be considered as deep beam when the ratio of effective span to overall depth ratio is less than 4.0 or regions with concentrated loads within twice the member depth from the face of the support. Pipes and ducts that intersect structural beams are necessary to accommodate essential services like water supply, sewage, air-conditioning, electricity, telephone, and computer network. Usually, the depth of ducts or pipes varies from a couple of centimeters to half a meter. In this paper, the ANSYS 11 finite element program is used to simulate the behavior of self-compacted reinforced concrete deep beams. The finite element model uses a **Solid65** and **link180** to model reinforced self-compacting concrete deep beams.

## II. ANALYTICAL MODEL

### *2.1 Element Types, Real Constants, Material Properties, and Parameters*

Characters of the finite elements types were used in modeling the eighteen SCC deep beams and studied by ANSYS program were summarized in Table (1). Each element type in this model has been used to represent a specified constituent of beams.
The real constants need the geometrical properties of the used elements such as cross-sectional area, thickness and values of the interface elements. While the material properties need the behavior and characteristics of the constitutive materials depending on mechanical tests such as yield stress, modulus of elasticity, Poisson`s ratio and stress- strain relationship.
However, each of the specified types of finite elements had a number of fundamental parameters that are identified in the element library of ANSYS. Values of those element parameters are necessary for similar representation of each test beam as they are used in estimating the elements real constants and material properties. Their numerical values are shown in Table (2).

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Table (1): Characteristics and identifications of the selected ANSYS finite element types representative of the main components for all beams

| Beam components | Selected element from ANSYS library | Element characteristics |
|---|---|---|
| Self-Compacting Concrete | SOLID65 | 8-node Brick Element<br>(3 Translation DOF per node) |
| 1-Reinforcing bars (main, horizontal and vertical stirrups)<br>2-Connector Studs outside interface. | LINK180 | 2-node Discrete Element<br>(3 Translation DOF per node) |
| Steel Bearing Plate of loading | SOLID45 | 8-node Brick Element<br>(3 Translation DOF per node) |

Table (2): Parameters identifications and numerical values for element types of the present ANSYS model for all beams

<table>
<tr><th>Element</th><th>Parameter</th><th colspan="5">Definition</th><th>Value</th></tr>
<tr><td rowspan="9">Solid65</td><td>$f'_c$</td><td colspan="5">Ultimate compressive strength(MPa)</td><td>40</td></tr>
<tr><td>$f_t$</td><td colspan="5">Ultimate tensile strength(MPa)</td><td>3.9</td></tr>
<tr><td>$\beta_o$</td><td colspan="5">Open shear transfer coefficient</td><td>0.15</td></tr>
<tr><td>$\beta_c$</td><td colspan="5">Close shear transfer coefficient</td><td>0.85</td></tr>
<tr><td>$E_c$</td><td colspan="5">Young’s modulus of Elasticity (MPa)</td><td>30000</td></tr>
<tr><td>$\upsilon$</td><td colspan="5">Poisson’s ratio</td><td>0.2</td></tr>
<tr><td colspan="7">definition of strain-stress relationship for concrete (SOLID 65)</td></tr>
<tr><td>Stress (MPa)</td><td>0</td><td>12</td><td>25.63</td><td>34.57</td><td>40</td><td>40</td></tr>
<tr><td>Strain</td><td>0</td><td>0.0004</td><td>0.00098</td><td>0.0015</td><td>0.00269</td><td>0.0035</td></tr>
<tr><td rowspan="10">Link180</td><td>Parameter</td><td colspan="5">Definition</td><td>Value</td></tr>
<tr><td rowspan="2">$A_b$</td><td colspan="3" rowspan="2">Cross sectional area (mm$^2$)</td><td colspan="2">Steel reinforcing stirrups Ø4</td><td>13.2</td></tr>
<tr><td colspan="2">Steel reinforcing main bar Ø16</td><td>203.655</td></tr>
<tr><td rowspan="2">$F_y$</td><td colspan="3" rowspan="2">Yield strength(MPa) for Ø4</td><td colspan="2">Steel reinforcing stirrups Ø4</td><td>442</td></tr>
<tr><td colspan="2">Steel reinforcing main bar Ø16</td><td>614</td></tr>
<tr><td rowspan="4">$E_s$ & $E_t$</td><td colspan="3" rowspan="4">Modulus of elasticity &strain hardening modulus (MPa)</td><td>$E_s$</td><td>Steel reinforcing stirrups Ø4</td><td>205000</td></tr>
<tr><td>$E_t$</td><td>Steel hardening Ø4</td><td>6150</td></tr>
<tr><td>$E_s$</td><td>Steel reinforcing main bar Ø16</td><td>215000</td></tr>
<tr><td>$E_t$</td><td>Steel hardening Ø16</td><td>6450</td></tr>
<tr><td>$\upsilon$</td><td colspan="3">Poisson’s ratio</td><td colspan="2">Steel reinforcing bars</td><td>0.3</td></tr>
<tr><td rowspan="2">Solid45 (for all tested beams)</td><td colspan="6">Modulus of elasticity (MPa)(assumed)</td><td>200000</td></tr>
<tr><td colspan="6">Poisson’s ratio</td><td>0.3</td></tr>
</table>

