Effect of axial stiffness and area of main tension reinforcement on behavior of deep beams

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***Abstract* - Strut-and-tie, modeling is one of the most important methods in analysis and design of structural concrete members which had discontinuity regions such as deep beams. Strut-and-tie models consist of struts and ties connected at nodes to form an idealized truss. When we design deep beams, the forces of truss shall be calculated, so we can also calculate the stresses in the different elements. The force of tie should not be exceeded 75 % of the force which can be carried by reinforcement before yielding occur. From this point, view increasing the area of tie reinforcement is assumed to have no effect on the beam as long as it is greater than once and a third the area in which the tie is needed. But increasing the area of reinforcement is followed by an increase in the local stiffness of tie, which in turn may reflect on the behavior of the deep beam. Eight beams were analyzed Numerically by using associated program to know the effect of increasing the rigidity of tie area on the behavior of struts in deep beams. Moreover, a new technique has been proposed to strengthen the beams to reduce the stresses in struts. It was concluded that using a tie with high axial stiffness has a significant effect on the induced of stresses and strains through the struts and tie.**

***keywords* - Deep beams, strengthening, local stiffness , strut, main steel ratio.**

I. INTRODUCTION

A deep beam is a member whose behavior is dominated by shear deformations. It will happen when span length-to-depth ratio is less than from two to four. In practice, engineers typically encounter deep beams when designing transfer girders, pile-supported foundations, or bridge bents. During the past fifty years, considerable research efforts have been directed towards obtaining a better understanding of the behavior and strength of reinforced concrete deep beams. Based on this research, the Strut and tie model was chosen to be used method for the design of deep concrete beams that's been for the last thirty years. Strut-and-tie models consist of struts and ties connected at nodes to form an idealized truss. struts are the compression members, ties are the tension members, and nodes are the joints. To design deep beams, you have to imagine a truss to transfer loads from their points of load effect to reach the supports then calculate forces in each member and finely determining the reinforcement based on the forces in ties after using strength reduction factors ϕ and check the dimension of concrete for struts and nodes.

Kong et al.[1] [2] studied the effect of steel ratio and a/d ratio on the ultimate shear strength of HSC deep beams. They studied Twenty-two reinforced concrete deep beams with cylinder compressive strengths f_c' generally exceeding 55 MPa (8000 psi) which were tested under two-point symmetric top loading. Based on the main steel ratio ρ_w, the beams were organized into four groups with ρ_w = 2.00, 2.58, 4.08, and 5.80 percent. Web reinforcement comprising 10 mm (0.4 in.) diameter plain mild steel stirrups at 300 mm (11.7 in.) centers were provided for all specimens, giving a vertical web steel ratio ρ_v of 0.48 percent. The beams were tested for different shear span-to-overall-height ratios a/h, ranging from 0.25 to 2.50 (equivalent to a/d from 0.28 to 3.14). The comparisons among the series serve to highlight the influence of ρ_w and a/h ratio on the shear behavior of high-strength concrete deep and short beams. It was shown that the a/ h ratio (or equivalent a/d) dominates the failure modes while the beneficial effect of ρ_w is more significant at the low value of a/d, say for $a/d \leq 1.50$. With $a/d > 1.50$, the influence of the main steel ratio declines, except for the particularly high value of 5.80 percent, where the relative increase in shear strength due to main steel remains constantly high, regardless of a/d. The test results are then compared with predictions based on the current ACI Code, the Canadian Code, and the UK CIRIA Guide-2. It was shown that the ACI predictions are generally conservative, with the smallest standard deviation, though with $a/d > 1.50$, a few cases are overestimated. The predictions from the Canadian Code are comparatively good, but the UK CIRIA Guide-2 estimations are generally conservative, with the greatest scatter. The study shows that the CIRIA Guide-2 predictions may be conservative for specimens with $f_c' \geq 55$ MPa (8000 psi) and with $\rho_w \geq 2.58$ percent.

Mitra Noghreh Khaja and Edward G. Sherwood.[3] reported that investigate the difficulties posed by this lack of a rational assumption for shear design by studying the effect that both the reinforcement ratio and the span-to-depth ratio, a/d, have on shear behavior of RC beams and one-way slabs reinforced with FRP rebars. Whereas the effect that has on shear strength has been widely studied (for both FRP- and steel-reinforced concrete), such is not the case for the effect of a/d on the shear strength. Of particular interest is the interacting effects that and a/d have on shear strength because the experiments described herein will shed light on the question of whether the shear strength of RC members depends merely on the quantity of flexural reinforcement or rather the strain in that reinforcement, which is a function of both and a/d. The benefits of basing shear design methods on a rational theoretical framework will also be investigated.

