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Enhancing the Structural Behavior of Wide Beams Through Reinforcement Schemes

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ABSTRACT

In this paper, numerical analysis of wide beams was presented. The proposed models were loaded with a static seismic load. Diverse models of reinforced concrete wide beams were studied numerically by ANSYS platform, and a parametric study was conducted. The studied parameters were web reinforcement percentage, tensile reinforcement percentage, and compressive reinforcement percentage. The values of tensile reinforcement percentage were (1.5%, 1%, 0.7%, 0.3%) of cross-section area, compressive reinforcement percentage were (0.8,0.6,0.5,0.4) of the tensile reinforcement ratio and web reinforcement percentage were (0.13%, 0.067%). The influence of these parameters was studied on ductility, dissipation, toughness, stiffness and over strength. The results demonstrated that the studied parameters affected all these properties, and the smallest ductility was noticed in the wide beam (B7) which has a value of 1.1.

1. Introduction

The width of R.C wide beams is bigger than that of the supporting columns, its structural behavior (shear and flexure) normally varies than that of the dropped beams. Stirrups configuration in R.C wide beams may influence its contribution to shear resistance as a ratio of the nominal shear stirrup strength. The deflection of the R.C wide beams is more than that of the dropped beams due to the variation of their inertia. Reinforced concrete structures with wide shallow beams supply various advantages and needs from construction and architectural points of view. A wide shallow beams system may decrease the amount of formwork through repetition and then the construction cost can be greatly decreased and the construction works can be simplified.

ACI-ASCE committee 352 [1] recommended that wide beam column connections not to be used when designing to afford seismic forces. The committee has suggested that such connections should be estimated experimentally so that the code provisions can be advanced for their use in seismic zones. Unlike to the committee 352 recommendations, the ACI Building code does allow the use of wide beam-column connections in seismic zones ACI Committee 318 [2]. On this code the width of wide beam should not exceed the column breadth plus 1.5 times the depth of the wide beam.

Some researchers examined Wide Beam-Column Connections Under Earthquake Form Loading, Gentry,T.R. and Wight,J.K [3] studied four specimens experimentally (exterior wide beam-column connections) and the influence the following parameter on this specimens, beam width to column width ratio b_w/b_c (2.43, 2.14, 2.43, 2.43), fraction of the longitudinal reinforcement anchored in the column core, the column moment to beam moment ratio Mr (1.46, 1.64, 1.5, 1.17) , f_{cu}=4000 psi, all steel f_y=60 for all specimens and stirrups f_y=48ksi and hook distance was increased beyond the ACI requirements of $6d_b$. Four specimens were tested in fixture with pin connections and the column exposed to a 20-kip axial compressive load to avoid tension in the column through testing. It was subjected to increasing cyclic displacements of 0.5% to 5% equivalent story drift. The behavior noted in the test specimens specified that exterior wide beam-column connections will be better if the transverse beam was not to a big extent cracked in torsion.

Recently, some researchers directed their efforts to study shear behavior of wide shallow beam. Ibrahim et el [4]

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studied four specimens experimentally. The dimensions of the specimens were width= 560 mm, depth= 215 mm, length= 1800 mm and shear span depth ratio a/d =4.52 these were reinforced with congruent longitudinal steel with ten bars of diameter= 16 mm. Specimen B4 reinforced with stirrups but other specimens no reinforced with stirrups. Specimen B1 includes a vertical solid steel plates on longitudinal, B2 includes a vertical steel plates with hollow on longitudinal and B3 includes a vertical steel plates with hollow on width of the beam. Steel plates with thickness = 4 mm, f_{cu}= 45 N/mm^2. Deformed steel bars were used in this work with diameters of (16mm) for longitudinal reinforcement in tension side with 100mm length hanging at both ends using 90° standard hook. While deformed steel bars (12mm) were used as web reinforcement in specimen B4. All specimens were tested using a hydraulic universal testing machine of (2000kN capacity) under monotonic loads up to ultimate load. Cracking behavior for all specimens, specimens were free of cracks in the early stages of loading. All specimens failed in shear and shear cracks traversed the compression region of specimen section. For specimens B1, B2 and B4, the shear cracks began without the occurrence of flexural cracks. For specimen B3, it was observed that the first early cracks were vertical flexural cracks and increasing the applied load, a series of flexural cracks were shaped at the bottom in the shear span zone and gradually spread toward the loading point while no crack had been observed at beam ends. The crushing of concrete in the strut region was caused by reaching the compressive stress in concrete to its ultimate value before yielding or rupturing these gagger plates were clear.

The objective of the study is to investigate the effect of different reinforcement configurations (web reinforcement, long reinforcement, compression reinforcement) on the reinforcement concrete wide beam structural behavior.

2. Verification

2.1 Specimens dimensions and material properties

A shallow beam from literature Tested by (Shuraim,2012) [7] was studied used numerical analysis via ANSYS software**.** Dimension of the tested beams were 700 mm, 3000 mm, 180 mm width, span, depth, respectively. The column cross section had dimensions B =140 mm, t =200 mm. Reinforced steel for beam (Compressive steel = 7ϕ14, Tensile steel = 7ϕ16, Horizontal transverse steel = 6ϕ12 @ 150mm,Stirrups of the beam = 9ϕ16/m) . The reinforcement steel for the column was (Longitudinal rebars = 8ϕ16, stirrup 1ϕ8 for four leg configurations as shown Fig (1). The material properties were, f_y = 580 MPa for longitudinal and horizontal transverse rebars of the beam, f_y = 465 MPa for stirrups of the beam. The concrete compressive strength was applied the load over the full-width of plates situated at the middle of each span. Each specimen was loaded with several load increments up to failure using displacement control scheme, as shown Fig (2). The wide beam of (Shuraim,2012) [7]) were modeled by using ANSYS platform as shown Fig (3) and compared results with experimental results.

