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Analysis Based On Ansys of PCC Deep Beams with Openings Strengthened With CFRP

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ABSTRACT

Reinforced concrete deep beams have wide range of applications and are used in gigantic structures to bear heavy loads. An opening in the deep beam decreases the load carrying capacity and reduces its serviceability. A PCC (plain cement concrete) deep beam with dimension 8000*5000*800mm (L*D*B) is modelled and analysed in ANSYS under uniform loading and simply supported conditions. The position of the circular hole with single and double opening is varied longitudinally and over the depth of the beam. The same beam is then analysed in ANSYS before and after assigning the CFRP (carbon fibre reinforced plastics) laminates along the inner surface of the opening. Stress in horizontal direction is studied in element below the CFRP laminate keeping loading condition, element type, and material properties constant. Thus the strength of the deep beam is a function of CFRP laminates as well as position of circular hole.

KEYWORDS: Composite laminates; Deep beams; ANSYS

I. INTRODUCTION

In today's modernistic and innovative world with continually increasing demands of community, burgeoning of big industries is inevitable. There are hardly any prominent industries that don't engage Deep beams in their construction and thus the focus has shifted on deep beams rather than traditional ones. In most of the gigantic industries, the load predicted during design is ought to augment after a few years when the production capacity of the industry is to be increased. This extra load cannot be resisted by the designed deep beam and thus extra reinforcement is to be provided to the existing deep beam to resist these increased loads. Internal reinforcement cannot be provided at this stage and thus external reinforcement if possible is best suited option. Water supply systems also adopt deep beams but with openings to allow the passage of pipelines through them. Even in industries, openings are to be provided in deep beams for the passage of electrical cables, etc. through them and therefore study of deep beams with openings is very crucial.

If the opening is to be provided during the casting phase of concrete, then adequate steel reinforcement to provide the needed stability can be provided in the initial phase itself but in most of the cases openings are needed after the deep beam has been already casted. In such cases, provision of openings to carry heavy loads through them augments the stresses in the periphery of the opening considerably and poses the risk of failure of deep beam due to crack formation. For such a case, Carbon Fibre Reinforced Plastic [CFRP] wrapping can be provided along the surface area of the opening which would reduce the stresses along its periphery considerably, thus providing stability to the deep beam and reducing the probability of failure considerably.

FRP(Fibre reinforced polymer) is a polymer matrix either thermoset or thermoplastic, that is reinforced with a fibre or other reinforcing material with a sufficient aspect ratio to provide a discernible reinforcing function in one or more directions. Thus FRP can be used as an excellent strengthening material. Ibrahim and Mahmood [1] proposed that FRP reinforcement shifts the behaviour of RC beam from shear failure to flexure failure at mid span and also CFRP is more efficient than GFRP (Glass fibre reinforced plastic) in strengthening for shear. Sahoo and Chao [2] experimentally showed that SFRC (Steel fibre reinforced concrete) specimen has three times greater strength than the RC specimen. Vengatachalapathy and Ilangovan [3] proved that web openings should be provided in the compression zone and also steel fibre augments the tensile strength and flexure rigidity of the deep beam. Nasir shafiq et al. [4] experimentally proved that CFRP augments the strength and reduces the deflection considerably as compared to additional steel bars. Though, the effect of FRP laminates as an efficient strengthening material has been studied by bonding them externally around the traditional beam as reported by Ibrahim and mahmood [1]. However, effect of FRP laminates wrapped along the surface area of circular opening for deep beam has not been studied yet.

The current study therefore focuses at the analysis of deep beams in ANSYS after the application of CFRP laminates along the surface area of openings. Deep beam with opening(s) at different locations is modelled and then analyzed. The specific objectives of the study are : (1) to observe stresses & deflection in deep beams after applying CFRP laminates along the surface of openings (2) to compare elemental stresses & deflection with and without CFRP wrapping (3) to suggest optimum location & size of an opening(s) for given loading & support conditions.

II. FINITE ELEMENT MODELING IN ANSYS:

The finite element modelling starts with the simulation of a model with the same conditions as that of the real life structure. The following properties were adopted while modelling our model of the deep beam:

2.1 Element type:

SOLID 185 element type is used in our model. This element type has 8 nodes with three degrees of freedom at each node – translations in the nodal x, y and z directions. This element has special cracking and crushing capabilities. The most important aspect of this element is the treatment of non linear material properties. This element type was selected due to its capability of being modelled even for materials with orthogonal properties i.e. FRP layer.

CONCRETE 65 (SOLID 65) is generally adopted for modelling concrete sections but it is not capable of being modelled with materials having orthogonal properties i.e. FRP layer. SOLID 185 has the basic shape and properties same as the SOLID 65 element as but with a few more advantages than SOLID 65. Thus SOLID 185 can be comfortably adopted with our model and also the results obtained from both were compared and negligible change in values was observed. A schematic of SOLID 185 is shown in the *figure* [1]:

The material properties used in the model are enumerated below:

Concrete (M-20 grade):
- Modulus of elasticity = 22361N/mm^2
- Concrete Poisson's ratio(v) = 0.18

CFRP properties
- Modulus of elasticity in X direction(E_X) = 300000 N/mm^2
- Modulus of elasticity in Y direction(E_Y)= 6500 N/mm^2
- Modulus of elasticity in Z direction(E_Z)= 6500 N/mm^2
- Modulus of rigidity in XY direction(G_{XY})= 4500 N/mm^2
- Modulus of rigidity in YZ direction(G_{YZ})= 4500 N/mm^2
- Modulus of rigidity in XZ direction(G_{XZ})= 4500 N/mm^2

Dimensions of deep beam: 8000*5000*800 mm is shown in *figure* [2]
Thickness of CFRP layer = 20 mm
Simply supported condition and Uniform loading = 7 N/mm^2
Size of mesh element = 80 mm
Number of sub-steps = 1
Type of analysis: Static linear
The different cases on which the effect of FRP has been studied are:
1. Single circular hole at L/2 from side and D/3 depth from top.
2. Single circular hole at L/2 from side and D/4 depth from top.
3. Single circular hole at L/3 from side and D/3 depth from top.
4. Two circular holes at L/3 from each side and D/3 depth from top.
5. Two circular holes at L/4 from each side and D/3 depth from top.

2.2 PARAMETRIC STUDY

L/D ratio: - The L/D ratio was varied from 1 to 1.9. The deflection pattern varies a lot within this range. In the first case, the zone of maximum deflection was concentrated in the upper portion of the beam while in the last case it is throughout the middle portion of the beam and has covered the bottom central band over there. In all other cases, the zone of maximum deflection was in transition state of reaching till the bottom of base as shown in *figure* [3].