Finally we can concluded that the area steel ratio had an effect on shear strength of RC deep beams but the question remains whether to change the number of rows , diameter and shape of the steel for the same area steel will have an impact on behavior of deep beams this is what we will try to explain during this article.

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II. VERIFICATION OF MODELING BY FINITE ELEMENT COMPUTER PROGRAM

The aim of simulating the finite element model is to make sure that the suggested type of elements, properties of material, real constants, and criteria of convergence are enough to make the behavior of the model like the real beam. To make the verification of the model, a beam with cross section 150 x 700 mm and length of 1600 mm was made in laboratory of reinforcement concrete at Assiut university. The beam was designed according to ACI code. The beam was simply supported over a span of 1300 mm and loaded by two concentrated loads. The spacing between the load and support is equal to 350 mm {a/d = 0.54} where a/d ratio is shear span to beam depth ratio. The shape of the truss was Supposed as a trapezoidal truss and the maximum forces values in the struts were calculated based on the inclination and the dimensions of the struts and concrete strength. Then the maximum load witch the beam can carried and the force of tie were calculated. Based on the force of tie the longitudinal reinforcement of the beam was chosen to be three bars with 18 mm. diameter. The minimum web reinforcement was chosen as stirrups with 10 mm. diameter and longitudinal bars with 10 mm. diameter with spacing 125 mm. in each beam side in two directions. Fig. (1), shows the geometry, reinforcement details, and loading of the analyzed beam. The steel had an average yield stress of 490 MPa , and the concrete had an average compressive strength of 42 MPa. The strength was determined by testing concrete cubes of dimension 150 mm x 150 mm x 150 mm made in laboratory. The maximum size of coarse aggregate was 20 mm. At age of 28 days the beam was tested under loads up to failure and the obtained results were recorded.

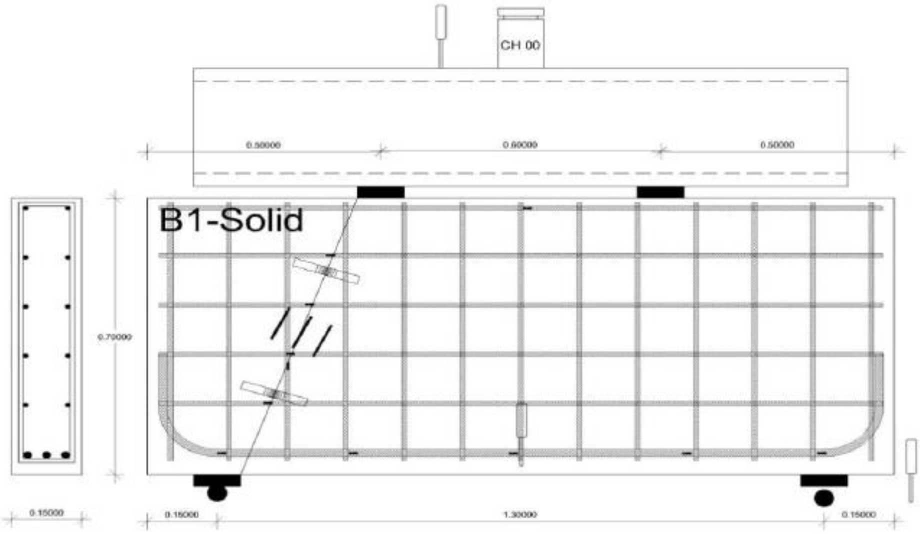

Figure (1) Geometry, Loading, and Reinforcement of Beam (B1) Tested in laboratory

Finite element model by associated program were set up by choosing solid element to represent concrete and link element to represent steel. Properties have been introduced for each material as well as dimensions. After the model was processed, a meshing was made to fit max. nominal size of aggregate. The type of supports and loads were chosen and applied to the model. The load with med span deflection curve obtained from finite element model with the experimental plots are presented and compared in Fig.