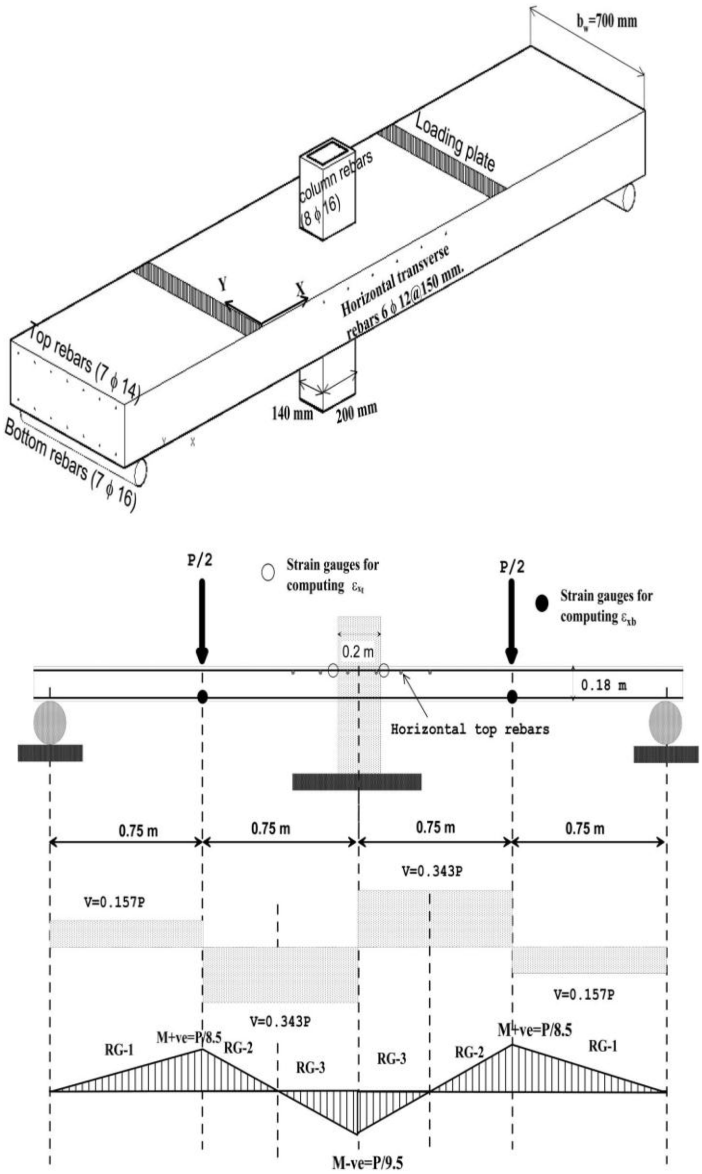

Fig (1) Details of tested beams (Shuraim,2012) [7].

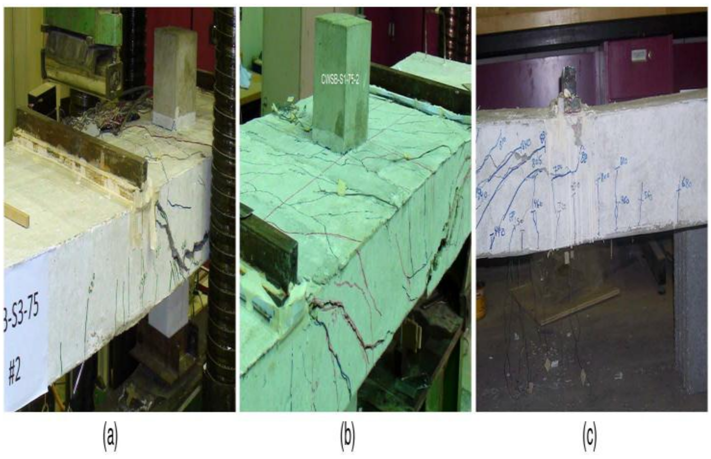

Fig (2) Test setup used by (Shuraim,2012) [7].

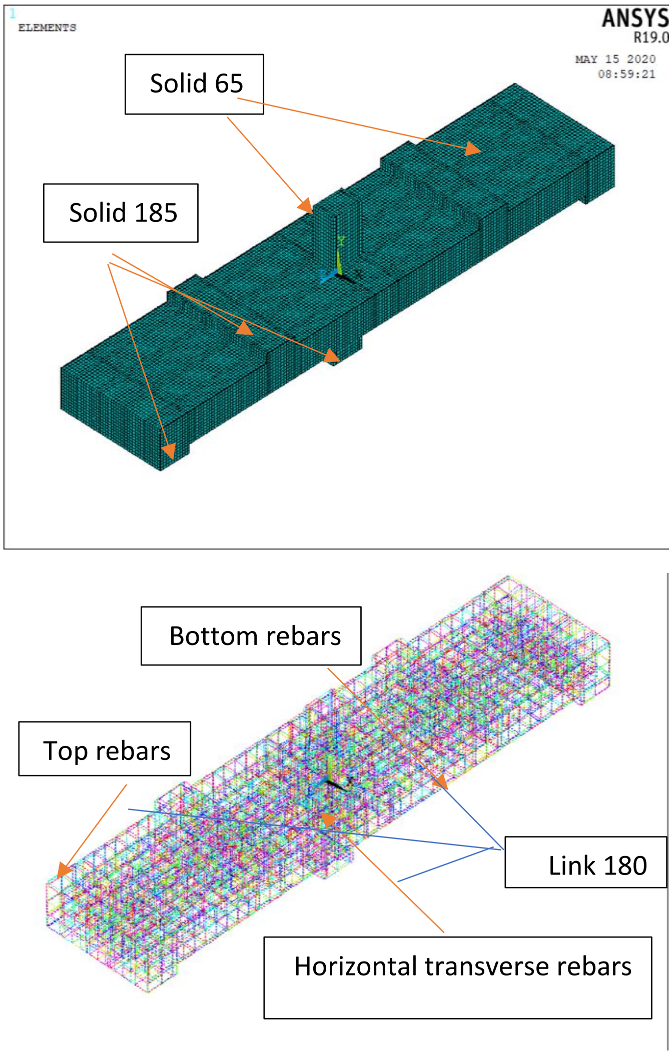

Fig (3) Finite element model details of studied beams

2.2 comparison between experimental and numerical program results

The results of proposed model were compared to experimental results carried out by (Shuraim,2012) [7].The comparison showed good agreement between the results. The comparison depended mainly on the ultimate load and failure pattern of the studied specimen. The finite element model showed a failure load of 830 kN which is about 92% of the experimental result recorded by (Shuraim,2012) [7],which was about 893 kN. The failure was noticed in both specimens near to the intermediate support as shown in Fig (4), at which the concrete reached its maximum stress value. The longitudinal steel reinforcement bars reached their yield stress value at the same position as shown in Fig (5). The deflection value was compared with that calculated manually and showed good agreement as well, as shown in Fig (6). The cracks shown in the proposed model agreement as well with the tested specimens, as shown in Fig (7) and (8).