Whereas on the other hand, the stresses do not change considerably for corresponding change in L/D ratio and hence an optimum ratio for making the provision of openings in it as illustrated in *figure* [4] was adopted. A graph between maximum deflection & the corresponding L/D ratio was drawn and based on the minimum deflection, X stress, Y deflection patterns; optimum ratio of 1.6 was taken for the analysis in ANSYS.

2.2.1 Change of opening position horizontally:-

Single Circular Hole: - Two different horizontal locations of a single circular hole at L/3 & L/2 were considered over the depth of D/3 from top. When stress patterns for 900mm opening size were compared at both positions, the L/3 case showed lesser stresses at the top of circular opening as compared to L/2 case. Similarly, the maximum deflection was more concentrated at the top middle portion of hole in L/2 case than that in L/3 case which is illustrated in *figure* [5]. Therefore, L/3 is more preferable.

Double Circular hole: - Two circular holes at two different positions L/4 & L/3 respectively from each side were considered over the depth of D/3 from top. The L/4 case showed stresses of higher magnitude than the L/3 case, where lesser stresses were concentrated in most part of beam. The deflection patterns for both the cases were nearly the same and thus based on stresses developed only as shown in *figure* [6] , the L/3 case is better than L/4 case.

2.2.2 Change of opening position vertically:-

A single circular hole at L/2 was taken at D/3 & D/4 vertical positions respectively. D/4 case showed higher stress band development at the top of opening. The maximum deflection is concentrated only at the top middle portion of hole in D/4 case whereas the change in deflection is very less throughout the depth of beam in D/3 case as illustrated in *figure* [7] . So hole at D/4 is more susceptible to cracks than hole at D/3.

III. DISCUSSION OF RESULTS

X stress opening area ratio curves

The x stress curves obtained after analysis of deep beams in ANSYS with respect to opening area ratio (Area of opening/Surface area of deep beam) are illustrated in *figure* [8] and *figure* [9]. Prior to application of CFRP laminates it is observed that 1 circular hole at L/3 and D/3 from top stress has uniformly increasing with augment in radius (300mm- 1100mm). Whereas 2 circular hole at L/4 from each end and D/3 from top has high stresses for the small opening ratio and low stress as compared to above case.1 circular hole at L/2 and D/3 from top has relatively high stress as compared to all the cases for the opening area ratio 0.07 and low stress for the > 0.07 opening ratio. 2 circular holes at L/3 from each end and D/3 from top have high stress for the opening area ratio 0.09 than all other position of hole.

Similarly after applying CFRP laminates the observation is that for 2 circular holes at L/4 from each end and D/3 from top the reduction in stress is insignificant at opening area ratio 0.01 and also for 2 circular holes at L/3 from each end and D/3 from top. At different opening position the stress induced is in the close range 2.75-3.75 to 4.2- 4.75 N/mm^2.

IV. CONCLUSION

It is always advisable to keep the opening radius as small as possible so that it fulfils the engineering application purpose and also the stress and deflection well within limit around the opening periphery. For opening area ratio up to 0.04 it is highly recommended to use 1 circular hole at L/3 and D/3 from top and also for greater than 0.04 opening ratio 2 circular hole at L/4 from each and D/3 from top. For opening area ratio 0.09 it is least recommended for any position of opening in deep beam as stress and max deflection is concentrated above the opening. CFRP has proved advantageous as stresses & deflection was considerably reduced for each element.

