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Research paper

Finite Element Modeling for Self-Compacting Reinforced Concrete Deep Beams Containing Web Openings

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Abstract

A nonlinear limited component display is utilized to approve the consequences of limited component investigation with that of test work got from written works with the end goal to foresee execution of self-compacted strengthened solid; profound pillars incorporate roundabout web openings. Six indistinguishable profound bars were considered for this reason; one of them was strong that considered as a control bar. ANSYS PC program was utilized to accomplish the investigation of these bars. Examination between the test and limited component strategy results shows a satisfactory understanding with the goal that the proposed model can be embraced in future for further investigations. The diagnostic tests which were improved the situation different cases considered showed that the heap redirection conduct and a definitive burdens are in great concurrence with the distributed library results. The outcomes demonstrate that most extreme contrast between the anticipated numerical extreme burdens to the trial extreme load for all cases was under (14%); while the greatest rate distinction for redirection esteems was about 11%. Likewise, the extent of the openings and its area influence the heap conveying limit of the shafts.

Keywords:*deep beams, Finite element methods, non linear analyses, Shear strength, web openings.*

1. Introduction

A profound pillar is characterized by the ACI 318M-14 code[1] as a part in which the reasonable range length (Ln) must not supersede multiple times the stature (h), or districts, with aggregated burdens lying at a separation not abrogate multiple times the height(measured from the essence of the help). In such shafts, extensive greatness of the connected burdens is frequently meant help by pressure push associated bolsters and the stacking focuses [2]. The basic twisting hypothesis of a straight line pressure dissemination is not any more material for profound shafts [3]. Because of the little estimation of range to profundity proportion, the quality of profound pillars is generally controlled by shear as opposed to flexural quality and As a result of this unique limit of profound bars in redistributing inside powers previously disappointment, the profound shafts shear quality is fundamentally more noteworthy than that of thin bars [4].

Due to the reason that of their extents, profound shafts are relied upon to be quality controlled by shear as opposed to flexure.

Rebared solid profound bars are comprehensively used as move supports in seaward structures, footings, fortifications' dividers and load-bearing dividers inside structures. Nearness of web openings, (for example, entryways and windows) in such shafts is ordinarily expected to supply straightforward entry; or to give fundamental administrations like ventilating, and channels of cooling [4,].The nearness of such openings may lessen the shear limit and that incited rendering a genuine security threat, especially when these openings arranged to meddle with the heap way. the mechanical conduct of profound shafts with web opening showcases astoundingly tangled stretch states because of shear pressure conveyance and stress fixation, along the edges of the opening[5].

Numerous looks into were found in the written works concentrated on the impact of web opening on the quality and splitting of profound beams[6, 7, 8, 9 and 10]. The factors considered in these explores were opening shapes and positions, the measure of steel fortification around the openings, a/d proportions, and the web steel proportion. The outcomes demonstrate that, on the off chance that the opening intruded on the heap way, the splitting and extreme load were fundamentally diminished.

The correct investigation of fortified solid profound shafts containing web openings presents impressive issues. Existing techniques for foreseeing extreme quality include either flexible hypothesis or semi-exact conditions, neither of which is totally worthy [11].It is notable that the limited component strategies yield reasonable and tasteful answers for nonlinear conduct of fortified solid structures. In this way, the present investigation planned to build up a basic limited component model to foresee the execution of strengthened solid profound bars with web opening under monotonic stacking condition. The approved limited component model might be embraced later by creators or different scientists to examine other contextual analyses where trial work is either impractical or exorbitant to execute.

2. Adopted experimental work (specimens details)

2.1. Properties of materials and specimen's configuration

Six simply supported deep beams had been chosen from the experimental work of Hasan [12] to examine the proposed finite element model. The span length of all deep beams was (1.4m), overall height (h=400 mm), and width of (b, =150mm). The effective depth was (350mm) with a/d ratio =1.0 (which fulfilled the definition of the ACI 318M-2014 [1]. Figure 1 shows thegeometry and detailing of specimens, while Table 1 summarizes the properties of the steel reinforcement. 3Φ16 mm deformed rebars were used for longitudinal tension reinforcements. On the other hand, the shear reinforcement was 4mm diameter deformed steel bars for both vertical and horizontal directions The Concrete compressive strength was 65 MPa.