*2.2 Modeling and Meshing of the Concrete Media and the Bearing Plates*

The initial step of modeling includes formation of blocks of the concrete and steel bearing plate volumes. Concrete and steel bearing plate volumes were formed by identifying keypoints of one side edge of the concrete block and the steel bearing plate, then creating lines between these keypoints to establish the areas and volumes that are created by extruding these areas.

After identifying the volumes, finite element analysis needs meshing of the model. Whereby, the model was divided into a number of small elements, to obtain good consequences. The use of a rectangular mesh is recommended to secure good results from the element **Solid65**. Therefore, rectangular meshing was applied in the present model. The volume sweep command was used to mesh the bearing plate at load points and support regions for deep beam by **Solid45** element. This correctly sets the length and width of elements in the bearing plates to be compatible with nodes and elements in the concrete portions of the model. The meshing of concrete and bearing plates at load points and support regions for solid deep beam DB-1 are shown in Fig. (1).

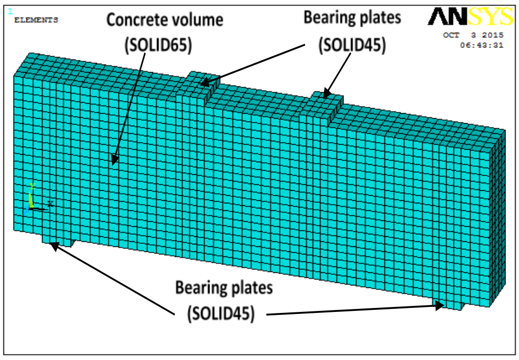


Figure (1): Finite element mesh used for concrete and bearing plate of deep beam reference (DB-1)

*2.3 Modeling of Steel Reinforcing Bars*

For all alignments of the steel reinforcing bars, LINK180 element was used as shown in Fig. (2) for beam DB-1. In spite of volumes meshing for concrete and while volumetric and real meshings are used for the concrete media and the steel plate, respectively, no meshing for LINK180 elements representing the reinforcing steel bars was needed because individual elements were introduced in the model through the nodes created by volumetric meshing of the concrete media.