V. ACKNOWLEDGEMENT

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FIGURES

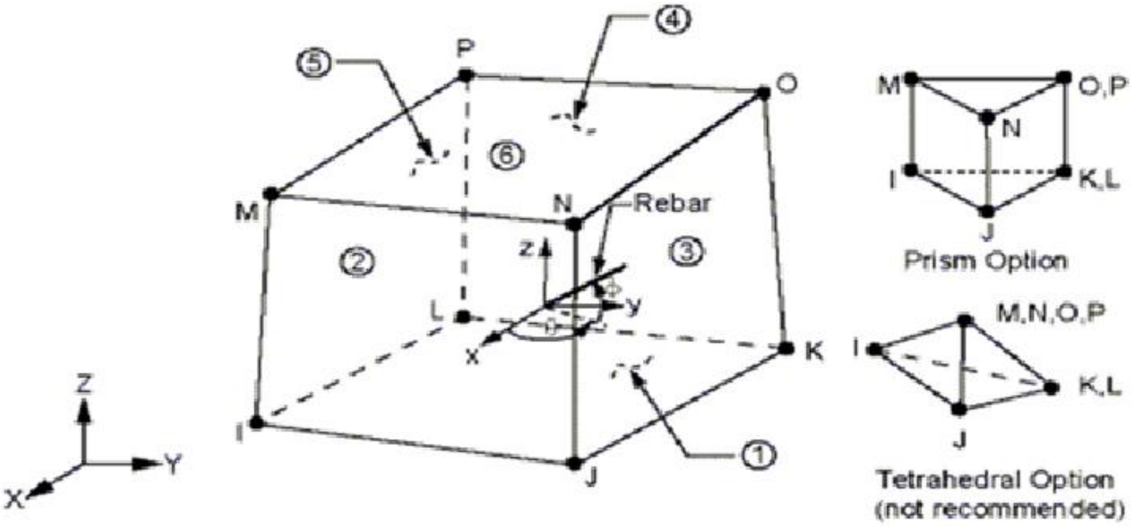


Fig 1. A schematic of SOLID 185 element

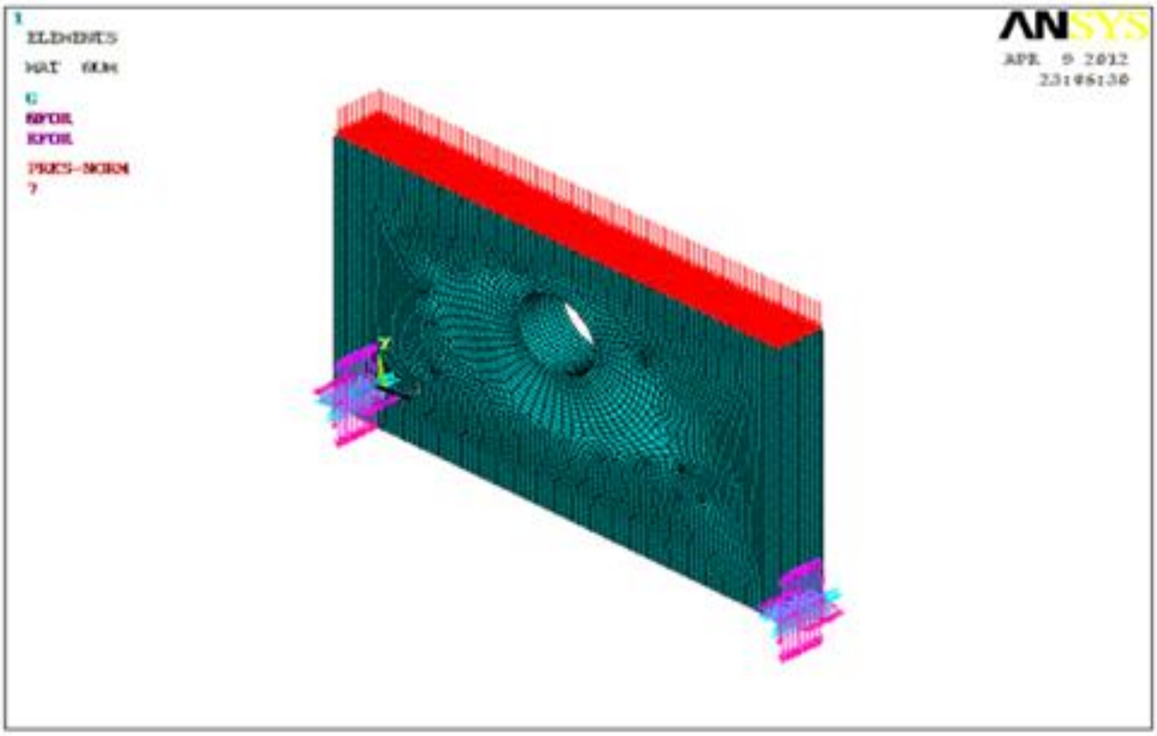


Fig 2. A schematic model in ANSYS showing uniform loading condition and simply supported condition