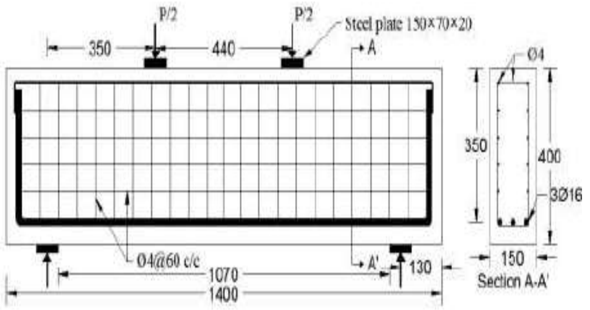


Fig. 1: geometry and detailing of a typical specimen [12].

Table 1: A property of steel reinforcing rebars

Reinforcing bar	Bar Dia. (mm)	Yield stress (fy)MPa	Ultimate strength (fu)MPa
Main reinforce-ment	16	593	676
Shear reinforce-ment	4	720	780

2.2 Web opening position details

Figure 2 and Table 2 illustrated the Details of the opening. In some beams, the openings are located at the critical positions (which could be defined as the path joining loading point and the support response points) while in the last two deep beams, the opening located to the top or bottom of the beams in order to investigate the influence of opening location on the shear capacity.

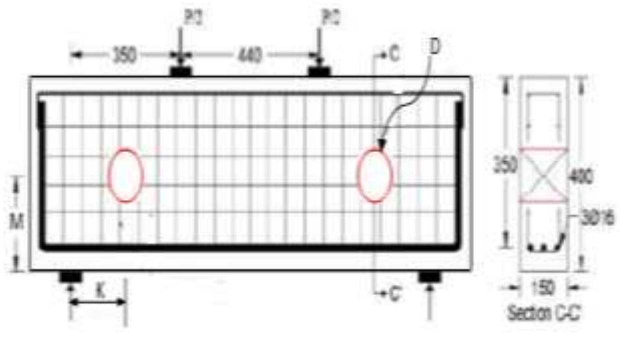


Fig.2: Arrangement and the position of web openings [12].

Table 2: Details of the web opening

Designation	D mm	K mm	M mm
DB-n	Control beam		
DB-75-OC	75	175	200
DB-110-OC	110	175	200
DB-160-OC	160	175	200
DB-160-OT	160	90	260
DB-160-OB	160	260	153

3. Finite element modeling

The chosen deep beams in the present work have been resolved or analyzed by a finite element model using ANSYS computer program. This model may help to confirm the theoretical calculations as well as to provide valuable supplement to the laboratory investigations. The advantage of geometrical symmetry was not utilized in the beam modeling in the present work because of the difference in modeling the two supports (one of them was assumed to be hinge and the other was roller).Also, Full bond between concrete and steel was assumed.

3.1 Elements for meshing

3.1.1 Concrete modeling

SOLID65 was utilized for the 3-D modeling of solids (with or without reinforcing steel rebars) (Figure 3a). The element is characterized by eight nodes comprise three degrees of freedom per node: translations in the nodal x, y, and,z, orientations.

3.1.2 Steelreinforcement bars

To model reinforcing steel bars, Link180 element was used to represent both, mains and shear reinforcement in vertical and horizontal directions. Discrete modeling is used by assuming a full-bonding between steel bars and concrete. Link180 element has two nodes and three degrees of freedom per each node which were matching to those of solid65 in having three degree of freedom per nod, (Figure 3b).

3.1.3 Steel plates

As in the actual beams, steel plates were added at support locations of the tested deep beams and under the two applied load points in the finite element models to provide stress distribution overthe support areas and prevent bearing failure of concrete. These plates are represented or modeled by using Soild185 finite element. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions (figure 3c).

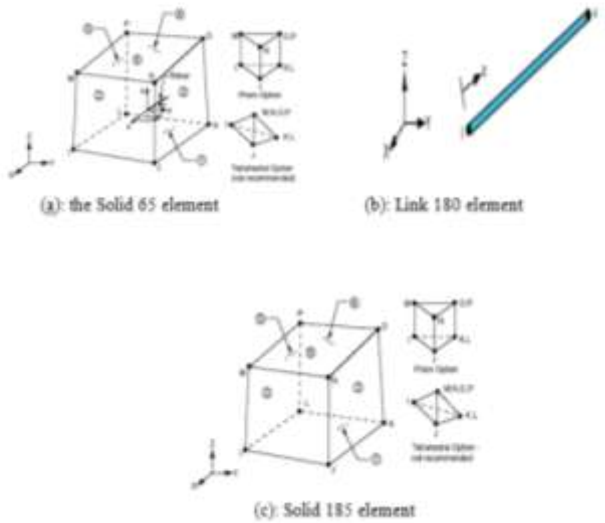


Fig.3: Elements used in the present study [13].

