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The Study of Behavior of RC Beam with Transverse Opening under Static Load

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Abstract:
In the construction of modern buildings, many pipes and ducts are necessary to accommodate essential services like water supply, sewage, air-conditioning, electricity, telephone etc. Usually, these pipes and ducts are placed underneath the soffit of the beam and, for aesthetic reasons, are covered by a suspended ceiling, thus creating a dead space. An alternative arrangement is made to pass these ducts through transverse opening in the floor beams this arrangement of building services leads to a significant reduction in the headroom and results in a more compact design. For small buildings, the savings thus achieved may not be significant compared to the overall cost. But for multistory buildings it is economical. In this paper, the static behavior of beams with and without opening with respect to location of opening is studied. Circular opening of diameter 100 mm is provided at L/3 and L/4 location of tensile zone of beam. Displacement and stress distribution are parameters studied.

Keywords: Circular opening, Building service, Static behavior

I. INTRODUCTION

In the construction of modem buildings, many pipes and ducts are necessary to accommodate essential services like water supply, sewage, air-conditioning, electricity, telephone, and computer network.

Figure 1 shows a view of the typical layout of pipes for a high-rise building. Usually, these pipes and ducts are placed underneath the soffit of the beam and for aesthetic reasons, are covered by a suspended ceiling, thus creating a "dead space." An alternative arrangement is to pass these ducts through transverse openings in the floor beams. As shown in Figure 2, this arrangement of building services leads to a significant reduction in the headroom and results in a more compact design. But provision of openings through beam, however changes its simple mode of behavior to a more complex one at both static and dynamic loading conditions. Therefore, the analysis and design of such beams needs special treatment, which currently falls beyond the scope of the major building codes.

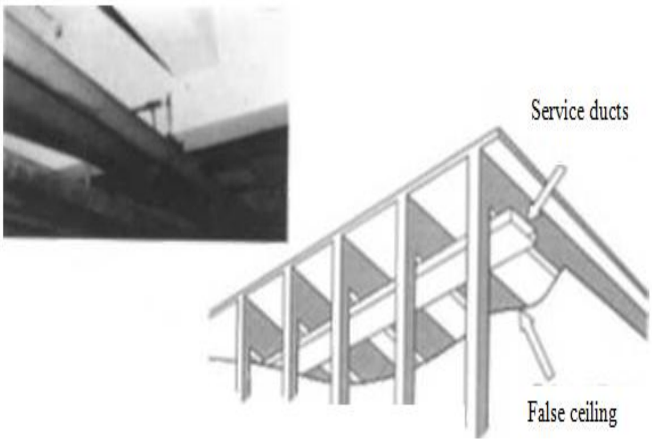

Figure.1. Typical layouts of service ducts and pipes

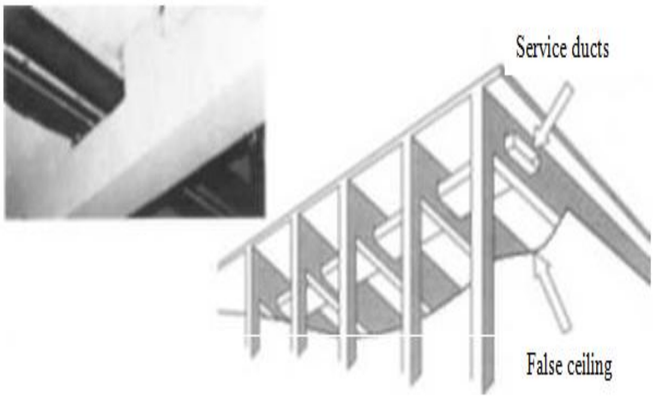

Figure .2. Alternative arrangements of service

II. SIGNIFICANCE OF STUDY

It is due to economy and a growing trend toward the use of system approach to building design that structural engineers are often required to keep provisions for transverse openings in beams. For small buildings, the savings achieved in terms of cost of construction by providing transverse openings in beams may not be significant compared to the building’s overall cost. But for multistory buildings, any saving in story height multiplied by the number of stories can represent a substantial saving in total height, length of air-conditioning and electrical ducts, plumbing risers, walls and partition surfaces, and overall load on the foundation.