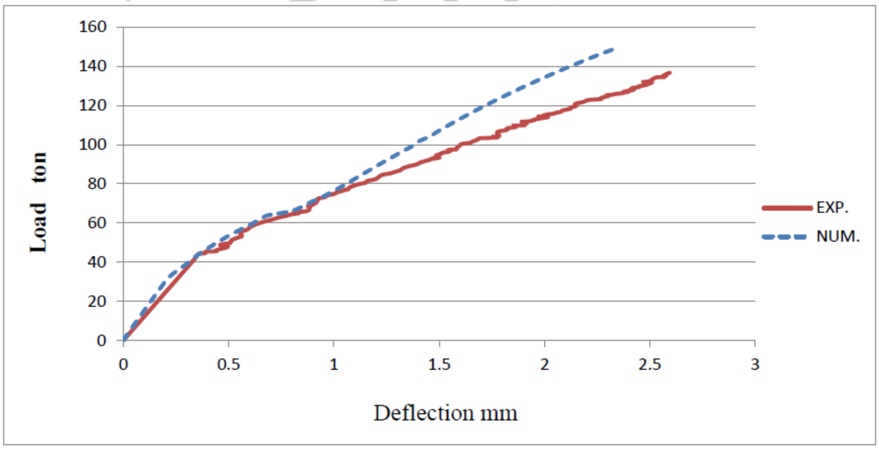

Figure (2) Load deflection curve for numerical and excremental beam

From the Fig. it can be noted that the numerical model give a good agreement with experimental beam. The two experimental and theoretical curves were identical and coincident at first part of loading up to 50% of the failure load, after that the experiment loads were somewhat smaller that the corresponding theoretical ones. This difference is the result of the treatment of concrete on the program as a single material and has certain properties and carrying capacity, but in fact the concrete consist of small particles of cement ,sand and gravel linked to each other. It is noticeable that the result of this difference occurred a slight increase in the stiffness and in the maximum load of the theoretical beam..

III. Numerical study and program

To study the effect of increasing the steel ratio on behavior of simply supported deep beam a program of eight beams has been developed. The associated program had been used to analyze the beams. Solid 65, link 8 and solid 45 elements were selected to represent concrete, steel and steel plate respectively. the properties of concrete were defined as Ec=27800 Mpa , Fcu= 43 Mpa , Fctr= 3.66 Mpa and the open & close coefficient were taken 0.3 , 0.5 respectively. The stress strain curve was expressed by equation number (1)

$$f_c = f_c' \left[\frac{2\varepsilon_c}{\varepsilon_{co}} - \left(\frac{\varepsilon_c}{\varepsilon_{co}} \right)^2 \right] \qquad \text{N/mm2} \qquad (1)$$

where fc = concrete compressive stress, f'c = concrete compressive trength, εc = concrete strain, εco = concrete strain. Fig. (3), shows the relation between stress and strain which describing the behavior of concrete.

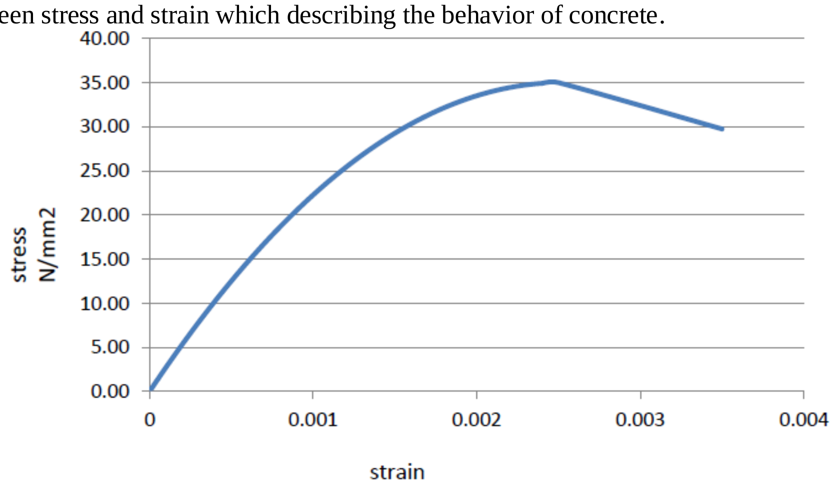

Figure (3) stress strain curve for concrete modeling

The modulus of elasticity of steel defined as Es=2000000 Mpa ,poison's ratio 0.3 and yielding stress 490Mpa. All beams had dimension 150*700*1600 mm the model was built for the entire sample. The beams was simply supported over span 1300 mm and curry two concentrated loads. The distance between them 600 mm. distance between load & support "a" = 350 mm and depth "d" = 650mm such that a/d ratio = 0.54 approximately. For all beams the used minimum web reinforcement consist of vertical stirrups with diameter 10 mm & spacing 125 mm and horizontal longitudinal bars with diameter 10 mm & spacing 125 mm. . Meshing was applied on all element to connect them together. Fig. (4) represent the beam with meshing from the finite element program.