4. Material modeling

Table 3 illustrates numerical quantities for the elements utilized in the present ANSYS modeling and the parameters needed to define the properties of the used material. Poisson's ratio (ν) for concrete was assumed to be equal to 0.20. Material properties for Link180 had been assumed to be bilinear isotropic. Poisson's ratio was assumed to be equal to (0.3) for steel reinforcement. The elastic modulus of elasticity (E_c) of the specimens was measured in the experimental work according to ASTM C469/C469M-14[14].

Table 3: Material properties and elements used in the modeling

Material model No.	Element type	Material type	Material properties	
1	Solid 65	Concrete	Linear Isotropic EX: 35995 PRXY: .2	Concrete ShrCf-Op: 0.2 ShrCf-Cl: 0.8 UnTensSt: 6.9 UnCompSt: 65 BiCompSt: 0 HydroPrs: 0 UnTensSt: 0 TenCrFac: 0
2	Link 180	Main Reinforcing Steel rebars	Linear Isotropic EX: 200000 PRXY: 0.3	Bilinear Isotropic Yield stress: 593 Tang Mod: 0
3	Link 180	Shear Reinforcing rebars	Linear Isotropic EX: 200000 PRXY: 0.3	Bilinear Isotropic Yield stress: 720 Tang Mod: 0
4	Solid 185	Steel bearing plate	Linear Isotropic EX: 200000 PRXY: 0.3	

5. Geometry and load conditions,

Figure 4 shows the finite elements representation and the typical steel reinforcement for the model of the control deep beam (without opening) in the current work, while Figure 5 illustrated the finite element representation for the beams with opening. All of the elements were assigned the same mesh size to ensure that each two different materials share the same node.
Numerical model for the supports with boundary conditions is represented in figure 6. Hinge support has been simulated by individual line of nodes created on a steel plate which was located under the applied load points and supports zones. These nodes were constrained in UY, and UX orientations. In addition to that, the degrees of freedom in the UY were constraint to simulate the roller support.
The steel plates were made to provide a better distribution for the stresses in the applied load points and supports areas as mentioned in article (3-1-3) above. The smart method of meshing was used for meshing the entire entities of the model. Hexahedral element was used and by sweep method had been used with solid element. For steel bars modeling, cutting volume method was used to generate located lines in volume then pick that line to component manger list according to physical properties and recall it during meshing.

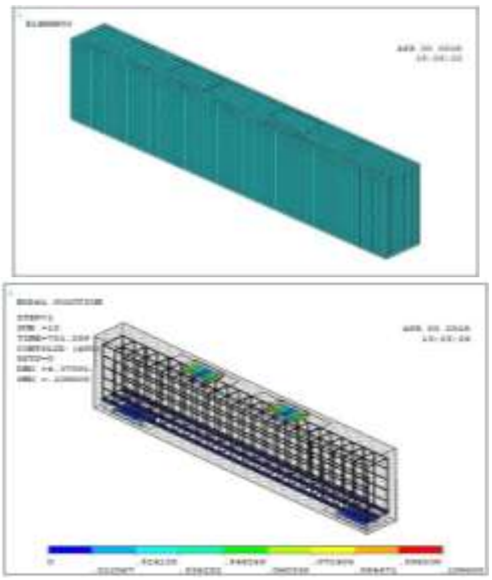


Fig.4: Finite element model representation for deep beam without opening

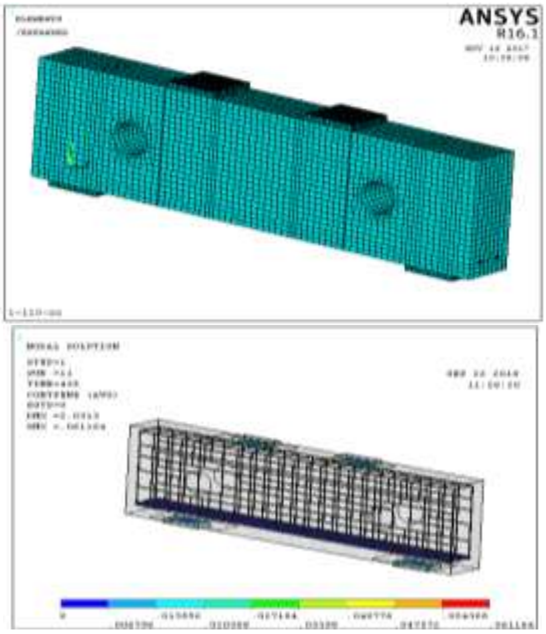


Fig.5: Finite element model representation for deep beam with opening.