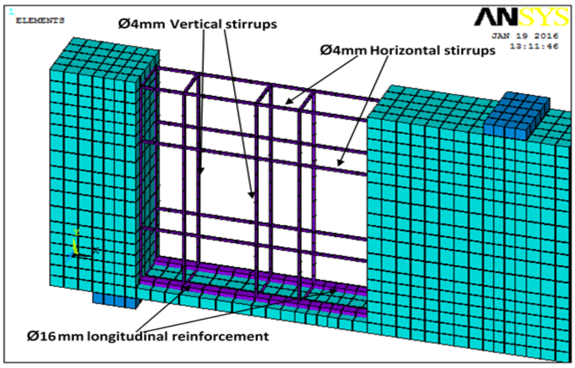


Figure (2): ANSYS modeling of reinforcing steel bars for beam DB-1 (reference)

*2.4 Loads and Boundary Conditions*

The left support was put as hinge support by constraining a single line of bearing plate nodes along the width of the beam soffit in the x- and y-directions (i.e Ux =Uy=0), and the right hinge support was put as roller by constraining the y-direction (Uy=0), see Fig. (3).

The external loads were distributed on the single line of the bearing plate nodes across the width of the top surface of the beam, see Fig. (4).

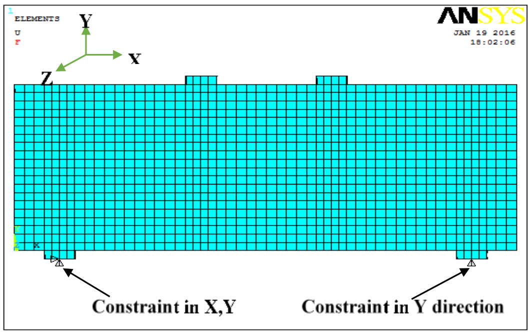


Figure (3): Boundary conditions for simple supports beam DB-1

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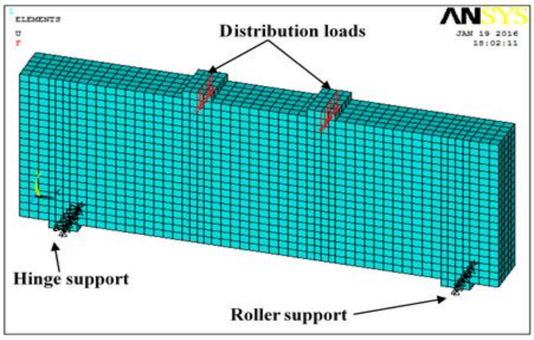


Figure (4): External loads for beam DB-1

*2.5 Analysis Type*

The finite element model for this analysis is a simple beam under transverse loading. For the purposes of this model, the Static analysis type is utilized. The Restart command is utilized to restart an analysis after the initial run or load step has been completed. The use of the restart option will be detailed in the analysis portion of the discussion. The Sol'n Controls command dictates the use of a linear or non-linear solution for the finite element model. Typical commands utilized in a nonlinear static analysis are shown in Table (3).

Table (3): Commands used to Control Nonlinear Analysis

| | |
|---|---|
| Analysis Options | Small Displacement |
| Calculate Prestress Effects | No |
| Time at End of Loadstep | 80* |
| Automatic Time Stepping | On |
| Number of Substeps | 3* |
| Max no. of Substeps | 64* |
| Min no. of Substeps | 1 |
| Write Items to Results File | All Solution Items |
| Frequency | Write Every Substep |

In the particular case considered in this work the analysis is small displacement and static. The time at the end of the load step refers to the ending load per load step. The sub steps are set to indicate load increments used for this analysis. The commands used to control the solver and output are shown in Table (4).

Table (4): Commands Used to Control Output

| | |
|---|---|
| Equation Solvers | Sparse Direct |
| Number of Restart Files | 1 |
| Frequency | Write Every Substep |

All these values are set to ANSYS defaults. The commands used for the nonlinear algorithm and convergence criteria are shown in Table (5). All values for the nonlinear algorithm are set to defaults.

Table (5): Nonlinear Algorithm and Convergence Criteria Parameters

| | |
|---|---|
| Line Search | Off |
| DOF solution predictor | Prog Chosen |
| Maximum number of iteration | 100 |
| Cutback Control | Cutback according to predicted number of iter. |
| Equiv. Plastic Strain | 0.15 |
| Explicit Creep ratio | 0.1 |
| Implicit Creep ratio | 0 |
| Incremental displacement | 10000000 |
| Points per cycle | 13 |
| Set Convergence Criteria | |
| Label | U |
| Ref. Value | Calculated |
| Tolerance | 0.005 |
| Norm | infinite |
| Min. Ref. | not applicable |

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The values for the convergence criteria are set to defaults except for the tolerances. The tolerances displacement is set as 5 times the default values. Table (6) shows the commands used for the advanced nonlinear settings.

