NUMERICAL ANALYSIS OF VOIED WIDE REINFORCED CONCRETE BEAMS USING STEEL PLATES FOR SHEAR REINFORCEMENT

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Abstract

The present paper intended to investigate the impact of the parametric study of wide reinforced concrete beams that used steel plates as shear reinforcement. The researcher used ANSYS software version 16.0 to analyse the flexural performance of the beam specimens. All the beams were 560 mm width and 215 mm height. The effective depth of the beam is 170 mm. These parameters included effect of concrete compressive strength, type of loading, shear span to effective depth ratio and thickness of steel plates. The selected values of compressive strength were 25 and 50 MPa with the experimental load deflection curves $f_c = 33$ Mpa. The values of shear span to effective depth ratio were 2 and 1.5 with the experimental value 3.53. The thickness of shear steel plates was 4 mm and 5 mm with the experimental thickness 3 mm. The obtained results of the present study have come conforming to the results of the experimental one. Increasing the concrete compressive strength, the ultimate load increases by 5.13%. Also state that ultimate load increase by 7.71% when applied two points loads on beams. The ultimate load of reinforced concrete beams with steel plates increased by 16.68% and 33.06% when $a/d$ decrease to 2 and 1.5 respectively. Also, the ultimate load increased by 3.67% and 10.24% when thickness of steel plates increased to 4 mm and 5 mm respectively.

Keywords : ANSYS, Parametric study, Reinforced concrete, Shear span, The shear steel plate, Wide beam.
1. Introduction
Recently, cross-sectional areas in structural framing systems the utilize of wide concrete beams was improved. This modification refers to the need for cheap keys that decrease building complexity and high structure, such as, new high-rises building engineers are regularly charged with carrying column loads in the pedestal or parking areas below the tower section over the column free spaces needed. Large beams may have adequate cross-section regions to reach the necessary capacity at a shallower depth than a network of narrower beams at parallel space in the tower, in addition to broad reinforced concrete links between column and beam. The experimental analysis has conducted in order to investigate the concrete strength and individual component members of different loading conditions. The actual structural behaviour has been provided in this method [1]. These structural components are often analysed using finite element method. FEM is a method used for the assessment of structures, providing an accurate prediction of the components subjected to different structural loads.

The simplest way to study concrete behaviour is to use FEM as it is cost effective and much easier than the experimental procedure. Modelling of the complicated behaviour of reinforced concrete beams using the FEM has become possible with the invention of sophisticated numerical tools for analysis such as FEM and it is a numerical analysis approach that divided the structural component into small pieces. Then simulates static charging conditions for concrete reaction evaluation. The enormous advancement of computer knowledge and engineering is due to the increase of using FEM. These method responses to the nonlinear analysis, as each component has specific behaviours of stress-strain. By using finite numbers of freedom degrees, the responses of each element expressed these degrees are characterized at a group of nodal points as the values of unknown functions [1].

2. Literature Review
A pilot study has conducted by Sherwood et al. [2] to examine the shear behaviour of thick boards and wide beams in addition to the effect of the width member. According to their investigation, they examined five samples of concrete wide beams of ordinary strength with a normally width of 470 mm. However, this varies in widths ranging between 250 to 3005 mm and a length of 2900 mm. On this basis, the research shows that all shear pressures resulting from wide beams and narrow beams are identical. Also showed that the member width was observed to have no significant effect on the shear stress at failure for one-way slabs and for wide beams. Further the presence of shrinkage and temperature reinforcement did not influence the one-way shear capacity.

According to the study of Lubell et al. [3] on the shear reinforcement spacing, it impacts on shear strength of reinforced concrete beams. Normal strength concrete was used to cast 13 samples with dimensions of 1170 mm width, 590 mm total height, and 4880 mm total length. The specimens were tested under three-point bending with a central span of 3700 mm giving a shear span-depth ratio a /d of approximately 3.65. A significant test component is the distribution of shear strengthening. The specimens constitute shear strengthening ratios near to minimal requirements ACI 318-11 [4]. It was found that; a reduction in the effect of shear reinforcement whereas at the same time there was an increase in the interspace of the web reinforcement legs that occurred throughout the member length.
little shear reinforcing leg even after extensively spaced up to a space of nearly 2d (d: spacing from the centre to the centre of stirrups), shows a decrease in the failure mode brittleness in relation to a geometrically identical member lacking a web reinforcement. To prove that the shear capability of all of the members with shear reinforcement were appropriate once of designing in step with ACI 318-11. The investigators prompted that the cross spacing of net reinforcement ought to be restricted to less depth of the particular member and together with 600 mm.