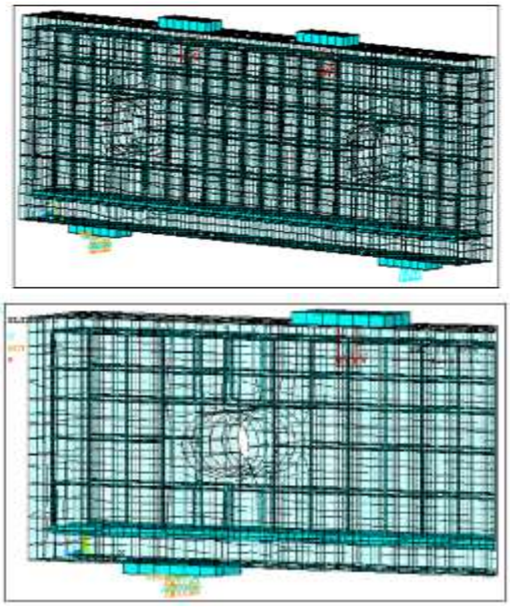


Fig.6: boundary conditions representation

6. Results and discussions.

The comparisons between the experimental and numerical results as well as the predicated behavior for the analyzed deep beams could be summarizes below:

6.1 Ultimate load capacity and deflections.

Table 4 shows the results of the comparative verification study of the central deflection at failure stage for all the analyzed deep beams in addition to the ultimate load results of the experimental work (Pu_{Exp}) and the finite element models results (Pu_{FEM}) as well, knowing that (a/d) for all beams was kept equal to 1.0. The results are sufficiently clear enough to reflect the appropriate conformity between analytical and experimental data. Maximum percentage difference between the experimental and numerical ultimate loads was about 14% while the maximum percentage difference for deflection values was about 11%. For more illustration, Results of (Table 4) are presented by bar charts as illustrated in

Figure7 for ultimate loads values and Figure 8 for Deflection values

Table 4: Comparison between the experimental and finite element analysis results

Beam Designation	Central Deflection at failure (mm)		% difference	Ultimate load (kN)		% difference
	(δv) FEM.	(δv) EXP.		(Pu) FEM	(Pu) Exp	
DB-n	5.9	6.4	8	810	870	7
DB-75-OC	3.8	4.1	7	435	410	6
DB-110-OC	3.5	4.2	2	475	410	14
DB-160-OC	3.1	2.9	6	275	290	5
DB-160-OT	4.2	4.4	5	593	580	2
DB-160-OB	4.3	4.8	11	595	620	4