Most engineers permit the embedment of small pipes, provided some additional reinforcement is used around the periphery of the opening. But when large openings are encountered, particularly in reinforced or pre stressed concrete members, they show a general reluctance to deal with them because adequate technical information is not readily available. There is also a lack of specific guidelines in building codes of practice (ACI, 1995; BS 8110-97), although they contain detailed treatment of openings in floor slabs. As a result, designs are frequently based on intuition, which may lead to disastrous consequences. There is at least one case on record, described by Merchant (1967) in which the failure of a large building was averted when severe distress at a large opening in the stem of a beam was discovered and mitigated in time. Hence it is important to study the behavior of beam with opening in order to accommodate it in the buildings during construction, and also to give more importance for the peak stress locations of beam during the designing part only.

SAEED AHMED AL-SHEIKH (2014) conducted experimental works to study the behavior of RC beam with different shapes of opening with varying diameters at different locations and un-strengthened by additional reinforcement. They casted 27 beams for experimental study, one beam (BN) without opening as a control beam and the remaining beams were provided with opening.

These beams were tested under four-point loading. The effect of size of opening with different locations was studied in terms of ultimate failure load, maximum deflection and failure mode. From the test results, it was concluded that the ultimate load carrying capacity of the RC beam with opening at shear zone was maximum reduction but at flexure zone, it showed minimum reduction. Rectangular opening increased the ultimate load reduction than square opening by (4%), while the circular opening reduced the ultimate load reduction than square opening by (8%).

VASUDEVAN.G, KOTHANDARAMAN.S (2011) conducted bending analysis of beams subjected to four point loading and the parameters studied were concrete constitutive properties, mesh density, use of steel cushion for the supports and loading points, effect of shear reinforcement on flexural behavior, convergence criteria, and impact of percentage of reinforcement. They used ANSYS finite element package to model and analyse the beams and concluded that an optimum mesh density should be arrived by performing few preliminary trial analysis, the initial cracking behaviour is not varying much with varying percentage of reinforcement. However, in the steel yielding level the variation was much and the ultimate strength could be varied by varying the percentage of reinforcement, the tension and shear reinforcements were to be precisely incorporated using discrete modeling technique in order to get more accurate behaviour.

III. PROBLEM DESCRIPTION

A three dimensional simply supported beam model is modeled in ANSYS with the following dimensions:

- Length of beam = 3m
- Depth of beam = 0.3m
- Breadth of beam = 0.23m

Firstly the solid beam without opening is modeled and analyzed. Then circular openings of diameter 100mm at different location are induced in the solid beam which is analyzed and the results are compared with the solid beam. Totally five cases of beams are considered including the solid beam.

Table .1. Types of beams considered

DESCRIPTION	BEAM NAME
Solid beam (control beam)	CB
Beam with single circular opening of 100mm diameter at L/3 from left support	SB-1
Beam with single circular opening of 100mm diameter at L/4 from left support	SB-2
Beam with double circular opening of 100mm diameter at L/3 location from both supports	DB-1
Beam with double circular opening of 100mm diameter at L/4 location from both supports	DB-2

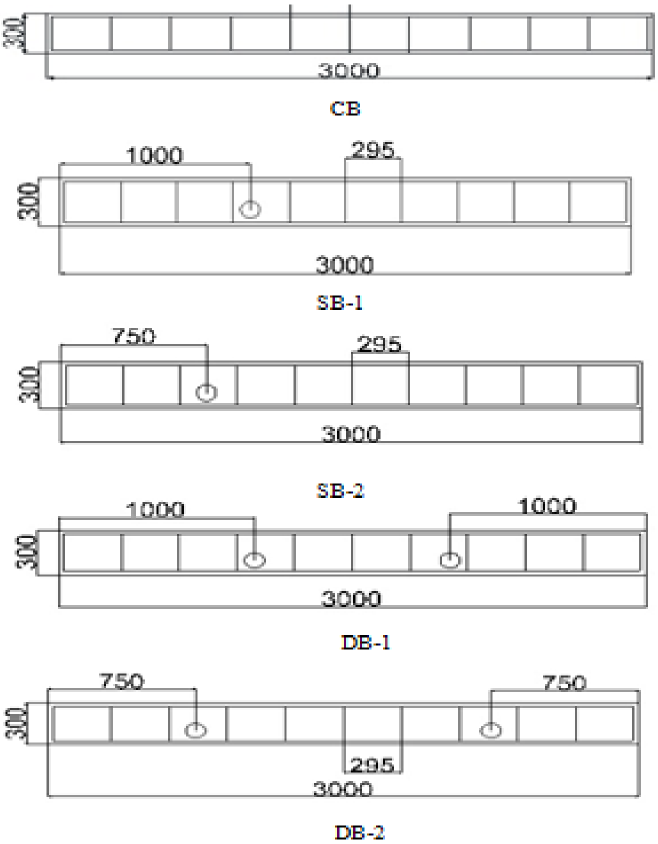

Figure.3. Beam cases (All dimensions are in mm)

For analyzing the beam in ANSYS, the element SOLID65 is used to represent the concrete and element LINK180 is used for reinforcement. The SOLID65 element has eight nodes with three degrees of freedom at each node. It is used for the three-dimensional modeling of concrete members. SOLID65 is capable of cracking in tension and crushing in compression.