L/D=1.6 L/D=1.7

L/D=1.8 L/D=1.9

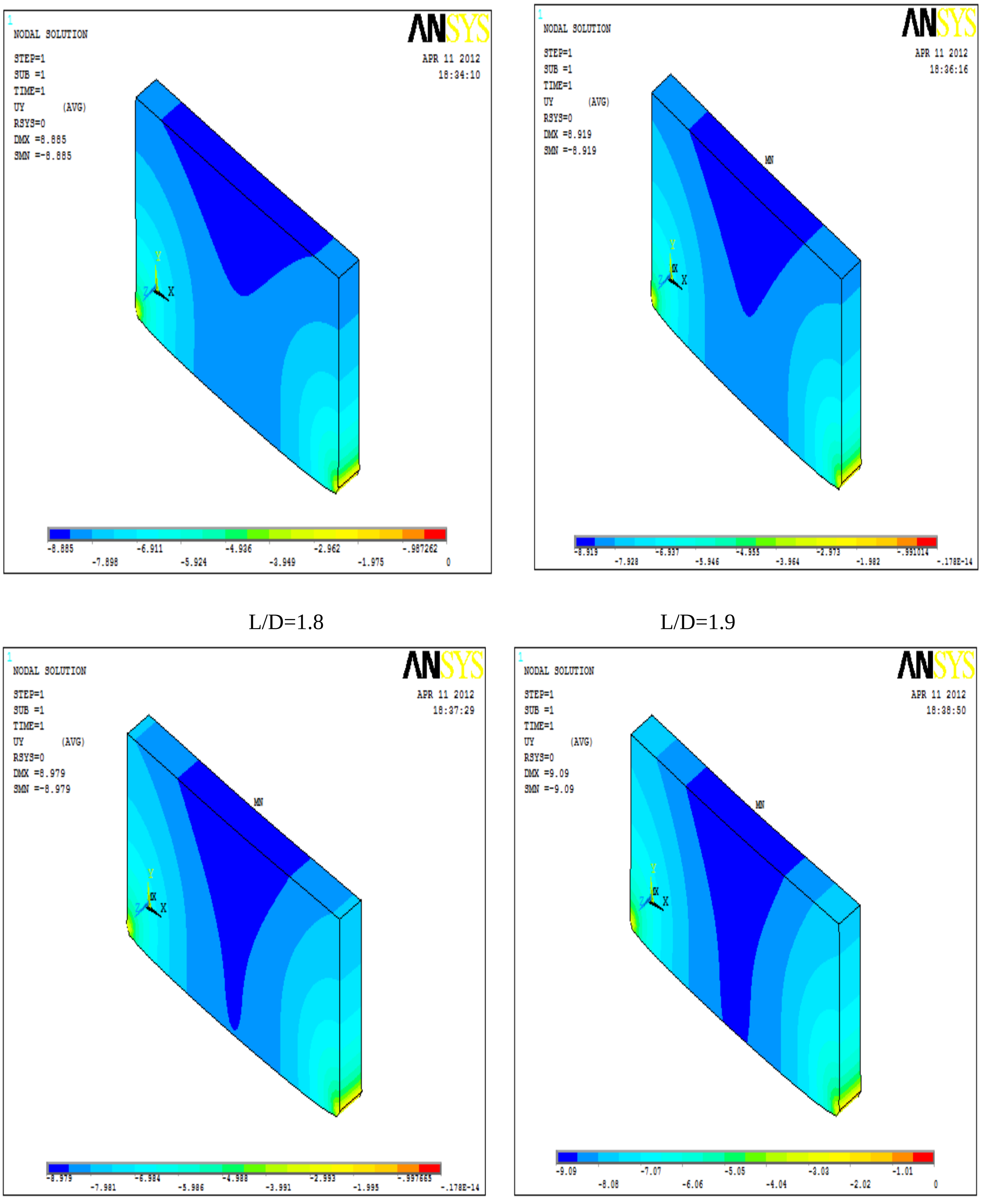


Fig 3 Diagram showing maximum deflection (mm) for L/D 1.6 to 1.9

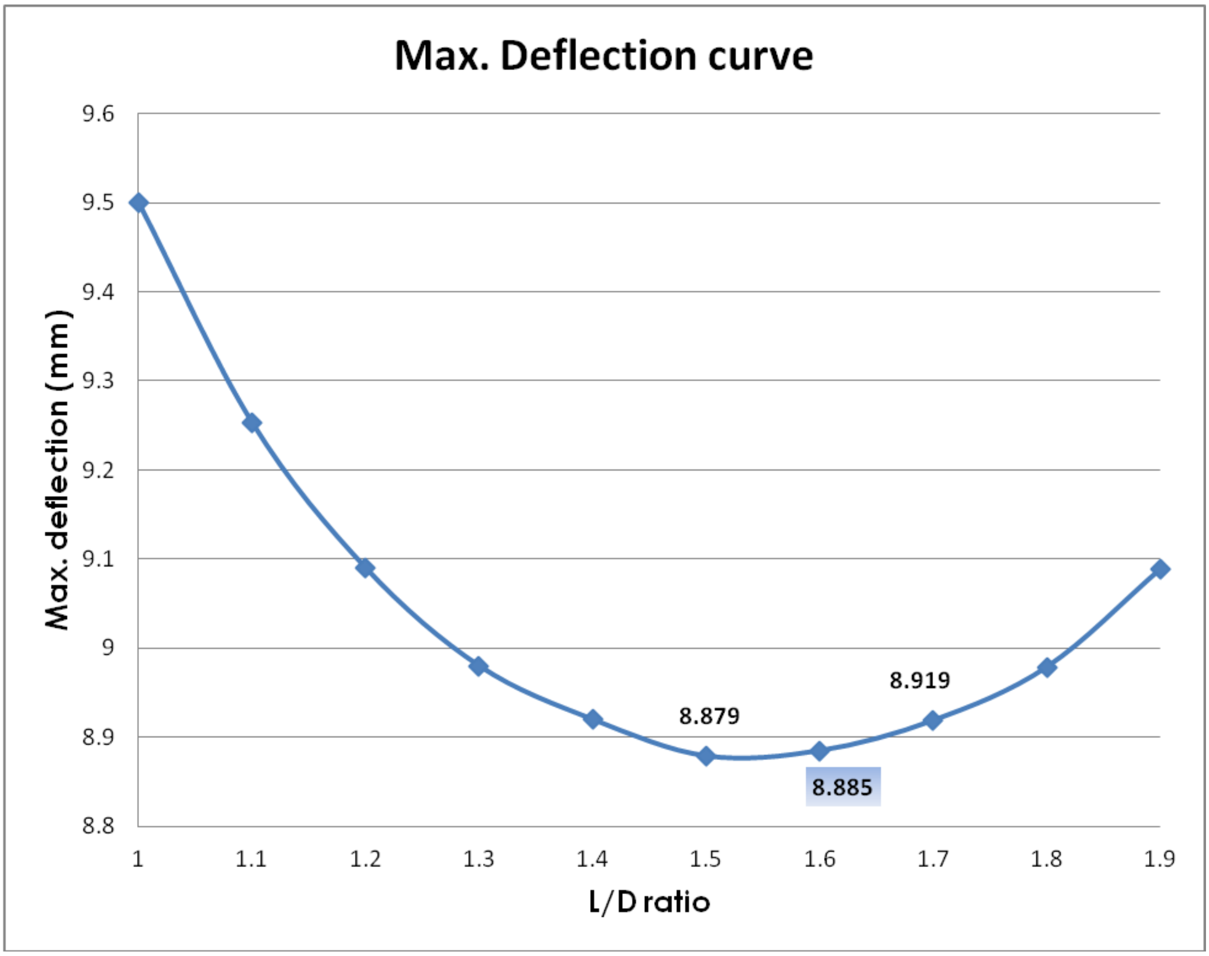
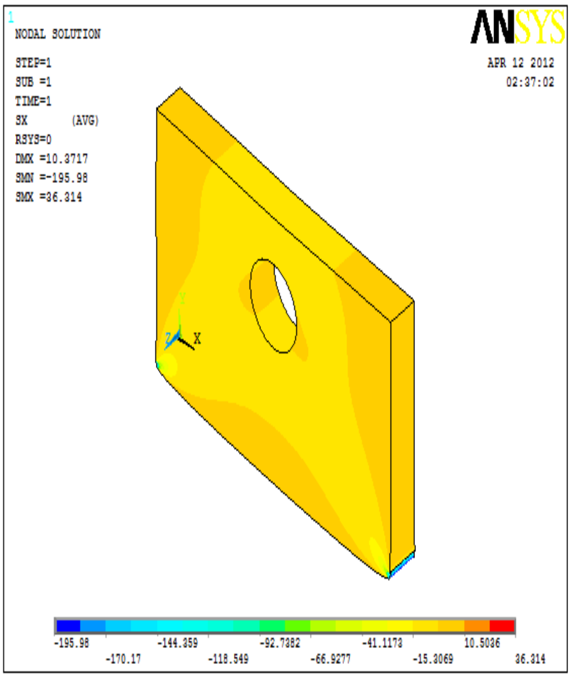
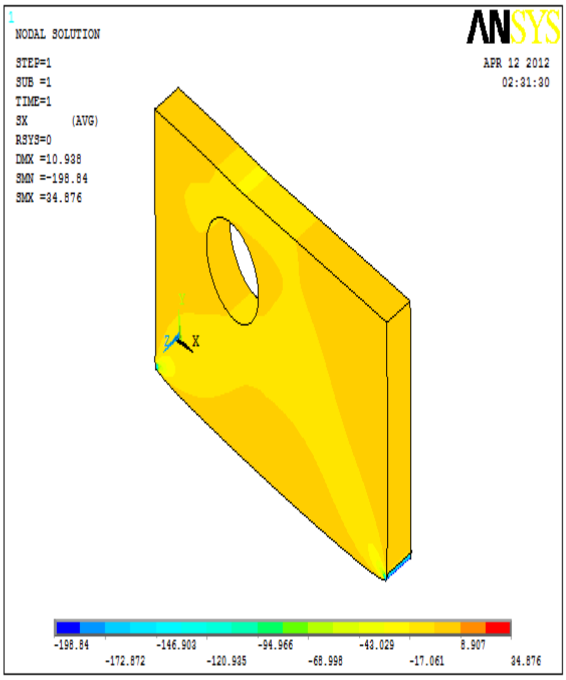