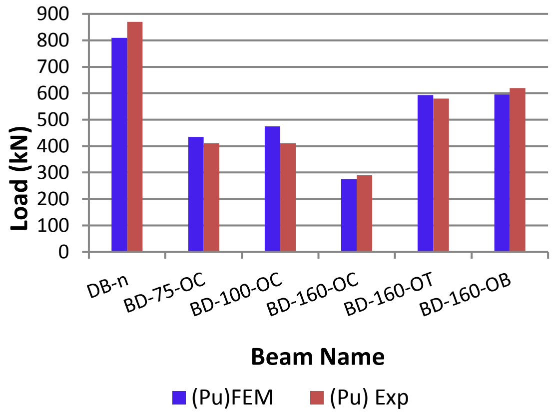


Fig.7: Comparison of ultimate loads values

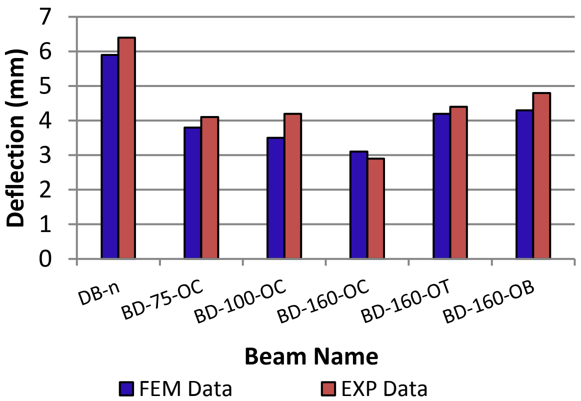


Fig. 8: Comparison Deflection values

6.2 Load -deflection curves

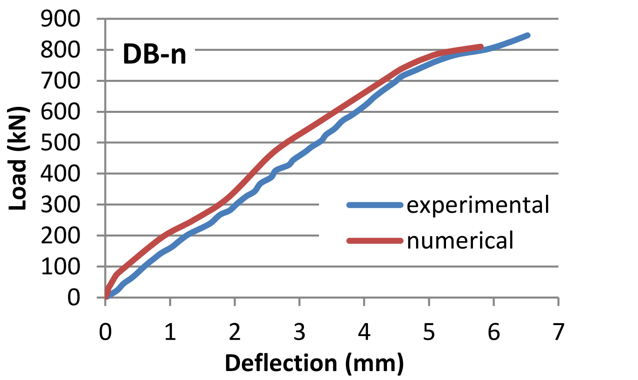
Load mid-span deflection curves of the numerical (FEM) model compared to experimental one for the tested specimens are displayed in figure 9. It could be noticed from that curves that the presences of web opening and its arrangement has an apparent influence on the beams load capacities and deflections. For an example, the presence of a 160 mm diameter opening in the mid-height of (DB-160-OC) beam (on the shear span zone) led to decrease the load capacity by about (5) % compare with the control one. Improved to the load carrying capacity was gained when the opening made to the bottom of the beam.It can be conclude by figure 9 and table 4 that, for all the tested beams, the increasing of opening size had not considerably effect on the values of deflection and ultimate loads. In addition to that, the effect of opening begins to decrease with the increasing of the opening size, this reflect the domination of shear failure of these deep beams. The deflection of (DB-160-OT and DB-160-OB) is somewhat larger than the deflection of (DB-160-OC) even when they all have the same size that could be due to the increasing the load capacity of the beams with top or bottom opening location and increasing the ability of the load path for transferring the applied loads to the supports when not interrupted.

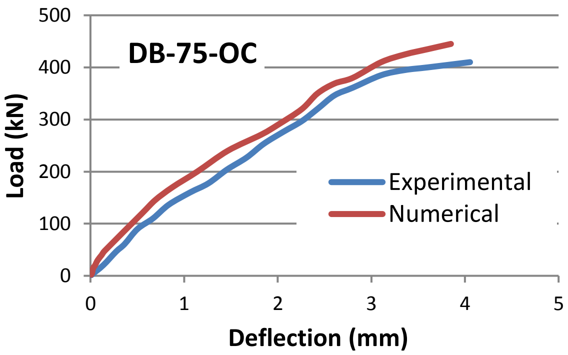
6.3 Failure modes

Figures (10-15) represent the experimental and predicted cracking patterns for the examined beams at failure stage. First of all, diagonal cracks at diagonal edges of the opening seemed at loads ranging from70 to150 kN (in almost all beams).As the applied load was increased, diagonal cracks were developed and propagated further (approximately analogous to the first ones). These diagonal cracks are effectively simulating the bottle shape of the strut region and they were of abets agreement with the experimental failure modes.

The width of shear and flexural cracks become more widening associated with the crashing of the concrete in compression zone at later stages of loading. The shape and values of deflections obtained using ANSYS are in acceptable agreement when compared to experimental outcome. It can be seen from figures (10-15) that the increasing of the opening size decrease the load capacity and increase the failure regions. All the beams were failed by splitting along the line joining bearing edges and the tangent of the openings

The percentage reduction in strength of beam 1-160-OT at failure was about 34% compared with the control one while this percent was about 28% for the beam DB-160-OB.This reduction was expected due to the negative influence to the opening located at the upper corner of the beam, while the opening positioned in the lower corner eliminated the concrete in the tension zone in which the concrete strength has no effect on the beam strength. The authors think that the optimal position for the opening is in the top corner of the beams so they do not affect the load capacity of the beams.