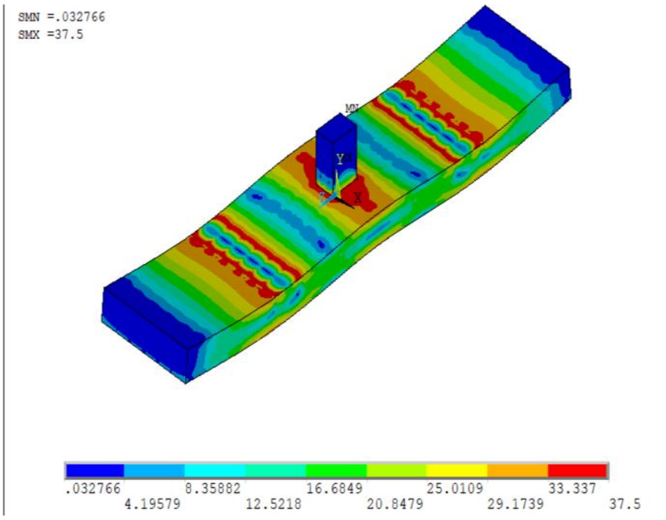

Fig (4) Stress in concrete

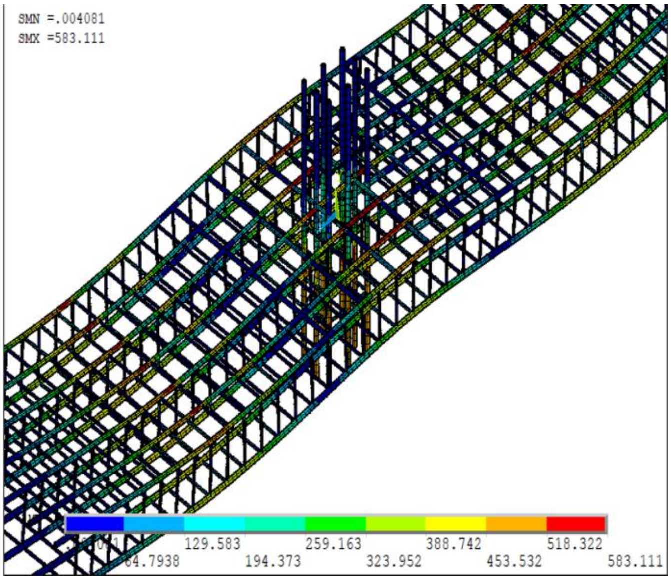

Fig (5) Stress in steel reinforcement

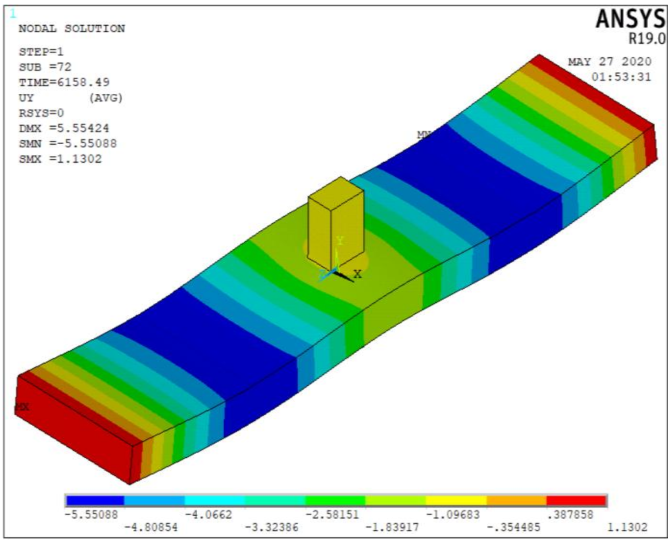

Fig (6) deflection of studied beam

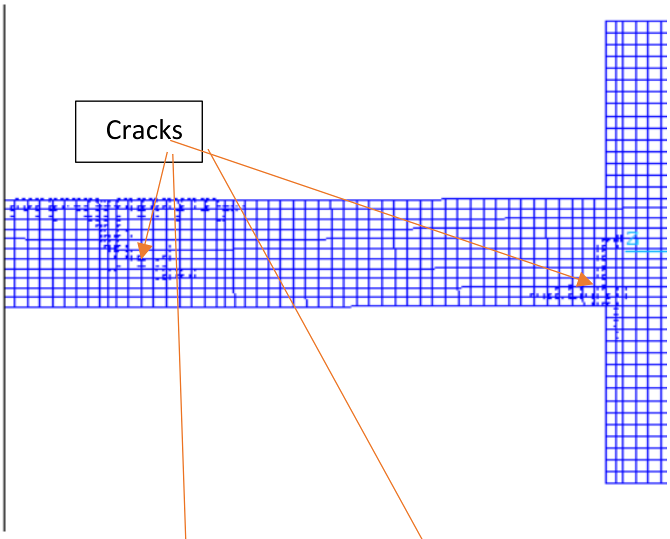

Fig (7) Crack pattern in finite element model

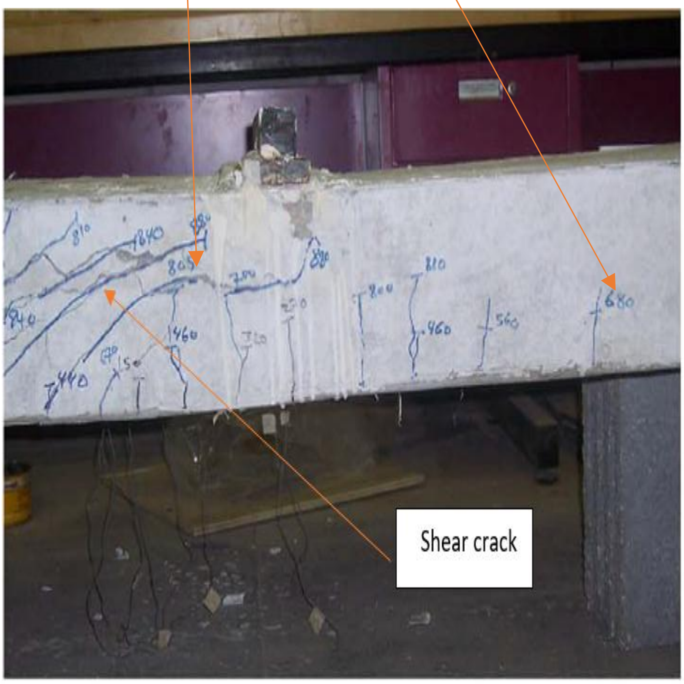

Fig (8) Cracks pattern for experimental from [7].

3. Numerical analysis (ANSYS)

3.1 Model Discretization

An eight-node solid element, Solid65, was used to model the concrete. The solid element has eight nodes with three degrees of freedom at each node – translations in the nodal x, y, and z directions. The element is able to plastic deformation, cracking in three perpendicular directions, and crushing. The beam and column are modeled using 3D solid 65 as illustrated Fig (9), A Link180 element was used to model the steel reinforcement. Two points are required for this element. Each point has three degrees of freedom, – translations in the nodal x, y, and z directions. Compressive, tensile steel, longitudinal steel column and stirrups was modeled using link 180 as shown Fig (10). In ANSYS the load can be applied in steps. Each load step is separated to load increments. The size of the load increments was chosen to achieve convergence and at the same time attains an adequate level of accuracy, the maximum chosen mesh dimension was 150 X 150 mm.