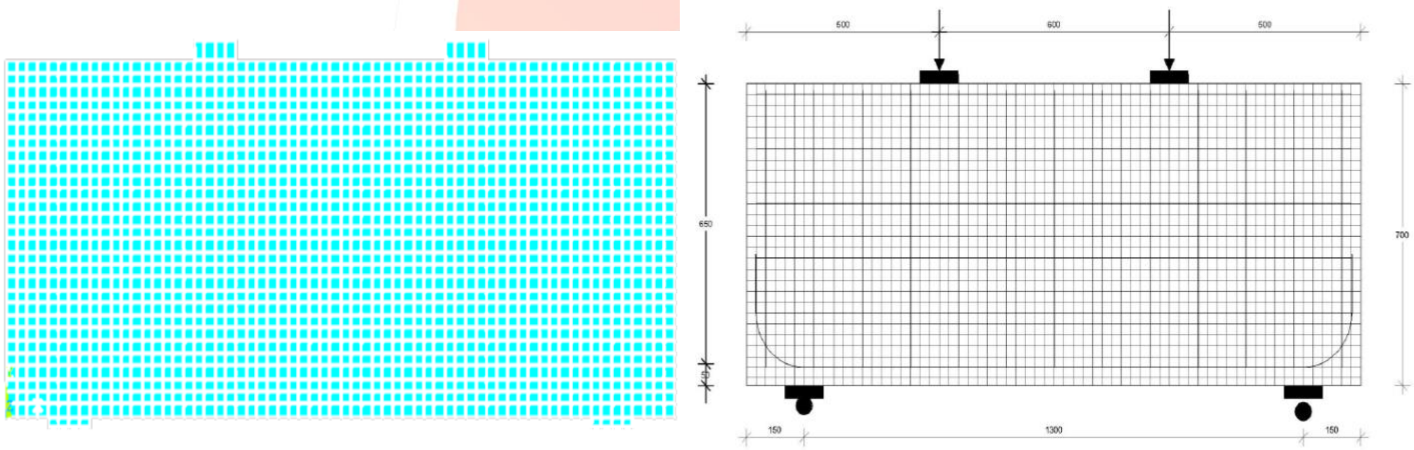

Figure (4) meshing and details of chosen model

The only deference between the beams was in the area and arraignment of main longitudinal steel which entails a change in value of stiffness. Eight forms of main reinforcement were studied, where the diameter was increased in order to increase the stiffness and then the same area of steel was taken but with a different stiffness. Table (1) & fig (5) illustrate the different shapes of the beams under study. Where (As) equal summation area of main reinforcement, (I) moment of inertia for main reinforcement , (d) depth of beam and (a) the distance between center of load and reaction. We must note that B6, B7 and B8 had the same area of reinforcement and a/d ratio approximately but the local stiffness totally different.

Table (1) Details of the Analyzed Simply-Supported Beams

Beam no.	Reinforcement	As mm2	I mm4	d mm	a/d
B1	3 Ø 18	762	0.15*10^5	650	0.54
B2	3 Ø 20	942	0.23*10^5	650	0.54
B3	3 Ø 22	1140	0.35*10^5	650	0.54
B4	3 Ø 25	1473	0.57*10^5	650	0.54
B5	3 Ø 32	2412	1.54*10^5	650	0.54
B6	3 Ø 40	3771	3.77*10^5	650	0.54
B7	6 Ø 28	3696	7.58*10^5	625	0.56
B8	3 Ø 18 + 2PL 15*100	3762	15.3*10^5	635	0.55