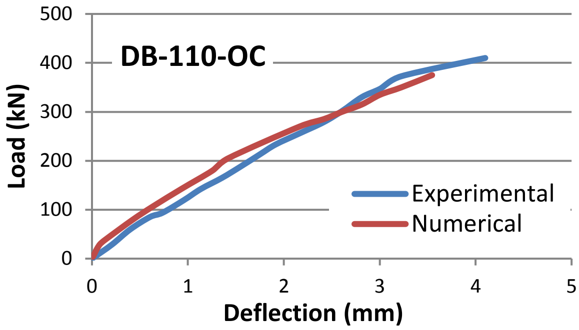
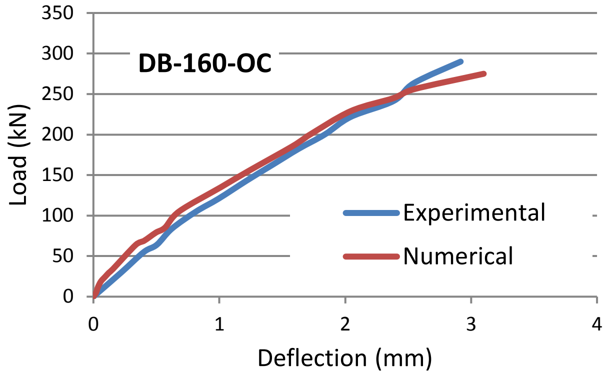
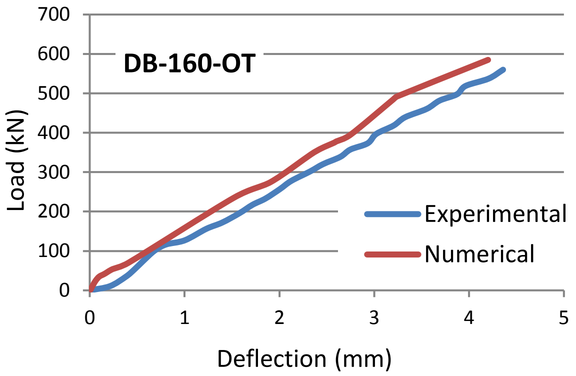


Fig.9: Load-midspan deflection relationships





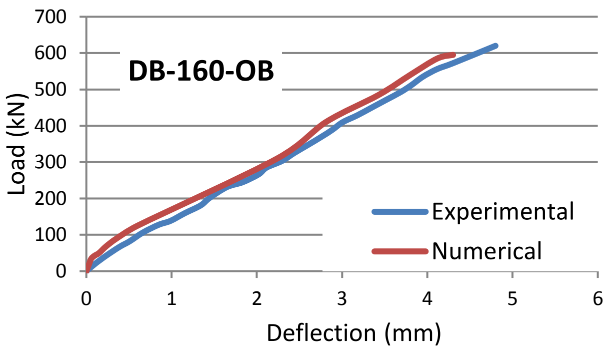


Fig.9:Continued

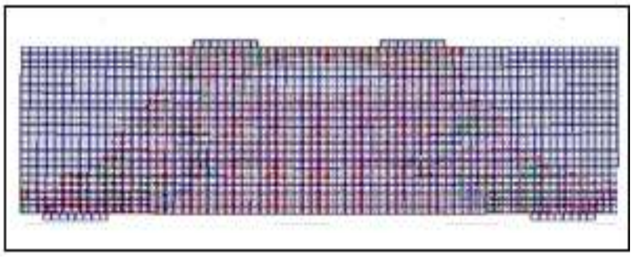


Figure 10: experimental and Numerical mode of failure of DB-n

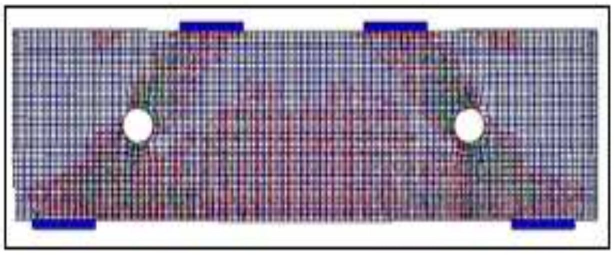


Fig.11: experimental and Numerical mode of failure of DB 75-OC.

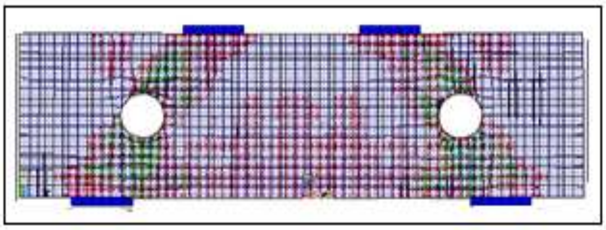


Fig12: experimental and Numerical mode of failure of DB 110-OC.