**Table (6): Advanced Nonlinear Control Settings Used**

| | |
|---|---|
| Program behavior upon nonconvergence | Terminate but do not exit |
| Nodal DOF sol'n | 0 |
| Cumulative iter. | 0 |
| Elapsed time | 0 |
| CPU time | 0 |

The program behavior upon non-convergence for this analysis was set such that the program will terminate but not exit. The rest of the commands were set to defaults.

## III. DETAILS OF BEAM SPECIMENS FOR THE ANALYSIS

Eighteen simply supported reinforced SCC deep beams have the same dimensions and reinforcement. They have an overall length of 1200 mm, a height of 440 mm and a width of 110 mm. All specimens are designed to fail in shear see Fig. (5). The amount of flexural bottom reinforcement for all tested beams is 2Ø16 mm (ρ=0.0132 where ρ is the flexural reinforcement ratio). The amount of shear reinforcement for the tested beams is Ø4 mm @100mm. The beams are tested with an overall clear span (Ln) of 1000 mm under two point symmetric loading which results in a ratio of clear span (Ln) to overall depth (h) equals to (Ln/h=2.3) which is less than 4 **[ACI Committee 318M-318RM, 2011]**. The locations of openings -if they exist- are at the center of the inclined struts. All these specimens have the same geometry and flexural reinforcement as shown in Fig (5).

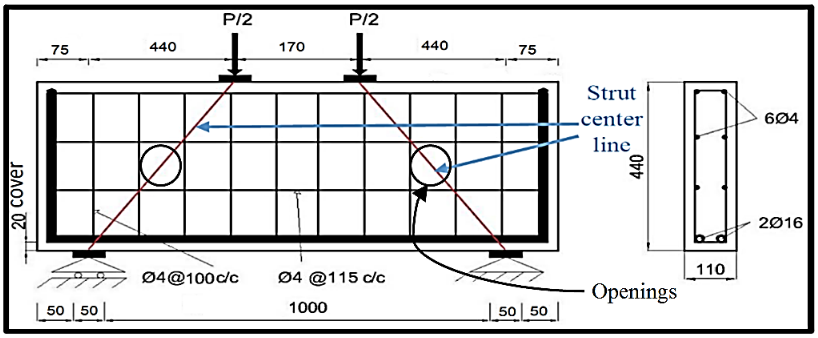


**Figure (5):** DB-8, deep beam with circular openings

## IV. PARAMETRIC STUDY

The parametric study presented here consists of analyzing eighteen deep beams which have been modeled using ANSYS numerical program. The parameters considered in this numerical study are: shear span (a) / effective depth (d) = (a/d), openings size, openings shape, concrete compressive strength (*f'c*) and the effect of the horizontal and vertical stirrups. The variables of the testing program specimens and the summary of test results of all specimens are shown in Table (7).

Table (7): Testing variables considered and testing results.