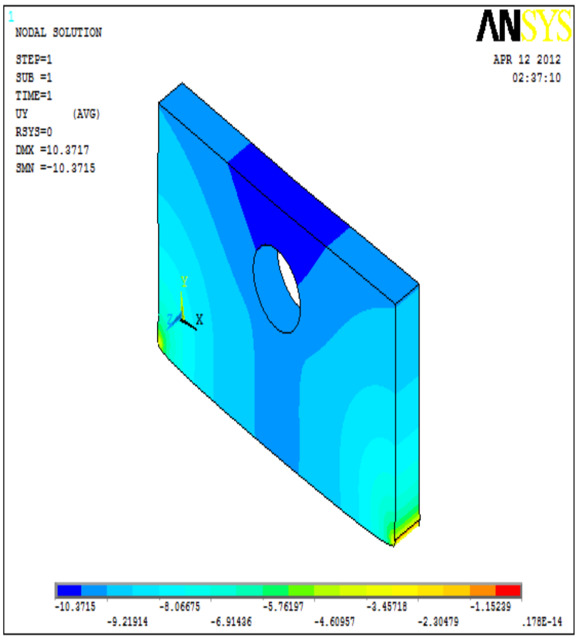
Fig 4. Graph plotted L/D vs. deflection

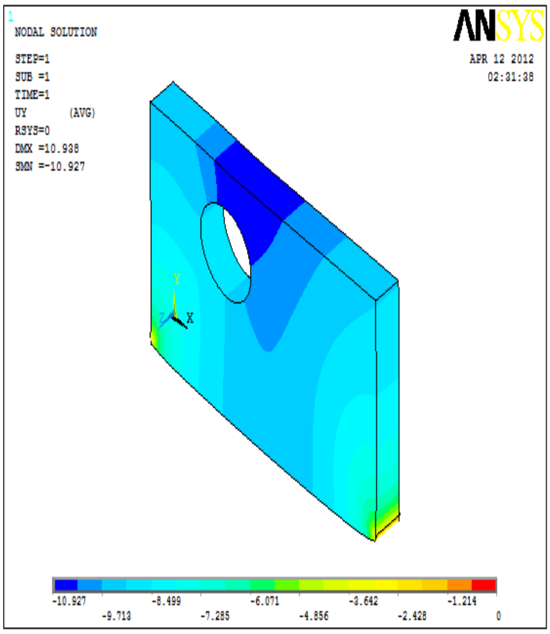
X Stress(N/mm²)





Y Deflection(mm)

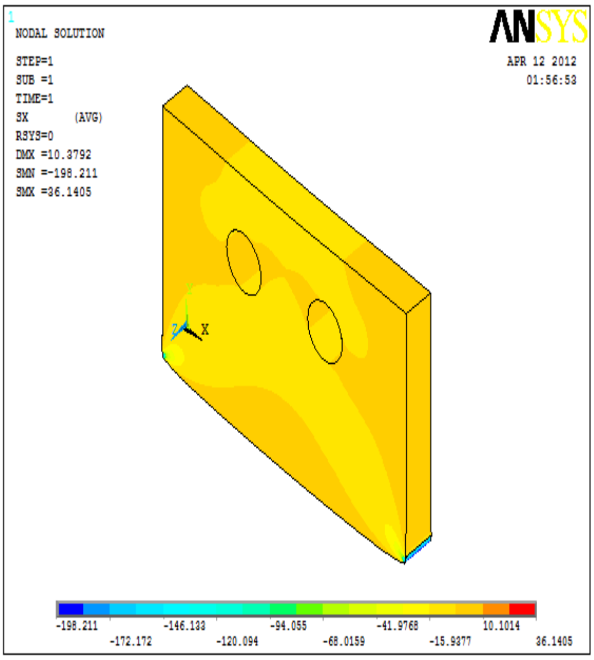


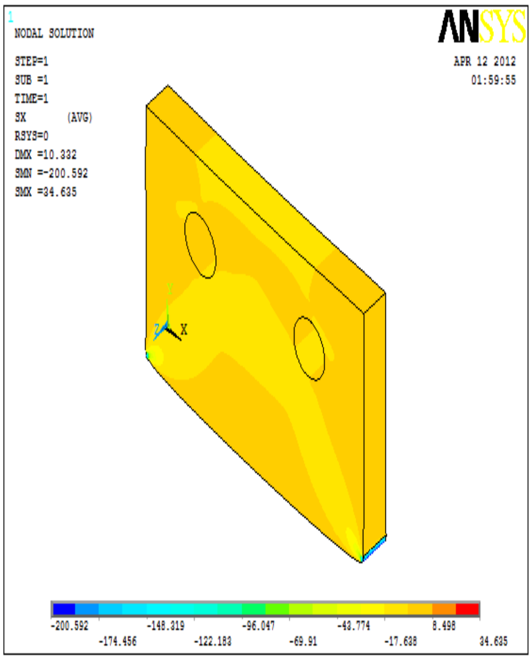


a) 1 Circular Hole 800mm at L/2 & D/3 b) 1 Circular Hole 800mm at L/3 & D/3

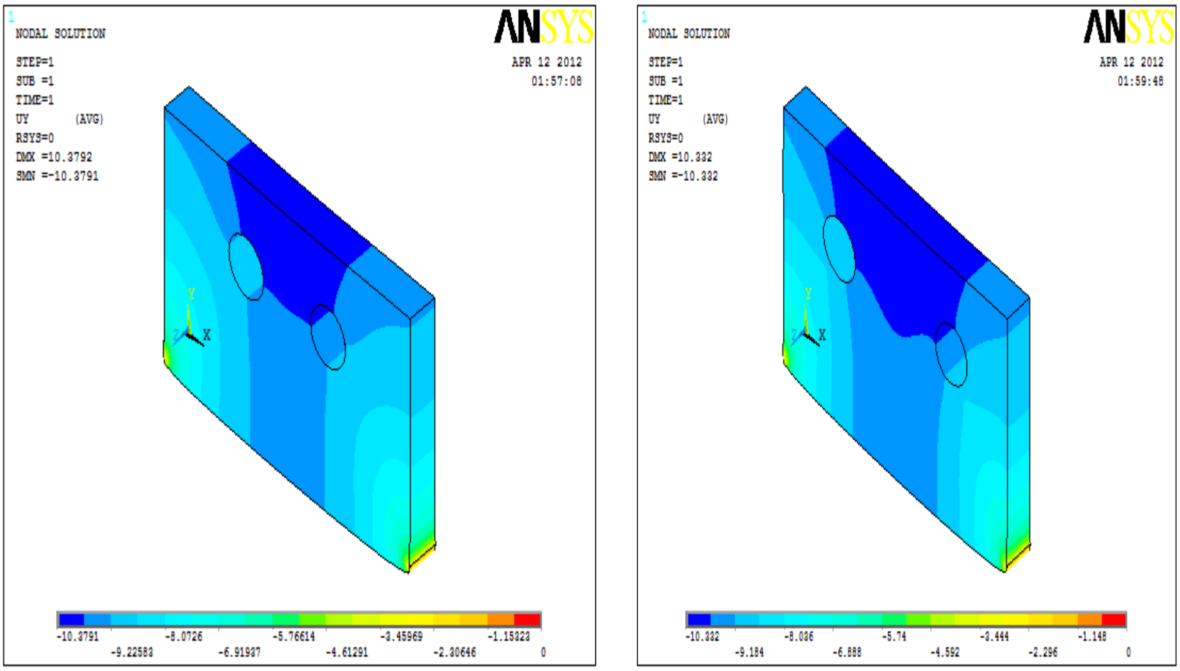
Fig 5. Stresses in X direction & Y Deflection