Hanafy et al. [5] present the test results of 12 concrete beam. All tested beams are 500 mm x 250 mm in cross section with 800 mm flange width along a length of 1100 mm cantered in span to ensure that shear failure would preclude flexural failure. All tested beams have 2000 mm clear span and the same flexural longitudinal top and bottom reinforcement (6T25+5T22 Bottom and 6T12 Top). The beams were simply supported and subjected to two concentrated static loads. The results plainly explain the crucial role of web reinforcement to improve the shear ability of wide beams elasticity that was compatible with the familiar standards and codes of universal.

Jamal Al et al. [6] presented the test results of four wide concrete beams in which their shear performances using gagger steel plates instead of stirrups was studied for the first time. The results showed that using steel plates had increased the shear capacity of wide beams significantly compared to using stirrups. An increase in load capacity was noticed. The load carrying capacity after the first shear crack became higher in comparison to beams using stirrups which show a gradual failure.

Ibrahim et al. [7] in 2015, in this study, shear behaviour of reinforced concrete wide beams was investigated experimentally. The experimental program consisted of four wide beams of 45 MPa concrete compressive strength tested with a shear span-depth ratio $a/d$ equal to 4.52. The study shows that the contribution of vertical steel plates to the shear capacity was significant and directly proportional to the existence and direction of the steel plates. The increase in the shear capacity ranged from 9.52% to 47.62% for the range of the tested beams compared with the control beam. Transverse vertical steel plates with voids were more effective in the contribution of the shear strength of wide beams and enhances the ductility of the wide beams.

Ibrahim et al. [8], this research was conducted to investigate the effect of using internal steel plates for shear reinforcement on flexural behaviour of SCC beams instead of using traditional reinforcement bars (stirrups) and to study the effect of their spacing and thickness on strength. The experimental work included destructive tests on six simply supported concrete beams with the same rectangular cross section of 0.3 m×0.2 m and the same overall length of 2 m were prepared. The beams were tested under two-point load where they were designed to fail in flexure.

In the current paper the numerical analysis of wide reinforced concrete beams with steel plates as shear reinforcement is conducted using the ANSYS program. The convergence as well as accuracy of the solutions depended on some elements like type of loading and compressive strength. So, the present study tries to analyse the wide reinforced concrete beams by conducting FEM. Specimens were specified in this side and taken from Mansoor [9].
3. Beam Geometry

According to a definition provided by Mansor [9] beam geometry was used for this study. The beam dimension and reinforced details are shown in Table 1 and Figs. 1 to 4. These beams having shear steel plate thickness of 3 mm. Table 2 shows the mechanical properties of steel plates provided by Mansor [9].

<table>
<thead>
<tr>
<th>Specimens</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B×H (mm)</td>
<td></td>
</tr>
<tr>
<td>As =2010 mm²</td>
<td></td>
</tr>
<tr>
<td>WBP3-1 560×215</td>
<td>Transverse plates with circle shape of voids and spacing 125 mm.</td>
</tr>
<tr>
<td>WBP3-2 560×215</td>
<td>Transverse plates with circle shape of voids and spacing 166 mm.</td>
</tr>
<tr>
<td>WBP3-3 560×215</td>
<td>Transverse plates with circle shape of voids and spacing 250 mm.</td>
</tr>
</tbody>
</table>

Fig. 1. Beam details.

Fig. 2. Section A-A of wide beam WBP3-1.
Fig. 3. Section A-A of wide beam WBP3-2.

Fig. 4. Section A-A of wide beam WBP3-3.

Table 2. Properties of plate.

<table>
<thead>
<tr>
<th>Nominal Thickness (mm)</th>
<th>Modules of Elasticity (GPa)</th>
<th>( f_y ) (MPa)</th>
<th>( f_u ) (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>193</td>
<td>210</td>
<td>300</td>
</tr>
<tr>
<td>4</td>
<td>193</td>
<td>240.5</td>
<td>345</td>
</tr>
<tr>
<td>5</td>
<td>193</td>
<td>400</td>
<td>580</td>
</tr>
</tbody>
</table>

4. Finite Element Modelling

4.1. Concrete

A brick element with eight nodes of the form SOLID65 was used to model concrete using the three-dimensional ANSYS. The SOLID65 is used with or without reinforcing bars for 3D solid modelling. Solid type element has been subjected to cracking due to tension and crushing due to compression making it more suitable for modelling concrete. The properties of the material and at each node including 8 nodes with 3 freedom degrees (translations of the nodes in three directions are x, y and z). Figure 5 displays the coordinate system for this element, the location of the
nodes and the geometry [10]. Concrete media volume meshing has been done
where a rectangular meshing was conducted by separating the volumes of the
concrete prism into tiny hexahedral brick components with an orthogonal side
dimension 25 mm.