| Group No. | Beam designation | a/d ratio | f'c | Web opening shape | Web opening size (mm) | Failure load (Pu) kN | Mid-span Displacement at failure (Δ) mm | Variable considered |
|---|---|---|---|---|---|---|---|---|
| 1 | DB-1 | 1 | 40 | - | - | 580 | 14 | concrete compressive (f'c) |
| | DB-2 | 1 | 35 | - | - | 518.6 | 12.2 | |
| | DB-3 | 1 | 30 | - | - | 455.4 | 10.7 | |
| | DB-4 | 1 | 25 | - | - | 382.5 | 8.6 | |
| 2 | DB-5 | 1 | 40 | square | 50x50 | 472.3 | 9.4 | web openings size |
| | DB-6 | 1 | 40 | square | 40x40 | 495.5 | 10.5 | |
| | DB-7 | 1 | 40 | square | 60x60 | 454.8 | 8.8 | |
| 3 | DB-5 | 1 | 40 | square | 50x50 | 472.3 | 9.4 | web openings shape |
| | DB-8 | 1 | 40 | circular | 56.5 | 490.8 | 9.8 | |
| | DB-9 | 1 | 40 | horizontal rectangular | 62.5x40 | 452 | 9 | |
| | DB-10 | 1 | 40 | vertical rectangular | 40x62.5 | 406.3 | 8.6 | |
| | DB-11 | 1 | 40 | rhombus | 50x50 | 482.2 | 9.6 | |
| 4 | DB-1 | 1 | 40 | - | - | 580 | 14 | reference |
| | DB-12 | 1 | 40 | - | - | 521.5 | 12 | without horizontal stirrups |
| | DB-13 | 1 | 40 | - | - | 472.9 | 10 | without vertical stirrups |
| | DB-14 | 1 | 40 | - | - | 402.6 | 8 | without horizontal & vertical stirrups |
| 5 | DB-1 | 1 | 40 | - | - | 580 | 14 | Shear-span to effective depth ratio (a/d) |
| | DB-15 | 1.2 | 40 | - | - | 534.3 | 15 | |
| | DB-16 | 0.8 | 40 | - | - | 642.1 | 11 | |
| 6 | DB-5 | 1 | 40 | square | 50x50 | 472.3 | 9.4 | Shear-span to effective depth ratio (*a/d*) |
| | DB-17 | 1.2 | 40 | square | 50x50 | 429.4 | 13 | |
| | DB-18 | 0.8 | 40 | square | 50x50 | 527.9 | 9 | |

*4.1 Effect of Concrete Compressive Strength (f'c):*

Four grades of concrete compressive strength have been used, (Group 1, see Table(7)). It can be noted that the increase in the value of the compressive strength (*fc*') from 25 MPa to 40 MPa leads to increase the ultimate capacity by 52% and increase the mid-span displacement by 63%. The load mid-span displacement response for Group 1 are shown in Fig. (6).

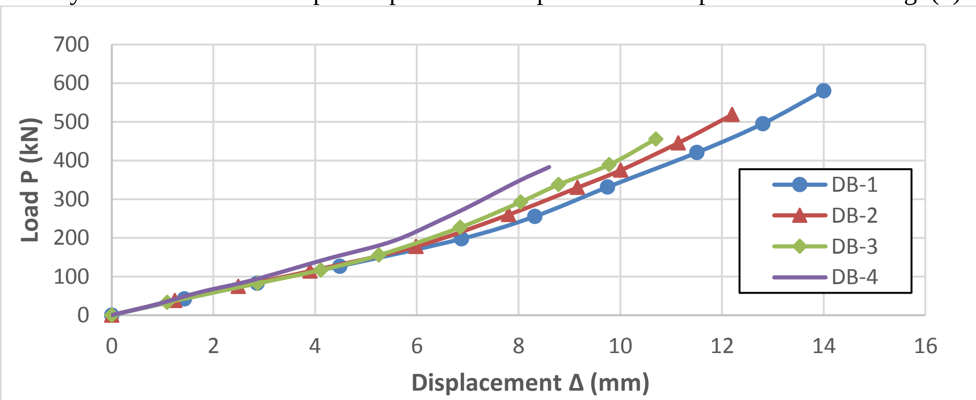


Figure (6): Load-midspan deflection for Group 1

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*4.2 Effect of openings size:*

To study the effect of web opening size on the ultimate capacity of deep beams, three beams with different square web openings size were provided, (Group 2, see Table(7)). It was noted that the decrease in opening area from 3600 mm2 to 2500 mm2 and then to 1600 mm2 leads to increase in the ultimate capacity by 4% and 5% respectively. The load mid-span displacement response for Group 2 are shown in Fig. (7).