3.2 Details of models

The proposed specimens were large scale and represent columns connected to a wide beam at the middle. The dimension of proposed model were 1500mm, 300mm, 6000mm width, depth, span respectively and column cross sections = 500*500 mm, column height=1500mm, as illustrated Fig(11), f_y =360 N/mm^2 for Tensile, compressive steel, column longitudinal and stirrups, f_y =280 N/mm^2 for Stirrups of beam , f_{cu}=30 N/mm^2 for beams and f_{cu}=45N/mm^2 for column, Young's modulus of concrete was taken 2.9 X 10^4 MPa from the slope of the stress-strain curve Fig (12), the Poison's ratio was assumed 0.2. The variations in the studied models (B1 to B8) was in tensile reinforcement ratio (1.5%, 1%, 0.7%, 0.3%) of cross section area, compressive reinforcement percentage (0.8, 0.6, 0.5, 0.4) of tensile reinforcement ratio and web reinforcement ratio (0.13%, 0.067%) as illustrate in table 1. Diameter of longitudinal bars for column were 25 mm^2. The boundary conditions of the finite element models were shown in Fig (13). The supports were restrained in all directions (Z, X and Y). Horizontal force was applied at top of the column. The proposed models were loaded with a static seismic load The loading steps in the sub-steps should be very small to avoid converging problem.