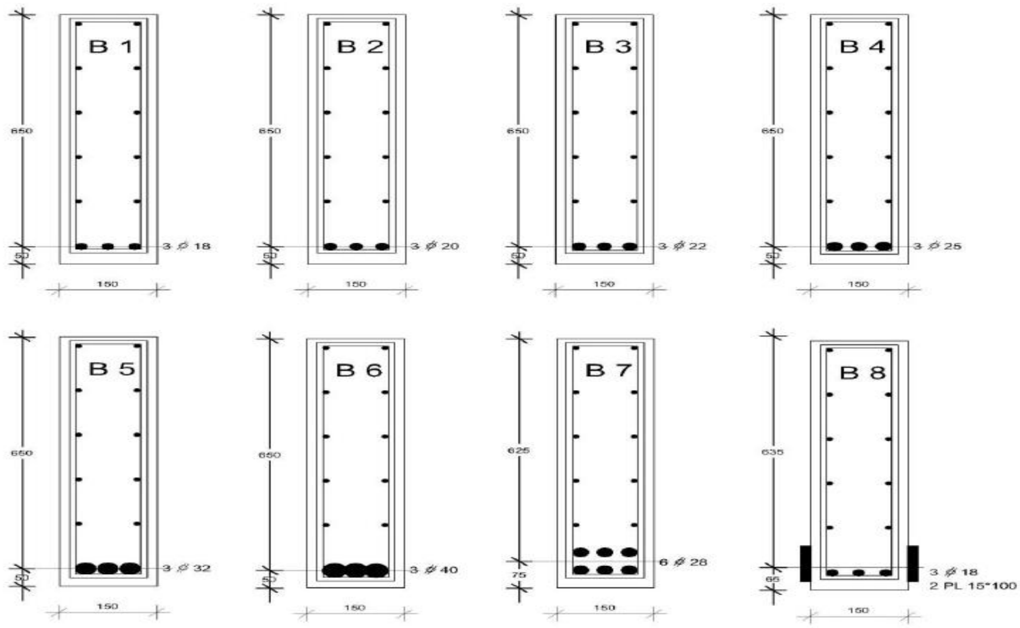

Figure (5) The deference between studded cases

For beams B5, B6 and B7 Note that they do not match with code in terms of distances between bars and this may lead to nesting in the concrete when poured in nature and affect the bonding between concrete and steel. As well as B8 it would be impossible to get full bond between plats and beam by using epoxy. This unlike the program where it always imposes a strong full bond between all the elements. To study the effect of tie rigidity , we will consider that the beams can be executed in this way.

IV. Results and Discussion

The outcomes of the numerical study are presented to evaluate the influence of local stiffness on the behavior of simply-supported, reinforced-concrete deep beams.

load deflection curve and load stages

Fig. (6) shows the relation between load on vertical axis and deflection at bottom mid span point at horizontal axis. In general, it can be noted that the increase area of tie resulted in the increase of the stiffness of the beam and the increase in the ability of the beam to curry the loads. There was a gradual increase in the load even if the percentage increase in the beam (B8) to 1.47 approximately. As for the ductility of beams , we find that the increase of local stiffness was followed by an increase in the ductility of the beams, but the beams number B2 and B4 had unexpected behavior and this could be due to the increase in the tie stiffness folded by change of the breakdown points in the beams.

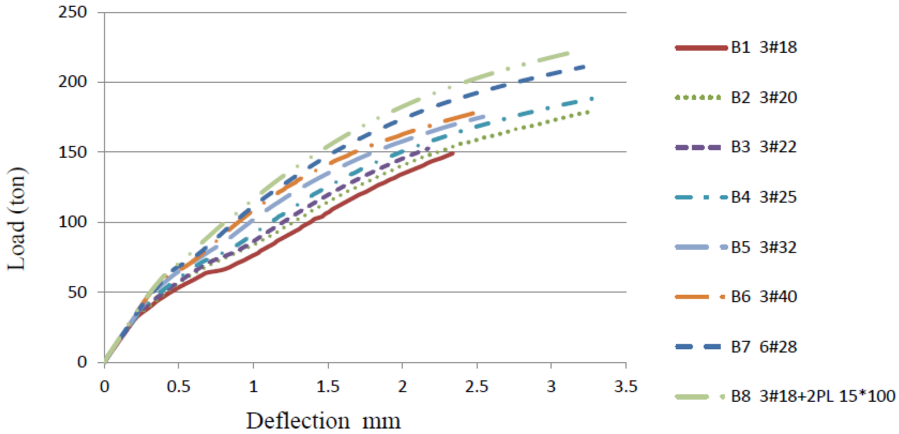

Figure (6) load deflection curves of all analyzed Beams

For loads, all curves of beams are identical up to the service load, which applies with equation (2) and mentioned in ACI and its value is 42.86 tons.

$$V_u \leq \phi 2.65 \sqrt{f_c'}\, b_w d \qquad \text{KN} \qquad .....(2)$$

It can be also note that the smaller reinforced beams were clearly in the yielding stage. The ultimate value of loads has increased significantly by increasing the stiffness of the tie. Table No. (2) shows the load values at the different stages of loading the beams.