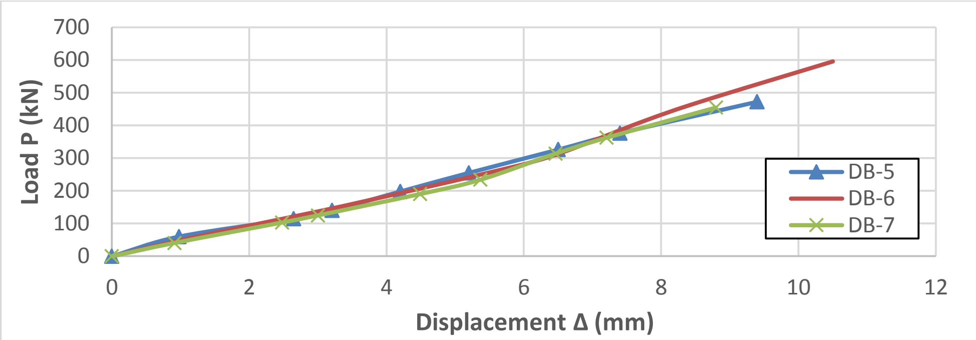


Figure (7): Load-midspan deflection for Group 2

*4.3 Effect of openings shape:*

Five different shapes of web openings with the same size and location were used in this study, (Group 3, see Table (7)). The locations of openings are in the centers of the inclined struts. All these beam specimens had same geometry, reinforcement, web openings size and tested under two point loads. It is noted that the minimum loss in ultimate capacity (Pu) takes place when the circular openings were used. Where, it is about 18.5%. The load mid-span displacement response for Group 3 are shown in Fig. (7).

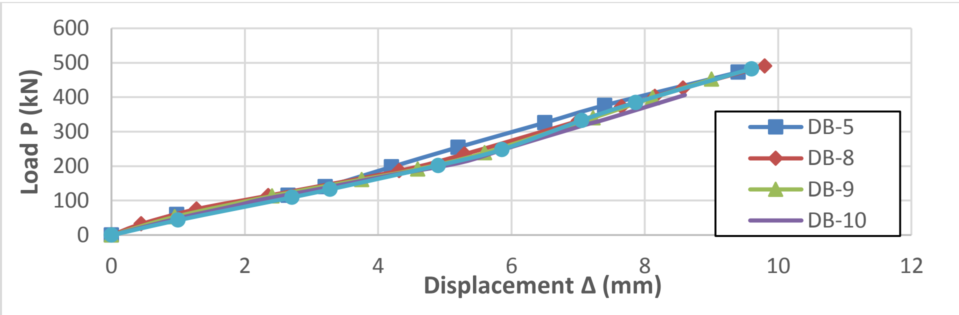


Figure (8): Load-midspan deflection for Group 3

*4.4 The effect of using the horizontal and vertical reinforcement:*

Four beam specimens are tested to study the effect of using horizontal and vertical stirrups, (Group 4, see Table (7)). It can be noted that the increase in both horizontal and vertical web reinforcement ratios $\rho vh$ and $\rho v$ from 0.0% to 0. 0.0132% leads to increase the failure load by about 44% and also increase the corresponding displacement by about 75%. The load mid-span displacement response for Group 4 are shown in Fig. (9).

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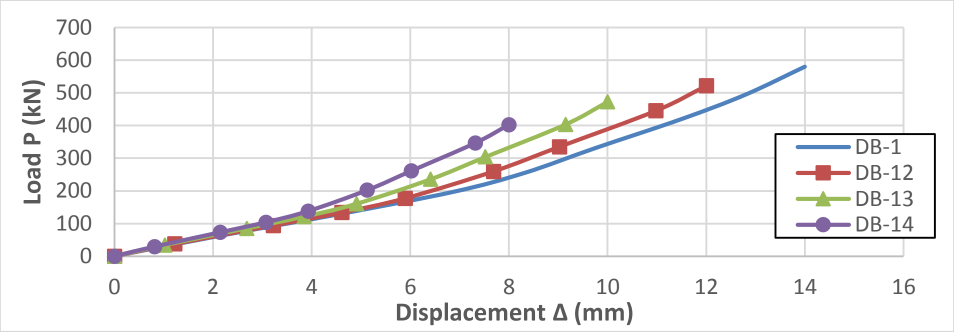