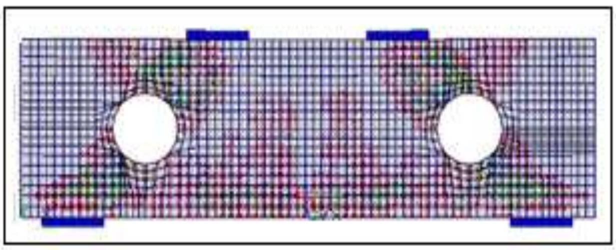


Fig13: experimental and Numerical mode of failure of DB 160-OC

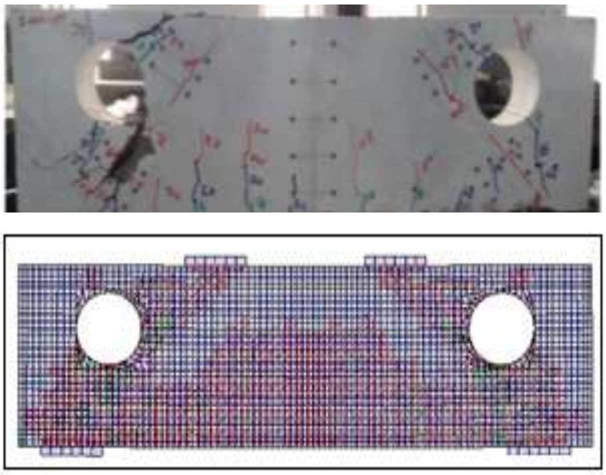


Fig14: experimental and Numerical mode of failure of DB 160-OT.

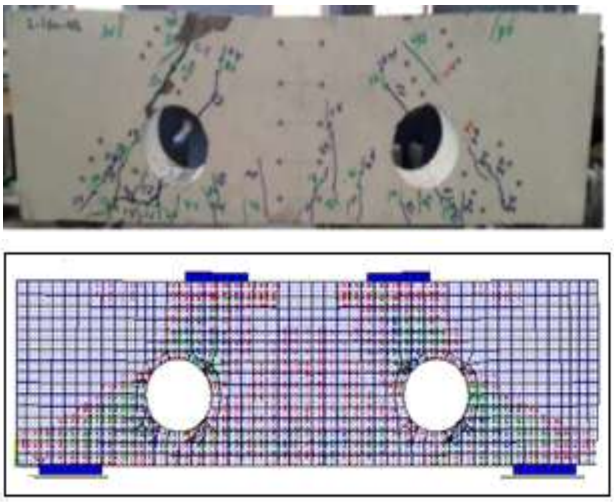
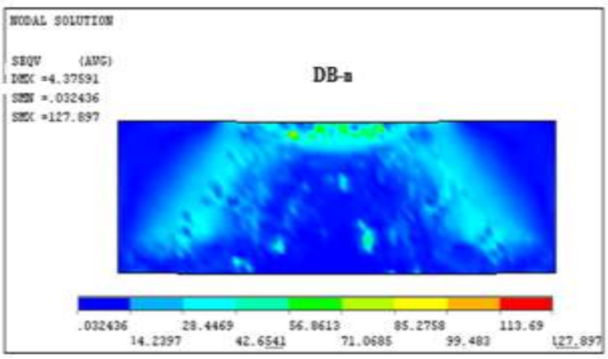


Fig15: experimental and Numerical mode of failure of DB 160-OB.

6-4 Distributions of stress

The good agreement obtained from the numerical analysis for the chosen deep beams with comparison to the same experimental one encouraged the use of the numerical analysis to study behaviors more than what were performed experimentally in this work. A numerical parametric study was done to demonstrate the stress distribution at ultimate (failure) load of the analyzed deep beams as illustrated in figure 16.

It is noticed from figure 16 that, the higher compressive stresses are located mostly over the line joining the load location and the support position, or what is known as strut-path. The strut-path could be obviously observed by this figure. Also, strains maximum values are again concentrated almost in the middle height of the beams which were satisfying the bottle shaped distribution. This behavior has similar trends to what expected in the behavior of the deep beams under the action of applied loads.