Table (2) values of ultimate & yielding loads and Increase ratios of analyzed Beams

Beam no.	Reinforcement	Yielding load (ton)	Ultimate load (ton)	Load at dif. 2mm (ton)	Inc. ratio from B1
B1	3 ø 18	65	150	140	1
B2	3 ø 20	70	180	146	1.2
B3	3 ø 22	72	151	151	1.01
B4	3 ø 25	75	183	155	1.22
B5	3 ø 32	81	175	170	1.16
B6	3 ø 40	65	180	175	1.2
B7	6 ø 28	70	210	180	1.4
B8	3 ø 18 + 2PL 15*100	72	221	190	1.47

Crack patterns and stresses distribution

Fig (7,8,9) shows the crack patterns and stresses distribution in two cases for all analyzed beams. The first stresses case of ultimate load and the second stresses case at deflection equal to 2 mm. In order to determine the effect of the increase the reinforcing steel of tie on the behavior of the beams.

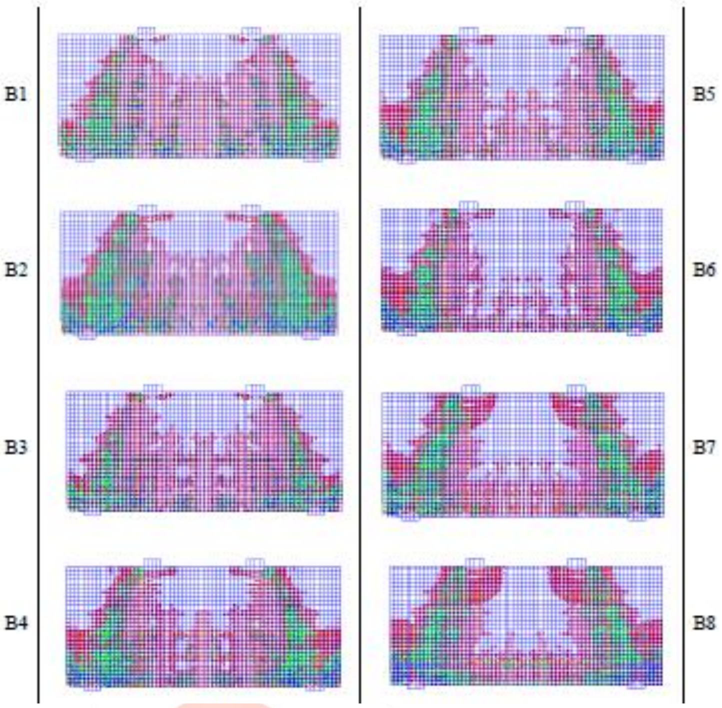

Figure. (7) crack pattern for all analyzed Beams

From the fig. increasing local stiffness of the tie contributed significantly to the reduction of the initial cracks in the central region. Cracks in high-stiffness beams have clearly reached and widened to the loading point. Cracks are also highly concentrated at the Anchorage points for steel. In the end, however, the shape of failure was shear failure in all the beams.