Figure (9): Load-midspan deflection for Group 4

*4.5 The effect of shear-span to effective depth ratio (a/d):*

The shear failure is mainly dependent on a/d ratio. To study the effect of this important parameter, six beams specimens were analyzed by ANSYS and divided in two Groups according to existing web opening. Group 5 have three solid deep beams with a/d=0.8, 1 and 1.2, respectively and Group 6 have three deep beams having square web openings with a/d=0.8, 1 and 1.2, respectively. The numerical results of ultimate capacity (Pu) and the corresponding mid-span deflection (Δf) for specimens are shown in Fig (10) and Fig (11). It can be observed that when reducing the shear span to effective depth ratio (a/d) from 1.2 to 0.8 leads to an increase in ultimate capacity by 20%.

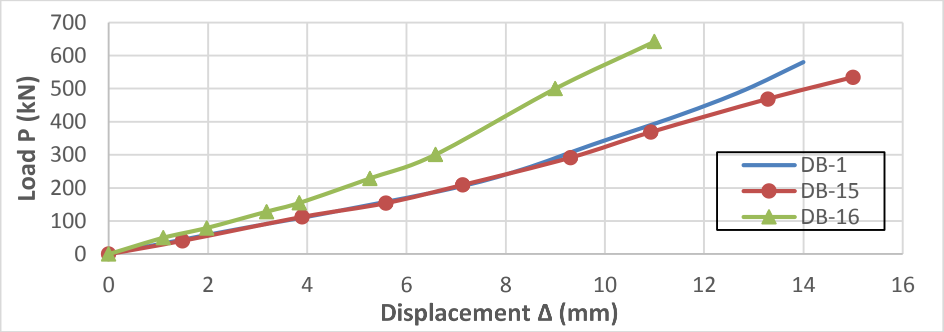


Figure (10): Load-midspan deflection for Group 5

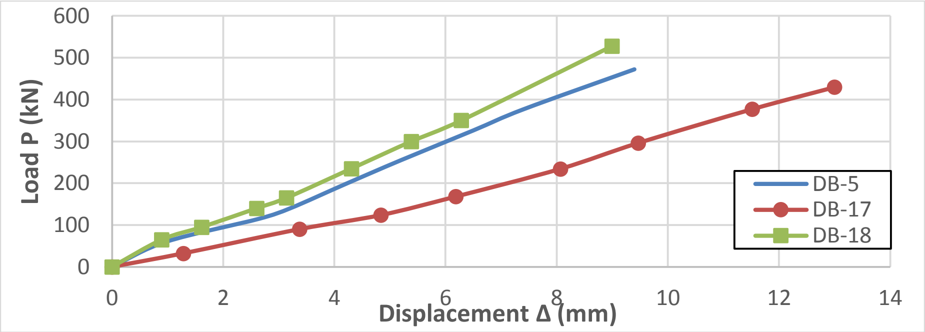


Figure (11): Load-midspan deflection for Group 6

## V. CONCLUSIONS

Based on the numerical study, following conclusions are arrived at.

1. The ultimate loads of deep beams with or without web openings increase when the *a/d* ratio decreases.
2. The concrete compressive strength significantly affects the capacity of SCC deep beams.
3. The increase in both longitudinal and transverse reinforcement ratios leads to an increase in the ultimate load of SCC deep beams
4. The circular openings make the less decrease in the ultimate capacity of solid deep when compared with rhombus, square, vertical rectangular and horizontal rectangular openings.
5. The decrease in the web openings size leads to increase the ultimate capacity of SCC deep beams.

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