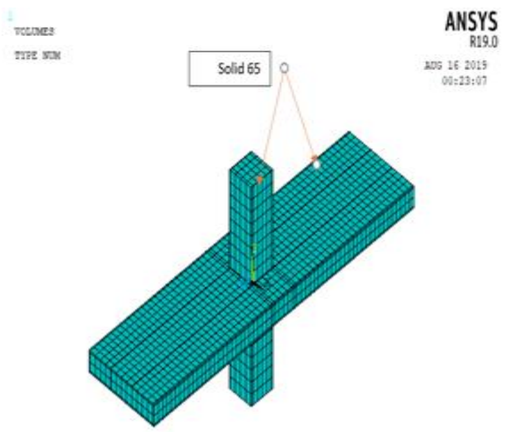

Fig (9) Modelling concrete

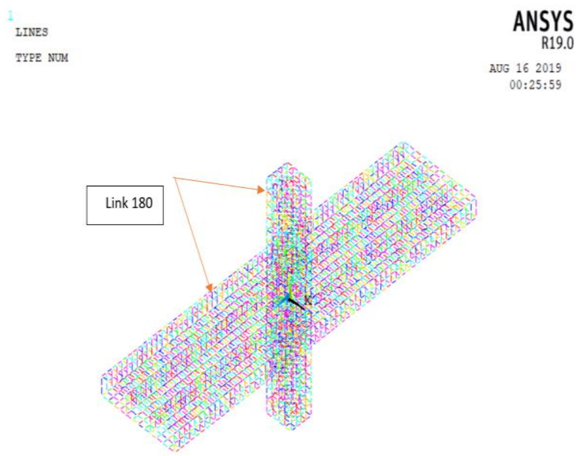

Fig (10) Modelling reinforcement steel

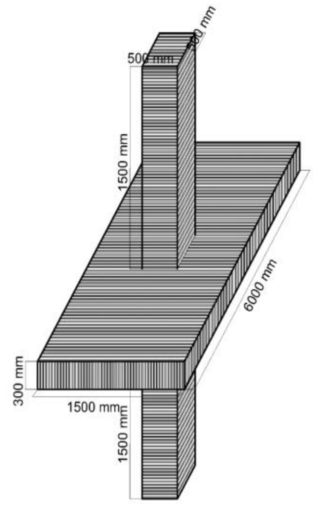

Fig (11) Beam and column Dimension

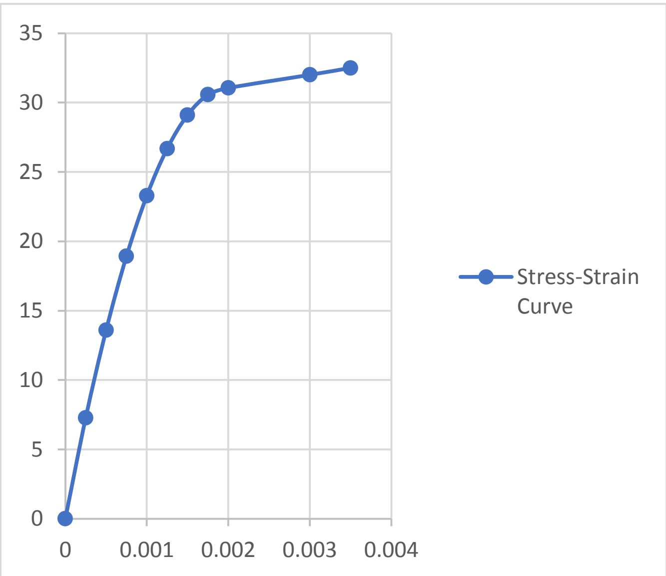

Fig (12) Stress-Strain Curve for Concrete

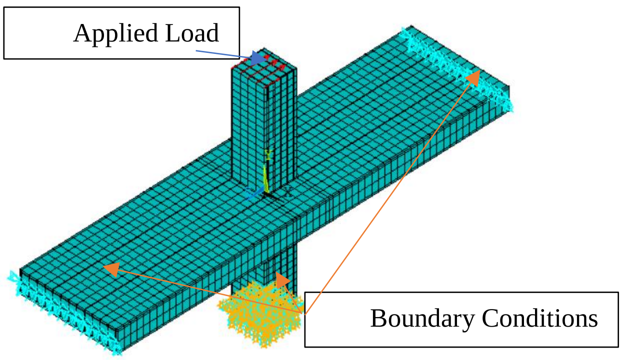

Fig (13) Applied loads and Boundary conditions.

Table 1: Reinforcement details of studied models

Beams	web reinforcement ratio	Tensile reinforcement ratio (As)	Compressive reinforcement ratio
B1	0.067	1.5% Ac	0.8As
B2	0.13	1.5% Ac	0.8As
B3	0.067	1.0% Ac	0.6As
B4	0.13	1.0% Ac	0.6As
B5	0.067	0.7% Ac	0.5As
B6	0.13	0.7% Ac	0.5As
B7	0.067	0.3% Ac	0.4As
B8	0.13	0.3% Ac	0.4As

4. Results

4.1 Force-Displacement Curve

The curves shown below illustrate the relationship between the force in y-direction and displacement in x-direction for eight wide shallow beams (B1, B2, B3, B4, B5, B6, B7, B8). Fig (14) shows a comparison between the load-deflection curves expected numerically for wide beam (B5) and wide beam(B6). The authors noted that wide beam (B5) collapsed at ultimate load 300kN before wide beam (B6) at ultimate load 400kN. The authors noted that wide beam (B7) collapsed at ultimate load 330kN before wide beam (B8) at ultimate load 340kN as shown Fig (15), wide beam (B1) at ultimate load 400 kN failed before wide beam(B2) at ultimate load 500 kN as shown Fig (16), wide beam (B3) at ultimate load 500 kN failed before wide beam(B4) at ultimate load 600 kN, displacement=1.1, 2.7, 1.8, 4, 1.5, 3, 3.5, 6.5 mm for B5, B6, B7, B8, B1, B2, B3, B4 respectively. The beams reinforced by five stirrups per meter collapsed before the beams reinforced by ten stirrups per meter, this may be due to the small number of stirrups per meter.