Table .2. General input data for analysis

Support Condition	Simply supported
Load applied on Beam	UDL = 0.04 N/mm^2 (calculation shown below the Table 4.2)
Density of concrete	25 kN/m^3 (From Clause 19.2.1, IS 456-2000)
Grade of concrete	M25
Characteristic compressive strength of concrete (f_{ck}) for M25 grade	25 N/mm^2 (From Table-2, IS 456-2000)
Modulus of Elasticity of concrete	$=5000\sqrt{f_{ck}}$ (From Clause 6.2.3.1, IS 456-2000) $= 5000 x\sqrt{25} = 25 \times 10^3$ N/mm^2
Poisson's ratio for concrete	0.2
Grade of Steel	Fe500
Density of steel	7850 kg / m^3
Modulus of Elasticity of steel	200 kN/mm^2 (From Clause 5.6.3, IS 456-2000)
Poisson's ratio for steel	0.3
Reinforcement details	2-12mm Ø bars (Tensile bars) 2-10mm Ø bars (Hanger bars) 2 Legged-8mm Ø bars @ 295 c/c (stirrups)

IV. RESULTS AND DISCUSSION

Contour plot of Displacement variation in beams:

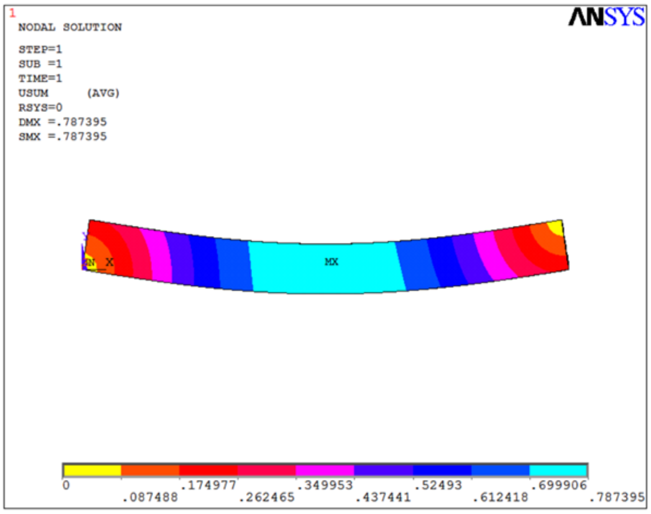

Figure .4. Contour Plot of Displacement of CB

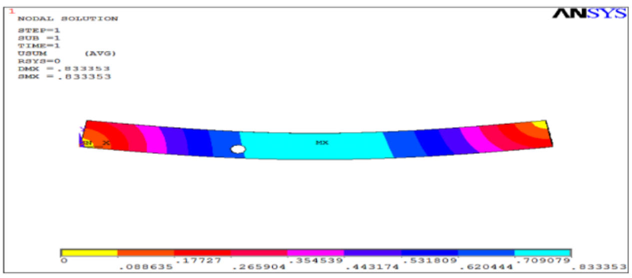

Figure .5. Contour Plot of Displacement of SB1

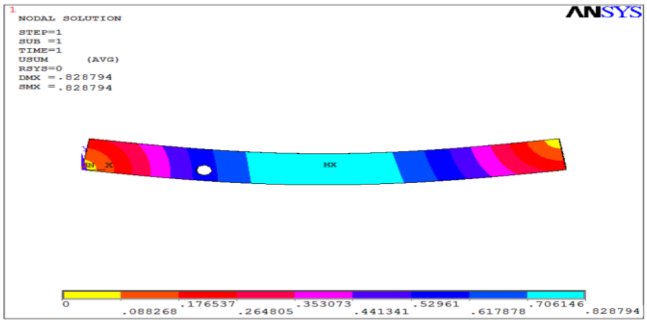

Figure 6. Contour Plot of Displacement of SB2

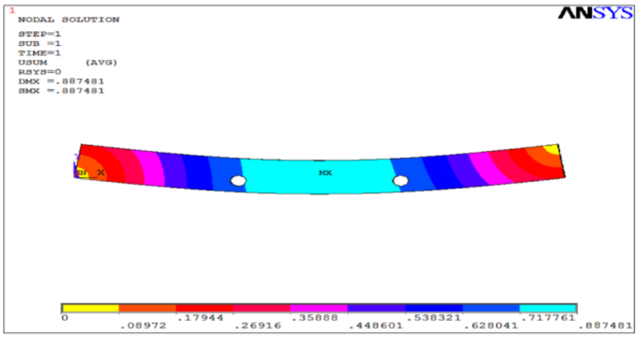

Figure .7. Contour Plot of Displacement of DB1

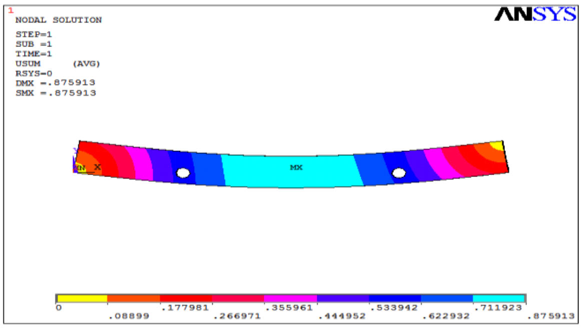

Figure. 8. Contour Plot of Displacement of DB2

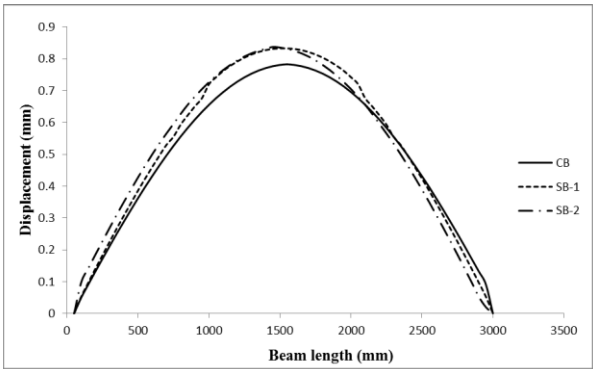

Figure. 9. Comparison of Displacement between CB, SB-1 and SB-2

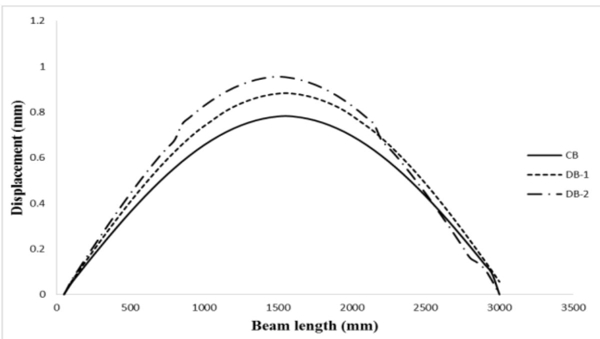

Figure .10. Comparison of Displacement between CB, DB-1 and DB-2

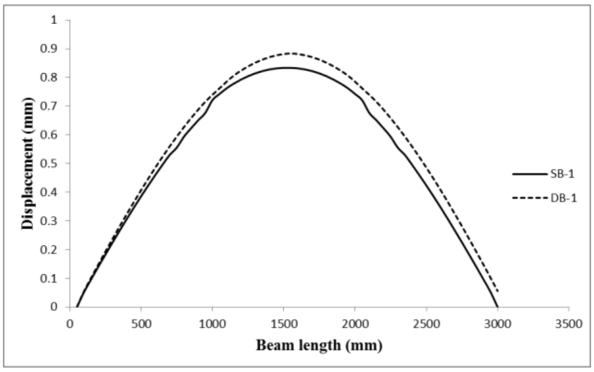

Figure .11. Comparison of Displacement between SB-1 and DB-1

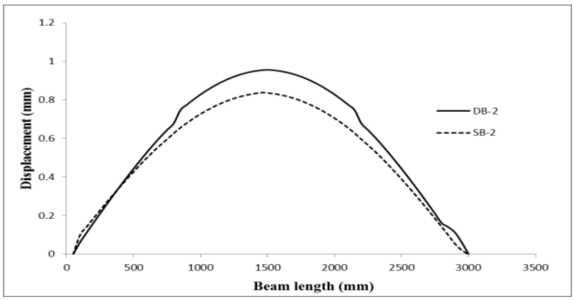

Figure .12. Comparison of Displacement between SB-2 and DB-2

Contour plot of Stress Distribution in beams:

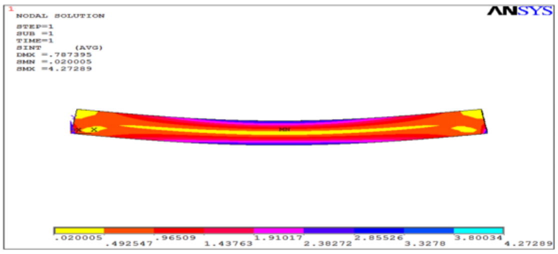

Figure .13. Contour plot of stress intensity of CB

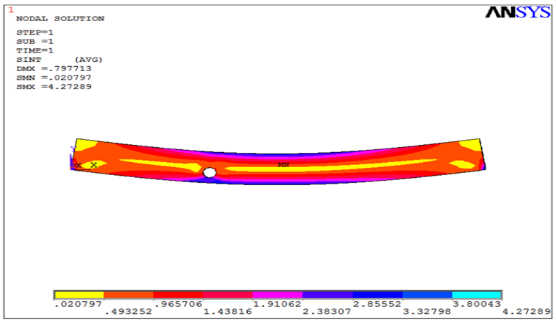

Figure .14. Contour plot of stress intensity of SB1

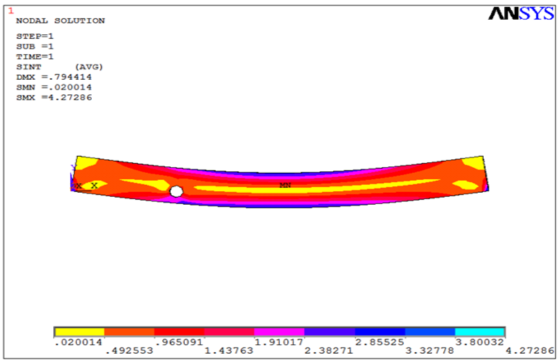

Figure. 15. Contour plot of stress intensity of SB2

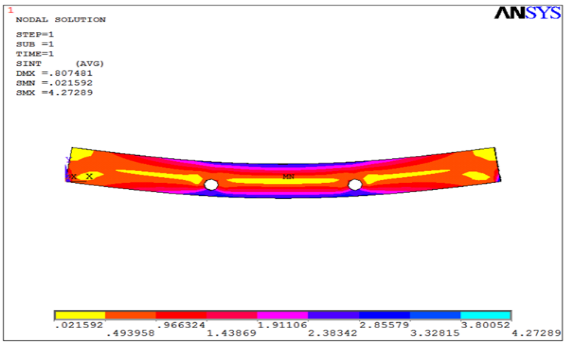

Figure .16. Contour plot of stress intensity of DB1

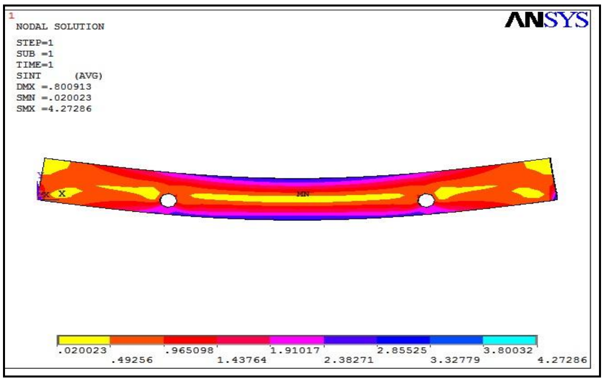

Figure .17. Contour plot of stress intensity of DB2

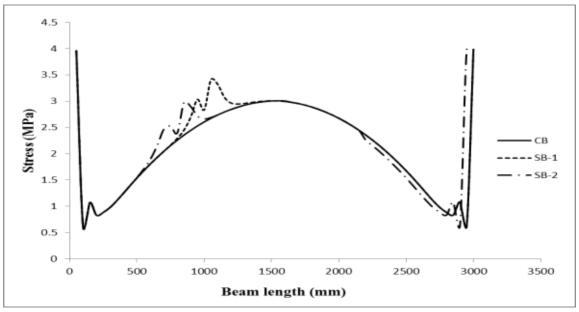

Figure .18. Stress distribution along length for CB, SB-1, SB-2

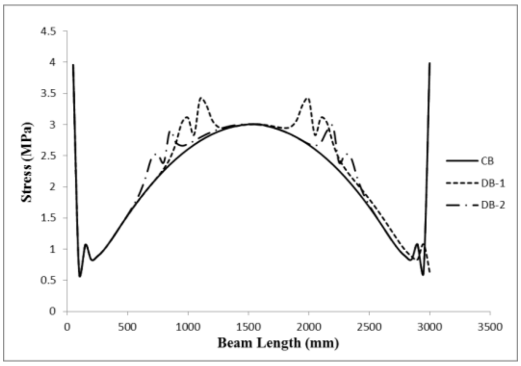

Figure.19. Stress distribution along length for CB, DB-1, DB-2

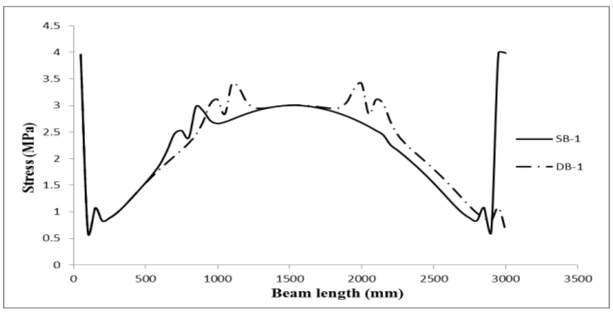

Figure. 20. Stress distribution along length for SB-1, DB-1

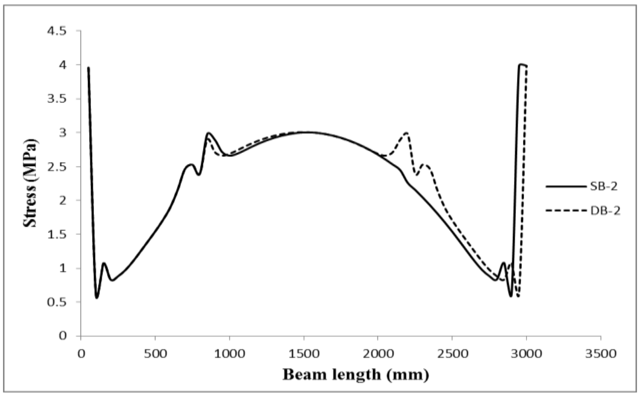

Figure .21. Stress distribution along length for SB-2, DB-2

From above results following observations are made during the study

- In the contour plots of displacement in Figure 4 to Figure 8, the cyan coloured portion of beam represents the location of maximum displacement and the yellow coloured portion represents minimum displacement.

- The variation of displacement of beams along the length is plotted in the graphs from Figure 9 to Figure 12. The displacement pattern of beams with openings for different location is compared with the beam without opening.

- From these graphs (Figure 9 to Figure 12) it can be observed that the deformations of all beams are of similar pattern and the difference is in terms of the value and location of maximum displacement.