![Fig. 5. Geometry of SOLID 65.](image)

For concrete, analysis system program needs input data for the material
properties. Which are ultimate uniaxial compressive strength, modulus of elasticity,
poison’s ratio, modulus of rupture, the coefficient of shear transfers for closed and
opened cracks and compression stress strain diagram for concrete. The concrete
properties as can be seen from Table 3. The modulus of elasticity and tensile
strength are based on the Eqs. (1) and (2) respectively [4].

\[
E_c = 4700\sqrt{f'c} \quad \text{MPa} \quad (1)
\]

\[
f_t = 0.62\sqrt{f'c} \quad \text{MPa} \quad (2)
\]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f'c$</td>
<td>Ultimate compressive strength (MPa)</td>
<td>36.6</td>
</tr>
<tr>
<td>$f_t$</td>
<td>Ultimate tensile strength (MPa)</td>
<td>3.75</td>
</tr>
<tr>
<td>$\beta_o$</td>
<td>Shear transfer coefficient for opened crack</td>
<td>0.55</td>
</tr>
<tr>
<td>$\beta_c$</td>
<td>Shear transfer coefficient for closed crack</td>
<td>0.6</td>
</tr>
<tr>
<td>$E_c$</td>
<td>Young’s modulus of elasticity (MPa)</td>
<td>28434.03</td>
</tr>
<tr>
<td>$\nu$</td>
<td>Poisson’s ratio (assumed value)</td>
<td>0.2</td>
</tr>
</tbody>
</table>

For the relationship of uniaxial stress strain to concrete in compression, the
research framework software asked for. To properly model the concrete,
multilinear and linear isotropic material characteristics are required for the element
of SOLID65. The condensed stress strain relation for concretes in compression is
obtained as shown in Fig. 6.

In uniaxial compression, Fig. 7 displays a typical uniaxial stress strain
behaviour of concrete. It is nearly linear up to 0.3 to 0.5 $f'c$. For the above stresses
of this point, the curve displays a gradual downward curvature up to 0.75 to 0.9 $f'c$
then the stress strain curve starts to lower at $f'c$ as far as failing happens because of
the concrete crushing at the ultimate strain [11].
Fig. 6. Stress strain relation model for concrete [11].

Through uniaxial tensile stress, the stress strain curves for concrete are almost straight up to about 0.6 $f_t$ at that point. The curve will generally diverge from straightness as long as micro crack propagation process in anticipation of the creation of continued cracking systems at stress peaks. That was accompanied by the development of variable micro crack systems that is speedily increased according to the tensile stress which took the materials to its post peak area [12]. Typical stress strain curve of concrete under uniaxial tensile stress as presented in Fig. 8.

Fig. 7. Typical uniaxial stress strain curve for concrete in compression [11].

Fig. 8. Typical uniaxial stress strain curve for concrete in tension [12].

4.2. Steel reinforcement

In this paper, LINK180 was used to represented longitudinal and shear reinforcement. The elements are described by two nodes with 3 degrees of translations. Nodes translations in three directions are $x$, $y$, and $z$. The nodes,
location, geometries and the coordinating system of these elements, which represented in Fig. 9 [10].

![Fig. 9. Geometry of LINK180 [10].](image)

The homogeneous material is in contrast to concrete steel and its strain stress behaviour can have similar tension and compression. Figure 10 displays typical stress strain curve for steel [13].

![Fig. 10. Typical stress strain curve for steel.](image)

Potential computational difficulties can occur when using programs. As a result, the relationship of alternative bilinear stress strain as shown in Fig. 11. Table 4 shows a list of steel reinforcement properties of ANSYS model. Steel reinforcement meshing has been done where a rectangular meshing was conducted by separating the steel reinforcement into tiny hexahedral brick components with an orthogonal side dimension 25 mm.