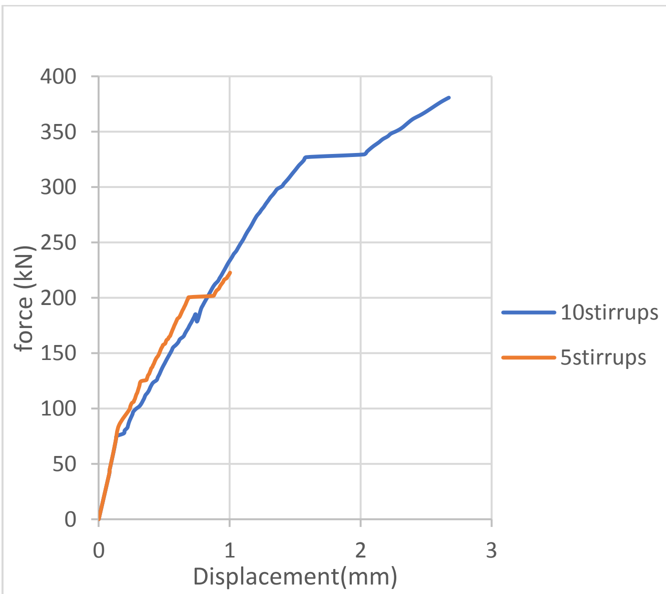

Fig (14) Load – Deflection relationships of B5, B6

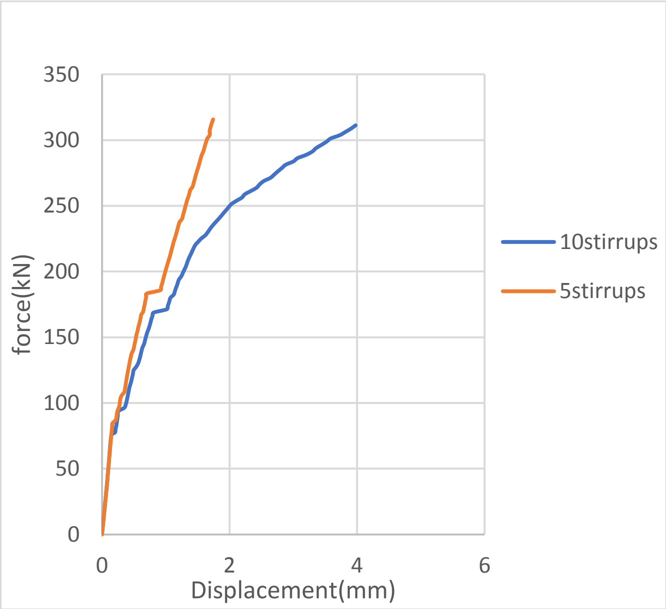

Fig (15) Load – Deflection relationships of B7, B8

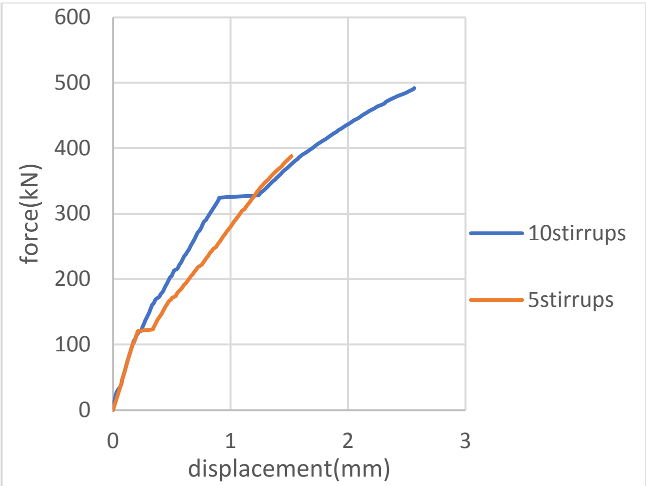

Fig (16) Load – Deflection relationships of B1, B2

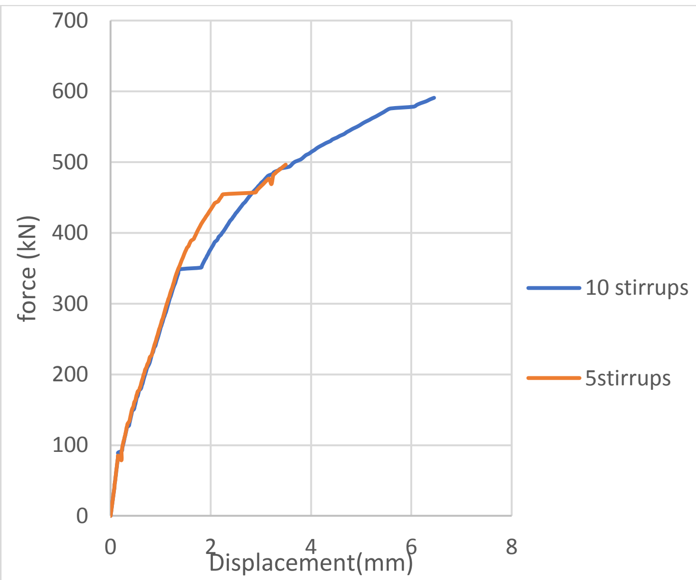

Fig (17) Load – Deflection relationships of B3, B4

4.2 Energy dissipation

Energy dissipation was the area under the (force-displacement) curve from force at yield to ultimate**.** Because the wide beam was composed of concrete and different reinforcing steel, its energy dissipation can be defined by the sum of the energy dissipation by concrete and reinforcing steel. Dissipation capacity available was largely dependent on the stiffness and strength degeneration that the beam-column connection undergoes as it experiences repeated cycles of inelastic deformation. One of the most important aspects of structural performance under static seismic loading was the capability of a structure to effectively dissipate energy. Fig (18) shown below the relationship between dissipation and percentage of steel. The highest dissipation was beam B4, lowest dissipation was beam B5. The authors noted that the dissipation of wide beam (B4) was higher than B1, B2, B3, B5, B6, B7, B8 by 97%, 75%, 97%, 99%, 86%, 99%, 70%, respectively because the displacement increased, the energy dissipated by static seismic load.

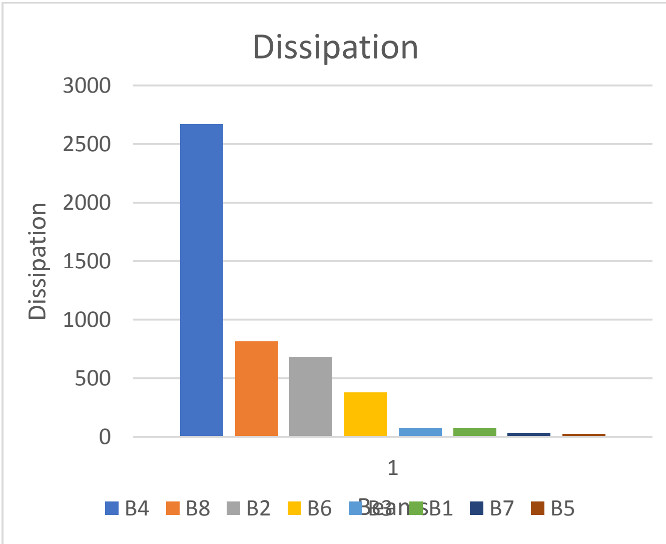

Fig (18) Dissipation verses percentage of steel

4.3 Failure mode

Table (2) show eight models, the strain of stirrup and steel of each model was obtained from ANSYS program and they were compared to yield strain to know the type of failure. The table illustrated two types of failures (ductile failure and shear failure).