X Stress(N/mm²)





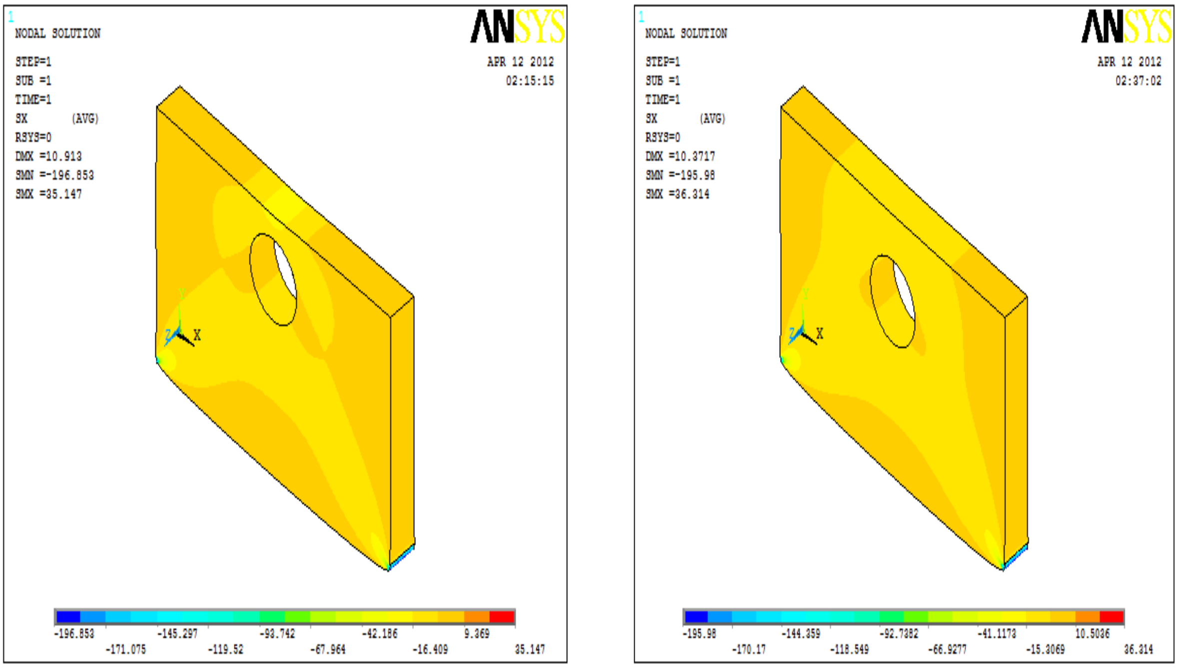
Y Deflection(mm)



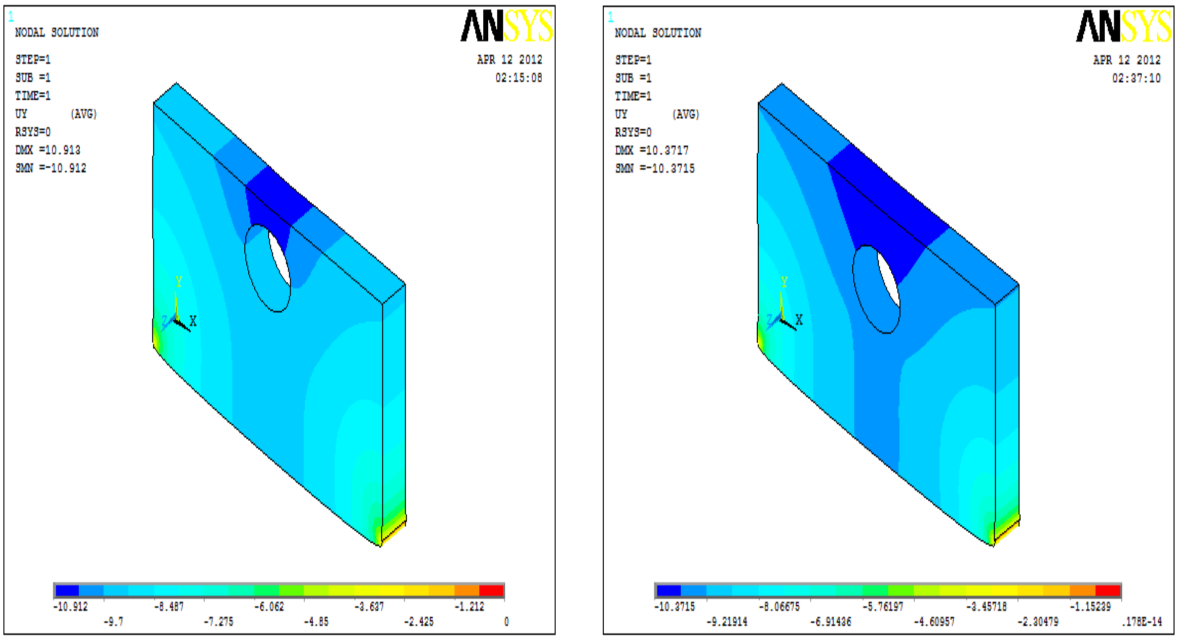
a)2 Circular Holes each 566mm at L/3 & D/3 b) 2 Circular Holes each 566mm at L/4 & D/3

Fig 6. Stresses in X direction & Y deflection

X Stress(N/mm²)