![Fig. 11. Idealization of computer calculations for steel.](image)
Table 4. Parameters and values of steel reinforcement.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_b$</td>
<td>Cross sectional area (mm$^2$)</td>
<td>Main reinforcement 202, Shear reinforcement 78.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$f_y$</td>
<td>Yield Tensile stress (MPa)</td>
<td>Main reinforcement 415, Shear reinforcement 397</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$E_s$</td>
<td>Modulus of elasticity (MPa)</td>
<td>Main reinforcement 200000, Shear reinforcement 200000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$E_t$</td>
<td>Steel hardening (MPa)</td>
<td>Main reinforcement 5000, Shear reinforcement 5000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\nu$</td>
<td>Poisson’s ratio (Assumed value)</td>
<td>Main reinforcement 0.3, Shear reinforcement 0.3</td>
</tr>
</tbody>
</table>

4.3. Web steel plate

In the ANSYS program the steel plates are represented by element SHELL281. There are 6 freedom degrees on the element at each node. The nodal rotations on x, y, and z-axes and the nodes translation in the following directions x, y, and z. SHELL281 is appropriate for nonlinear applications with linear, great rotation and/or great strain. The locations of nodes, geometry and system of coordinates for these elements that are presented in the Fig. 12 [10]. Steel plate meshing has been done where a rectangular meshing was conducted by separating the area of the steel plates into tiny hexahedral brick components with an orthogonal side dimension 25 mm.

![Fig. 12. Geometry of SHELL281.](image)

The steel plates thickness used in the research was 3 mm, 4 mm and 5 mm. Steel plate’s properties are shown in Table 5.

Table 5. Properties of shear steel plates.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T$</td>
<td>Thickness of SHELL281 (mm)</td>
<td>3, 4, 5</td>
</tr>
<tr>
<td>$f_y$</td>
<td>Yield tensile stress (MPa)</td>
<td>210, 240.5, 400</td>
</tr>
<tr>
<td>$E_s$</td>
<td>Modulus of elasticity (MPa)</td>
<td>200000</td>
</tr>
<tr>
<td>$E_t$</td>
<td>Steel hardening (MPa)</td>
<td>5000</td>
</tr>
<tr>
<td>$\nu$</td>
<td>Poisson’s ratio (assumed value)</td>
<td>0.3</td>
</tr>
</tbody>
</table>
4.4. Bearing steel plates

In the ANSYS system the bearing plates are represented by SOLID185 which was developed using eight nodes. That node has three freedom degrees, and the nodes are represented in the following directions x, y and z. In the finite element models steel plates used to support locations and loading points were added to produce more stress distributions. For the plates, Poisson ratio of 0.3 and corresponding elastic modulus of 200000 MPa are used. Steel plates should be linear, elastic materials. The geometry of this element is shown in Fig. 13 [7]

![Geometry of SOLID185](image_url)

**Fig. 13. Geometry of SOLID185.**

5. Boundary Conditions and Applied Load

Considering the conditions of the displacement limit to oblige the model serves to obtain a novel answer. Two basic beam supports were modelled by confining the centre node far from the edge of the beam for each bearing plate 100 mm. One as a roller $U_y=0$ and the other as a hinge $U_y=0$ and $U_z=0$ as shown in Fig. 14 dispensed over the width of the beam lowest surface. The load applied is split equally to two loads. Every load is applied at 725 mm from the respective beam fringe leaving a gap of 350 mm between them. Figure 14 shows how each charge is dispensed across the width of the beam’s highest surface on the centre nodes of the correspondent bearing plates.

![Boundary conditions and external loads](image_url)

**Fig. 14. Boundary conditions and external loads.**
6. Numerical Analysis
The numerical analysis attempts to examine the impact of parameters on the actions of reinforced concrete wide beam with shear reinforced steel plate. Parameters were concrete compressive strength, type of loading, shear span to effective depth ratio and shear steel plates thickness.

6.1. The concrete compressive strength effect
Two values of concrete compressive strength were used to study the influence on the behaviour of a wide reinforced concrete beam. The values selected were 25 and 50 MPa with the experimental $f'_c = 33$ MPa. Figures 15 to 17 display the impact of concrete compressive strength on the load deflection behaviour of the reinforced concrete wide beam with steel plates. Compared with Mansoor’s experimental results [9] the behaviour is slightly stiff. Figures 15 to 17 also display that ultimate load increases by 5.42 % with the increase of $f'_c$. Additionally, it seems obvious that increasing the concrete compressive strength leads to increasing the maximum predicated deflection.