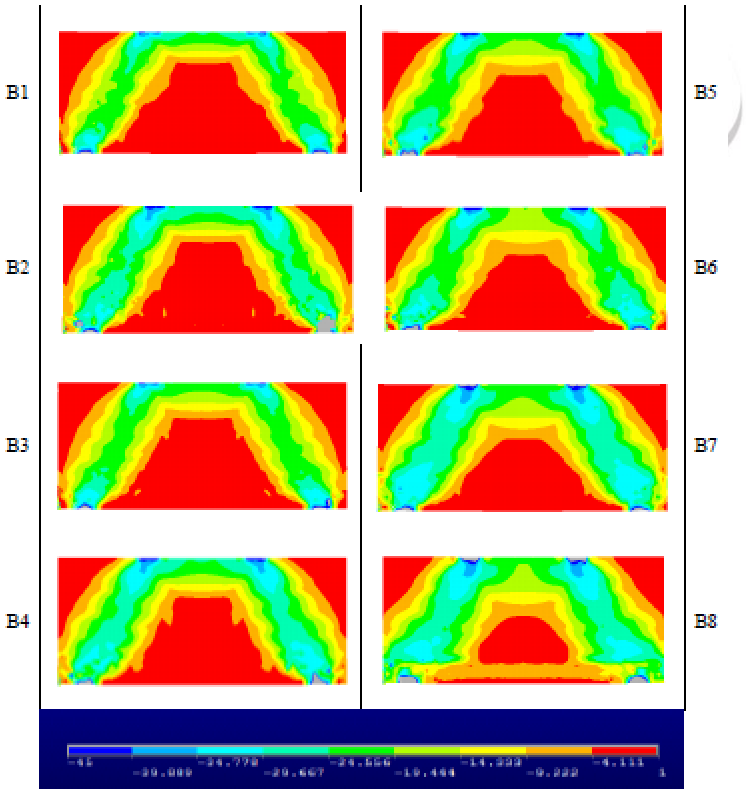

Figure (8) stress distribution at the end of loading for all analyzed Beams

We note from the distribution of stresses that the result of the increase of the stiffness of the tie increased the strength of bearing the beam and this led to the increase of the force in the strut as shown in Figure (8) also note increase the width of the strut significantly. So you feel in the high local stiffness tie that the beam are subjected to compression stresses on all parts. The horizontal strut between two loading point the compression stresses decreases and widened to reach any half of the beam proximately.

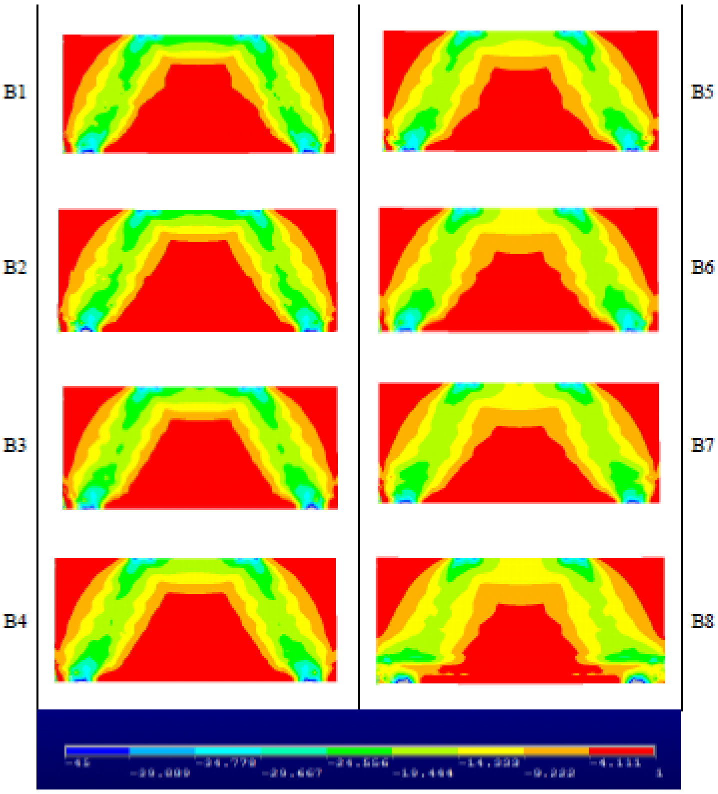

Figure (9) stress distribution at deflection equal 2 mm for all analyzed Beams

From Fig (9) Which shows the distribution of stresses on all beams when deflection in the middle of the beam of 2 mm . We will notice that for diagonal and horizontal struts, ie, all the struts of the beam by increasing the stiffness of the tie reduced stresses values and increased the width. We also note that the load path changed in the middle region to lean slightly inward in the high value of local stiffness in beams.

Conclusions

- Increasing the stiffness of tie reduces stresses distribution in beams by increasing strut widths this, of course, leads to increased load capacity of beams. This explains why the tensile steel ratio of 5.8 had an effect in behavior of beam on the Kong et al.[1] [2] beam's as they added a new row of steel and thus increased the local stiffness of tie value.
- When designing deep beams, it is preferable to increase the local stiffness of the tie by increasing the number of rows of tensile steel.
- The load paths in the beams are affected by the local stiffness of tie in the beams, which makes us able even to control these paths, which can have many applications for deep beams. We can also increase the local stiffness to the existing beams by adding external plates to strengthening these beams.

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