Table ٢: Failure mode

model	Pu (kN)	μ bottom	μ top	μ V	£ yv	ductility	Failure mode
B1	388	1.5% Ac	0.8As	0.067%	0.0011	1.2	shear failure
B2	491.9	1.5% Ac	0.8As	0.13%	0.0014	3.3	Ductility failure
B4	590.9	1%Ac	0.6As	0.13%	0.0015	5	Ductility failure

B6	380.7	0.7% Ac	0.5As	0.13%	0.0014	1.6	Ductility failure
B8	311.3	0.3% Ac	0.4As	0.13%	0.0015	2.6	Ductility failure
B3	496.4	1%Ac	0.6As	0.067%	0.0013	1.1	shear failure
B5	286.4	0.7% Ac	0.5As	0.067%	0.0007	1.1	shear failure
B7	315.7	0.3% Ac	0.4As	0.067%	0.0001	1.1	shear failure

Where:

$£_y = 0.0014$
Ac=B*T B=1500 mm T=300 mm
As=µbottom *Ac, µbottom is the ratio of the reinforcement in the concrete section
µv = (n*A) \ (B*S), µv is percentage of stirrups per meter
n=no of branches
S= Distance between stirrups
A= area of bar
B=width of beam

4.4 *Over strength factor(Ω)*

Overstrength was ratio between yield-ultimate tangent stiffness to Initial stiffness. The authors noted that the highest over strength was wide beam with reinforcement 1% Ac in tensile and 0.6As in compression, ten stirrups per meter with value 5.6. The outhers noted that the beam B4 was higher than the B1, B2, B3, B5, B6, B7, B8 by 84% ,39%, 41%, 96%, 45%, 93%, 38% respectively. Fig (19) shown below the relationship between over strength and percentage of steel.

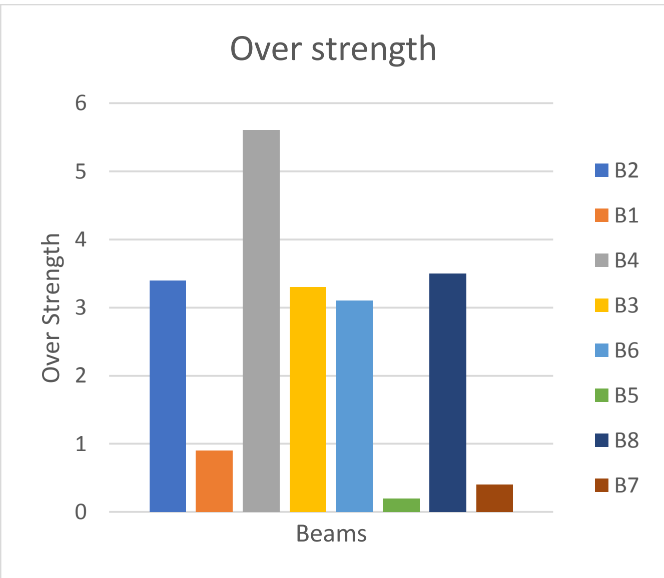

Fig (19) over strength

4.5 *Stiffness*

It was ability of the body to resist the deformation by an applied force. It was the ratio of yield force to the yield displacement. Fig (20) demonstrates the relationship between initial stiffness and percentage of steel for various specimens. The highest stiffness was beam B2, lowest stiffness was beam B3. The authors noted that the beam B2 was higher than the B1, B3, B4, B5, B6, B7, B8 by 27%, 58%, 25%, 40%, 43%, 52%, 52% respectively.

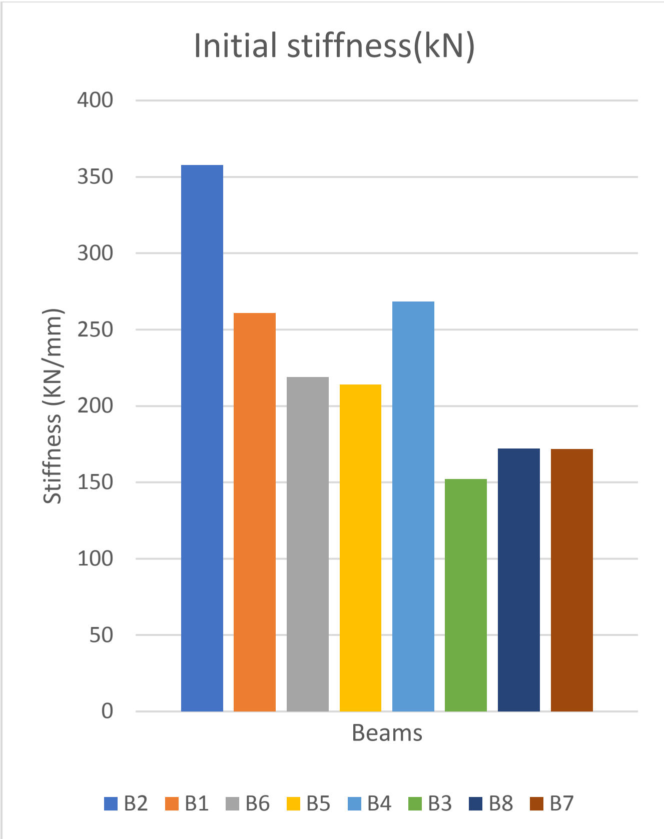

Fig (20) Stiffness

4.6 *Crack and crushing*

Fig (21, 22, 23,24) shown below cracks and crushing at ultimate load of various specimens. Cracks that happened in the following specimens were shear cracks which may be due to that the bent bars and stirrups were inadequate to withstand the shear force or the impact of loading on it was more than the load can be sustained by the flexure cracks were due to over Load or the reinforcement was not enough to resist the stress. Inclined cracks and vertical cracks represented shear cracks.