Fig. 15. Effect of concrete compressive strength on the load deflection Behaviour of wide beam WBP3-1.

Fig. 16. Effect of concrete compressive strength on the load deflection behaviour of wide beam WBP3-2.
6.2. Effect of type loading

Two types of loading namely single concentrated load and two concentrated load to study the impact of it’s on the behaviour of a wide reinforced concrete beam. Figures 18 to 20 state the impact of type loading on the load deflection behaviour of the reinforced concrete wide beam with steel plates. Also state that ultimate load increase by 7.71% when applied two concreted loads on beams. This is because cracks started to appear and spread during loading as the load increased. It continued until plastic hinge formation where the stress intensified and increased to failure.

Fig. 17. Effect of concrete compressive strength on the load deflection behaviour of wide beam WBP3-3.

Fig. 18. Effect of loading type on the behaviour of wide beam WBP3-1.

Fig. 19. Effect of loading type on the behaviour of wide beam WBP3-2.
6.3. Effect of shear span to depth ratio

Various values of \( a/d \) ratio were used to study the influence of it’s on the behaviour of wide reinforced concrete beam. The values selected were 2 and 1.5 with the experimental \( a/d \) ratio 3.53. Figures 21 to 23 display the impact of shear span to depth ratio on the behaviour of the reinforced concrete wide beam with steel plates. Figures also display that the load carrying capacities of reinforced concrete beams with steel plates increased by 16.68% and 33.06%, when \( a/d \) decrease to ratio 2 and 1.5 respectively.
6.4. Effect of the steel plates' thickness

Various values of steel plate thickness were used to study the influence of it’s on the behaviour of wide reinforced concrete beam. The values selected were 4 mm and 5 mm with the experimental steel plates thickness of 3 mm. Figures 24 to 26 display the impact of shear steel plates thickness on the behaviour of the reinforced concrete wide beam with steel plates. Figures also display that the load carrying capacities of reinforced concrete beams with steel plates increased by 3.76% and 10.24% when thickness of steel plate increase to 4 mm and 5 mm respectively. This is because increasing thickness enhanced its shear strength contribution \((V_s)\). Consequently, the shear strength of steel and concrete \((V_s\) and \(V_c\)) is raised causing diagonal shear cracks formation at the outer parts of the beam, while stresses are transferred to the middle part.
7. Conclusion

Through the result obtained out of the numerical analysis of wide reinforced concrete beams using steel plates, the researchers have come up with the following conclusions:

- The models of finite element indicated by load-deflections curves at the central of span behave similarly to the experimental results. However, they are stiffer than the experimental test.
- The increasing in the concrete compressive strength, lead to increase in ultimate load by 5.13%.
- The ultimate load increase by 7.71% when applied two concreted loads on beams.
- The ultimate load of reinforced concrete beams with steel plates increased by 16.68% and 33.06% when a/d decrease to 2 and 1.5 respectively.
- The ultimate load increased by 3.67% and 10.24% when thickness of steel plates increased to 4 mm and 5 mm respectively.
Nomenclatures

\( A_s \)  Area of steel reinforcement, \( \text{mm}^2 \)
\( a \)  shear span, m
\( d \)  Effective depth of concrete beam, m
\( E_c \)  Modulus of elasticity of concrete, MPa
\( E_s \)  Modules of elasticity of steel, MPa
\( E_t \)  Steel hardening, MPa
\( f_c \)  Compressive strength of concrete, MPa
\( f_t \)  Uniaxial tensile strength of concrete, MPa
\( f_y \)  Yield stress, MPa
\( P_u \)  Ultimate load of the beam, kN
\( t \)  Thickness of shear steel plates, mm
\( U_x \)  Horizontal displacement in \( x \)-direction, mm
\( U_y \)  Deflection or vertical displacement, mm
\( U_z \)  Displacement in \( z \)-direction, mm
\( v \)  Poisson’s ratio
\( V_c \)  Shear in concrete, kN
\( V_s \)  Shear in steel, kN
\( x, y, z \)  Global coordinates system

Greek Symbols

\( \beta_0 \)  Shear transfer coefficients for an open crack
\( \beta_c \)  Shear transfer coefficients for a closed crack
\( \varepsilon \)  Strain
\( \sigma \)  Stress

Abbreviations

ACI  American Concrete Institute
ANSYS  Analysis System
FEM  Finite element method

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