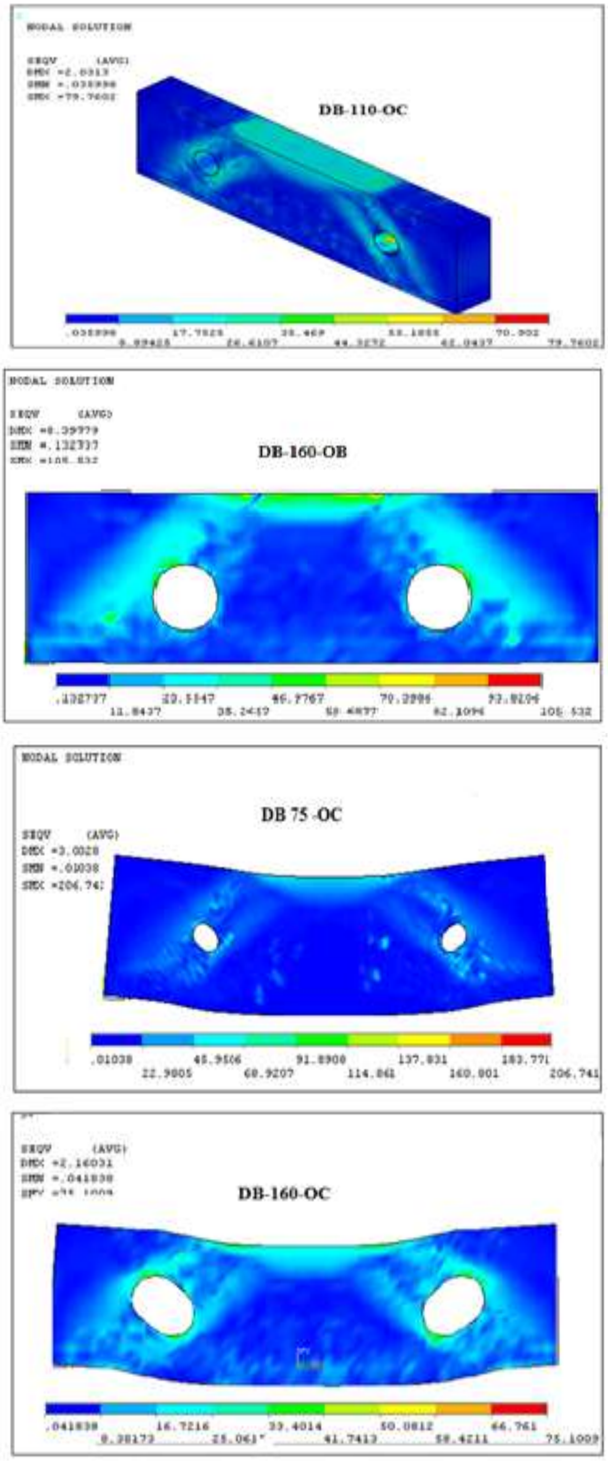


Fig16: the stress distribution at ultimate load

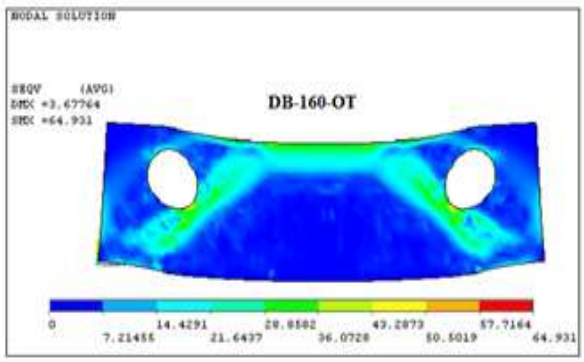


Fig16: Continued

7. Conclusions

The present examination expected to proposes a model to anticipate execution of profound bars with web opening. The impact of web opening size and area were explored. The accompanying end are drawn dependent on results examined in this paper

(1) The numerical model used as a piece of the present work can recreate the conduct of self-compacting profound shafts with web opening. The scientific tests which were improved the situation different cases examined showed that the heap redirection conduct and a definitive burdens are in great concurrence with the distributed libratory results. The greatest distinction between the anticipated numerical extreme burdens to the trial extreme load for all cases has estimation of (14%) and that was for DB-110-OC which has a 110mm width openings in the center tallness of the bar (along the swagger way).
(2) It was appeared from the outcomes that the measure of the openings influence the heap conveying limit of the shafts. For instance, the nearness of 75mm web opening in DB-75-OC had prompted diminish in the heap conveying limit by about 53% contrasted with the strong control one (BD-n), while the nearness of 160mm distance across opening in DB-160-OC prompted a reduction about 66% contrasted with the strong control.
(3) The rate decrease in quality of shaft 1-160-OT at disappointment was about 34% contrasted and the control one while this percent was about 28% for the bar DB-160-OB.This decrease was required because of the negative impact to the opening situated at the upper corner of the pillar, while the opening situated in the lower corner dispensed with the solid in the strain zone in which the solid quality has no impact on the bar quality.
(4) It can undoubtedly utilize the confirmed numerical model to evaluate the sum and dissemination of the extra support which could be put around the openings with the end goal to build the heap limit of such bars.

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