Y Deflection(mm)



a)1 Circular Hole 800mm at L/2 & D/4 b)1 Circular Hole 800mm at L/2 & D/3

Fig7. Stresses in X direction & Y deflection

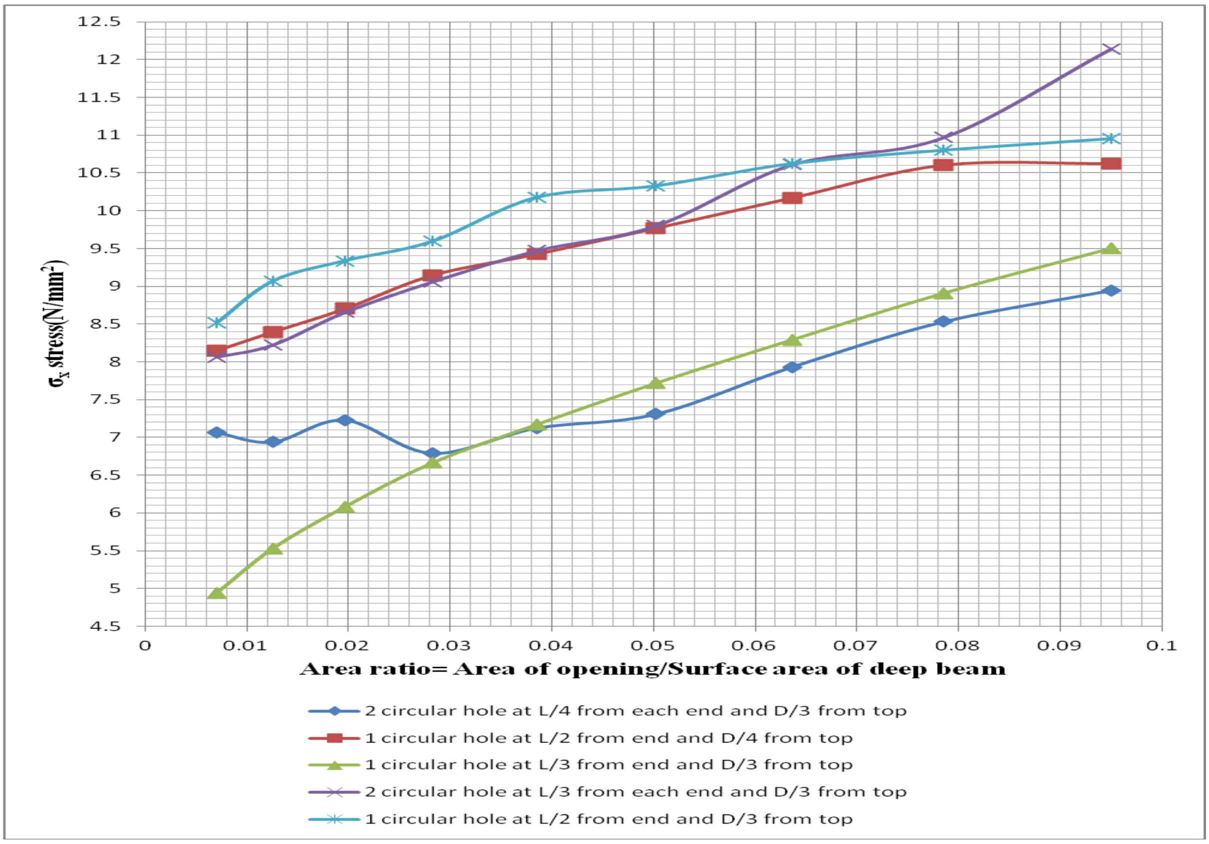


Fig 8. Graph plotted x stress vs opening area ratio without using CFRP laminates.

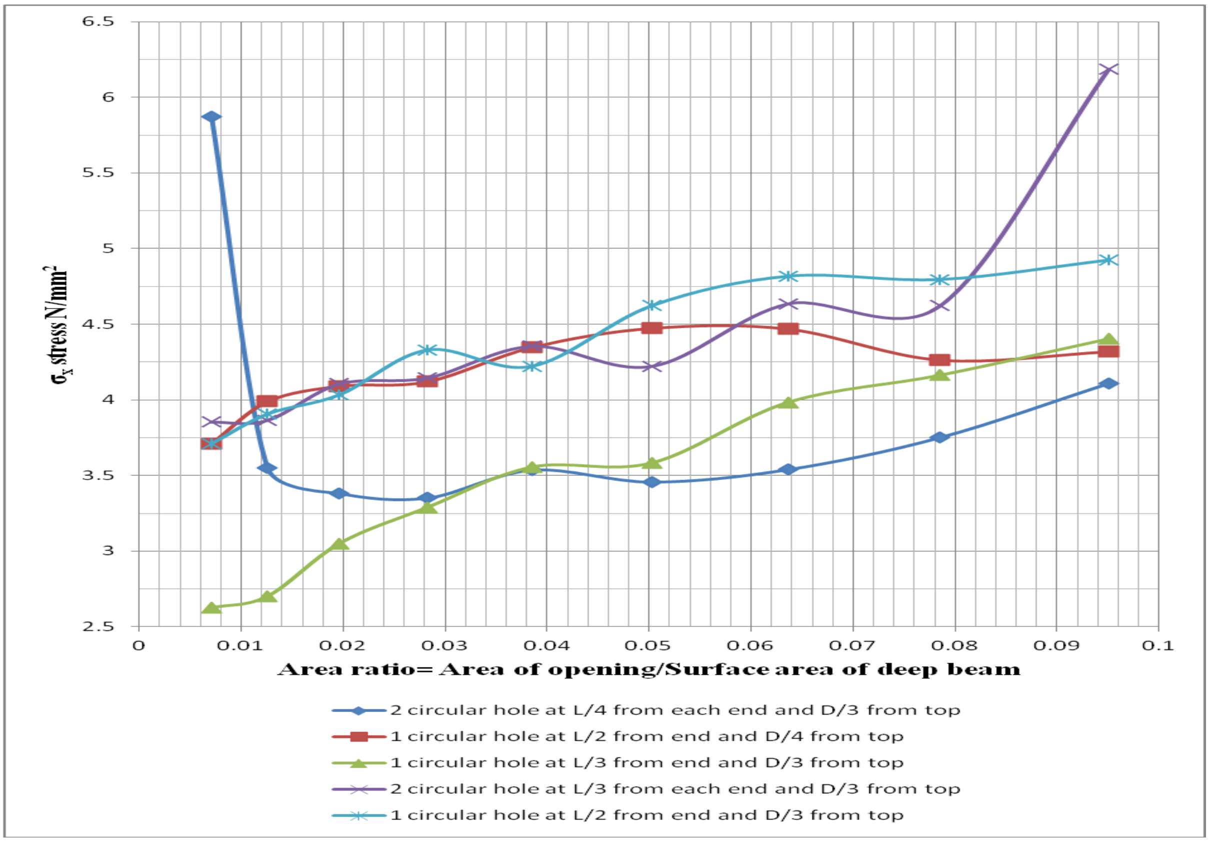


Fig 9. Graph plotted x stress vs opening area ratio with using CFRP laminates

TABLES

Table 1. Comparison of two circular holes at L/4 from each end and depth D/3 from top, with and without using CFRP