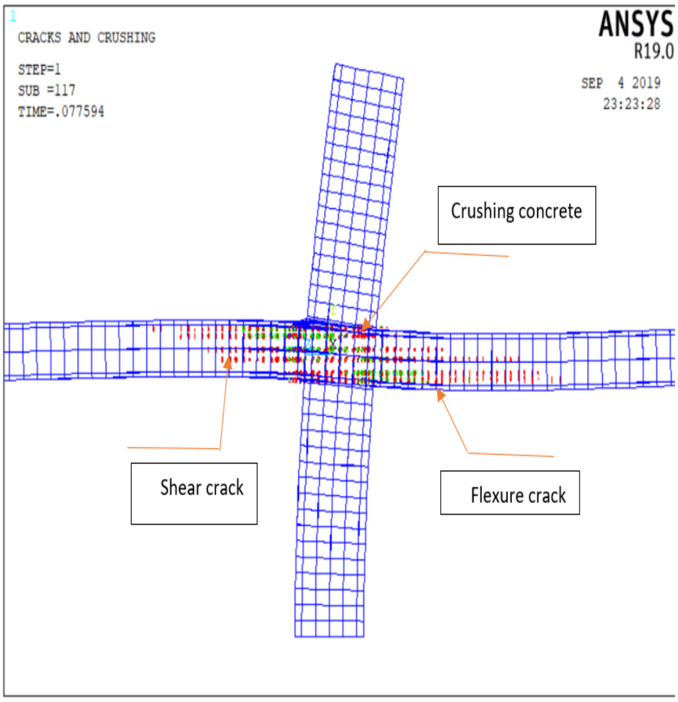

Fig (21) Cracks at Pu=400 kN for beam B1

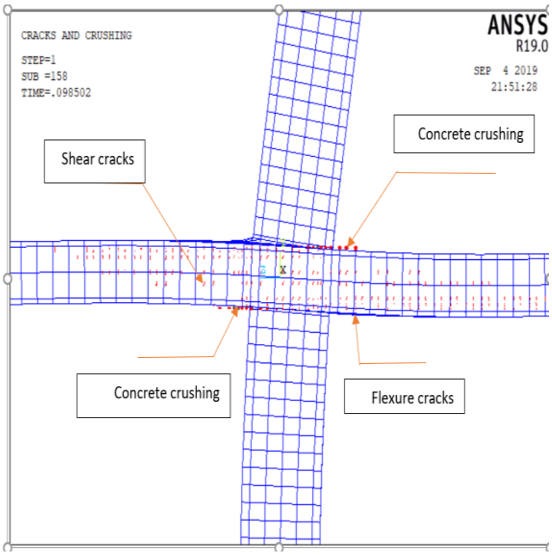

Fig (22) Cracks at Pu=500 kN for beam B2

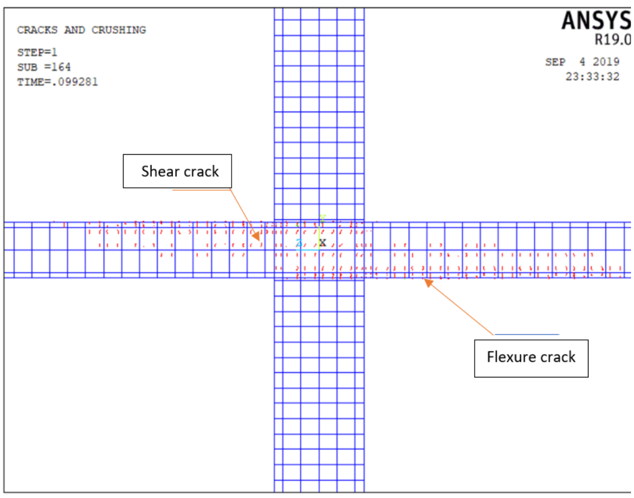

Fig (23) Cracks at Pu=500 kN for beam B3

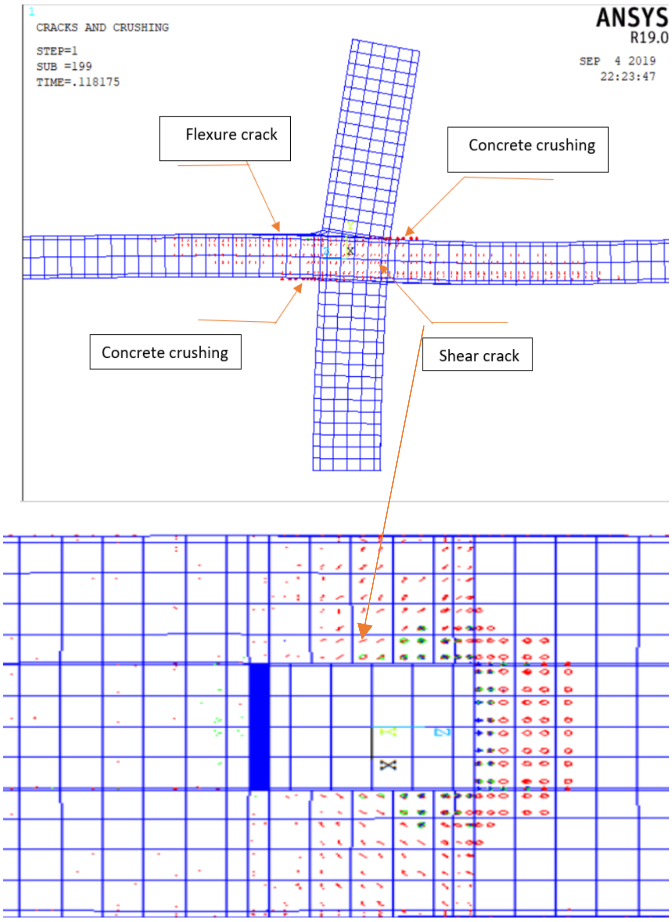

Fig (24) Cracks at Pu=600 kN for beam B4

5. Conclusion

1. The biggest dissipation occurred at beam (B4) with reinforcement (1.0% Ac, 0.6As, 10 stirrups per meter) and the smallest dissipation occurred at beam (B5) with reinforcement (0.7% Ac, 0.5As, 5 stirrups per meter).
2. Stiffness for beam B2 with reinforcement (1.5% Ac, 0.8As, 10 stirrups per meter) was the highest and the beam B3 with reinforcement (1.0% Ac, 0.6As, 5 stirrups per meter) was the lowest.
3. Overstrength for beam B2 with reinforcement (1.5% Ac, 0.8As, 10 stirrups per meter) is bigger than that the beam B1 with reinforcement (1.5% Ac, 0.8As, 5 stirrups per meter) which is about 74%.
4. The maximum deflection for wide beam B5 with reinforcement (0.7% Ac, 0.5As, 5 stirrups per meter) and wide beam B6 with reinforcement (0.7% Ac, 0.5As, 10 stirrups per meter) were 1.1 mm and 2.7 mm respectively.
5. The beam B4 with reinforcement (1.0% Ac, 0.6As, 10 stirrups per meter) is the best for ductility, toughness, Shear.

Reference:

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