- In case of openings through beams at span/4 distance from ends the maximum displacement slightly shifts towards the opening compared to opening at span/3 and control beam. This can be seen in Figure 9, and also the displacement is more than the control beam.

- In Figure from 10 to 12, where the displacement of beam with double opening is compared with control beam, it can be clearly seen that the maximum displacement of beam with double opening is more that the control beam and also beam with single opening.

- Here in the contour plots of stress distribution from Figure 13 to Figure 17 it can be observed that the provision of opening changes the pattern of stress distribution when compared to control beam.

- From the graphs in Figure 18 to Figure 21, it can be clearly observed that the stress variation and intensity of stress increases in the presence of opening.

- In Figure 18 it can be observed that at the location of opening the stresses varies when compared to control beam. Figure 18 clearly shows the shift of stress variation as the location of opening shifts.

V. CONCLUSIONS

- The inclusion of openings in reinforced concrete beam decreases its stiffness significantly.

- The maximum displacement and stress in beams increases, when openings are provided.

- The inclusion of openings varies the stress distribution pattern in the beam.

- Openings cannot be provided at maximum displacement or maximum shear region of the beam.

- Openings can be provided between the maximum displacement and maximum shear region after proper analysis.

- External steel support or internally increasing the shear strength around the opening region should be provided to strengthen the beam if openings are required.

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