2 Circular holes at L/4 & D/3							
Without CFRP			With CFRP				
Max (N/mm²)	Min (N/mm²)	Avg (N/mm²)	Max (N/mm²)	Min (N/mm²)	Avg (N/mm²)	Radius (mm)	Area ratio
7.339	6.791	7.065	6.204	5.537	5.8705	212	0.0070686
7.158	6.72	6.939	5.034	2.067	3.5505	283	0.0125664
7.48	6.98	7.23	4.847	1.917	3.382	353	0.019635
7.032	6.55	6.791	4.764	1.94	3.352	424	0.0282744
7.338	6.909	7.1235	4.955	2.117	3.536	495	0.0384846
7.598	7.021	7.3095	4.851	2.064	3.4575	566	0.0502656
8.234	7.631	7.9325	4.892	2.188	3.54	636	0.0636174
8.903	8.163	8.533	5.088	2.416	3.752	707	0.07854
9.38	8.515	8.9475	5.539	2.678	4.1085	778	0.0950334

Table 2. Comparison of two circular holes at L/3 from each end and depth D/3 from top, with and without using CFRP

2 Circular holes at L/3 & D/3							
Without CFRP			**With CFRP**				
Max (N/mm²)	**Min (N/mm²)**	**Avg (N/mm²)**	**Max (N/mm²)**	**Min (N/mm²)**	**Avg (N/mm²)**	**Radius (mm)**	**Area ratio**
9.265	6.864	8.0645	5.035	2.672	3.8535	300	0.007069
9.269	7.178	8.2235	5.12	2.612	3.866	400	0.012566
9.729	7.58	8.6545	5.329	2.885	4.107	500	0.019635
9.83	8.29	9.06	5.547	2.746	4.1465	600	0.028274
10.02	8.922	9.471	5.57	3.14	4.355	700	0.038485
10.401	9.205	9.803	5.801	2.645	4.223	800	0.050266
11.18	10.04	10.61	6.272	3	4.636	900	0.063617
11.57	10.37	10.97	6.132	3.117	4.6245	1000	0.07854
12.47	11.82	12.145	7.581	4.792	6.1865	1100	0.095033

Table 3. Comparison of single circular hole at L/2 from end and depth D/3 from top, with and without using CFRP

Single Circular hole at L/2 & D/3							
Without CFRP			**With CFRP**				
Max (N/mm²)	**Min (N/mm²)**	**Avg (N/mm²)**	**Max (N/mm²)**	**Min (N/mm²)**	**Avg (N/mm²)**	**Radius (mm)**	**Area ratio**
9.11	7.92	8.515	5.304	2.115	3.7095	300	0.007069
9.603	8.533	9.068	5.253	2.56	3.9065	400	0.012566
9.944	8.728	9.336	5.495	2.573	4.034	500	0.019635
10.277	8.912	9.5945	5.726	2.933	4.3295	600	0.028274
10.824	9.524	10.174	5.51	2.933	4.2215	700	0.038485
11.082	9.574	10.328	5.895	3.35	4.6225	800	0.050266
11.394	9.851	10.6225	6.021	3.612	4.8165	900	0.063617
11.448	10.15	10.799	5.885	3.704	4.7945	1000	0.07854
11.718	10.187	10.9525	5.948	3.898	4.923	1100	0.095033

Table 4. Comparison of single circular hole at L/2 from end and depth D/4 from top, with and without using CFRP

Single Circular hole at L/2 & D/4							
Without CFRP			With CFRP				
Max (N/mm²)	Min (N/mm²)	Avg (N/mm²)	Max (N/mm²)	Min (N/mm²)	Avg (N/mm²)	Radius (mm)	Area ratio
8.609	7.691	8.15	5.307	2.114	3.7105	300	0.007069
8.948	7.845	8.3965	5.582	2.396	3.989	400	0.012566
9.255	8.15	8.7025	5.564	2.618	4.091	500	0.019635
9.677	8.617	9.147	5.524	2.718	4.121	600	0.028274
10.016	8.836	9.426	5.694	3	4.347	700	0.038485
10.373	9.168	9.7705	5.745	3.202	4.4735	800	0.050266
10.74	9.6	10.17	5.625	3.311	4.468	900	0.063617
11.07	10.14	10.605	5.238	3.287	4.2625	1000	0.07854
11.116	10.137	10.6265	5.231	3.406	4.3185	1100	0.095033

Table 5. Comparison of single circular hole at L/3 from end and depth D/3 from top, with and without using CFRP

Single Circular Hole at L/3 & D/3							
Without CFRP			With CFRP				
Max (N/mm²)	Min (N/mm²)	Avg (N/mm²)	Max (N/mm²)	Min (N/mm²)	Avg (N/mm²)	Radius (mm)	Area ratio
5.096	4.786	4.941	3.913	1.335	2.624	300	0.007069
5.79	5.27	5.53	3.875	1.526	2.7005	400	0.012566
6.394	5.765	6.0795	4.173	1.928	3.0505	500	0.019635
6.983	6.346	6.6645	4.364	2.215	3.2895	600	0.028274
7.58	6.758	7.169	4.608	2.502	3.555	700	0.038485
8.185	7.253	7.719	4.535	2.631	3.583	800	0.050266
8.808	7.774	8.291	4.955	3.012	3.9835	900	0.063617
9.478	8.34	8.909	5.081	3.245	4.163	1000	0.07854
10.114	8.893	9.5035	5.273	3.533	4.403	1100	0.095033

Table 6. Approximate reduction in stresses after applying CFRP laminates.

Cases	Reduction in stress(approx.)
1 circular hole at L/2 & D/3 from top	56.3%
1 circular hole at L/2 & D/4 from top	54.6%
1 circular hole at L/3 from one end & D/3 from top	42.8%
2 circular hole at L/3 from each end & D/3 from top	46.6%
2 circular hole at L/4 from each end & D/3 from top	49.2%