NUMERICAL SIMULATION OF BEAM WITH WEB OPENING

A. F. Mazumder & A. A. Sarfin*

Department of Civil Engineering, Presidency University, Dhaka, Bangladesh
**Corresponding Author:* A. A. Sarfin

ABSTRACT
Transverse opening in RC beams allows the utility line to pass through the structure and encourages the designer to reduce the height of the structure leading to an economical design. Because of sudden changes in the dimension of cross section of the beam; the corners of opening would be subjected to stress concentration and it is possible to induce transverse cracks in the beam. Also it can reduce the stiffness, which leads to excessive deflection, both elastic and plastic, under service load. The main objective of this paper is to study the deflection and stress of beam, numerically using COMSOL, with and without of square web opening and to provide additional reinforcement to overcome excessive deflection and stress. To overcome the excessive deflection in the beam, two additional reinforcement bars across the width were provided. COMSOL result showed that deflection was reduced because of providing additional reinforcement. Similarly, both elastic and plastic stresses increase with the increment of the size of web opening which can be reduced with additional reinforcements, though bars with higher diameters do not have any significant effect on plastic and elastic stresses.

Keywords: RC beam; web opening; additional reinforcement; COMSOL

INTRODUCTION
A beam is a structural element that is capable of withstanding load primarily due to bending. The bending force induced into the material of the beam as a result of the external loads, own weight, and external reactions. In the construction of modern building, many pipes and ducts are necessary to accommodate essential services like water supply, sewage, air-conditioning, electricity, telephone, computer network 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". In each floor, the height of this dead space that adds to the overall height of the building depends on the number and depth to be accommodated. The depth of ducts or pipes may range from a couple of centimetres to, as long as, half a meter. An alternative arrangement can be undertaken by allowing these ducts to pass through the transverse opening of the floor beams. This arrangement of building services leads to significant reduction in the headroom and results in a more compact design. For small building, saving may not be significant compared to the overall cost. But for multi-storey buildings, any saving in story height multiplied by the number of stories can represent a substantial saving in total height of structures, length of air conditioning and electrical ducts, plumbing risers, walls and partition surfaces, and overall load on the foundation. Some researcher studied this phenomenon and tried to give practical and economical solution (Amiri et al, 2011; Chen et al, 2008; Mansur, 2006; Vasehiamiri and Alibygle, 2004).
The main objective of this study is to understand the behaviour of a beam with web opening. The specific objective of this study is to observe the deflection and stress of beam with & without of web opening and to provide additional reinforcement to overcome excessive deflection and stress.

METHODOLOGY
In this study, a simply supported solid beam (control specimen) had been analyzed by commercially available software COMSOL 4.3b. Then the same beam with different web openings (Table 1) had been analyzed and deflection and stress had been recorded and compared with the deflection and stress of the control beam.

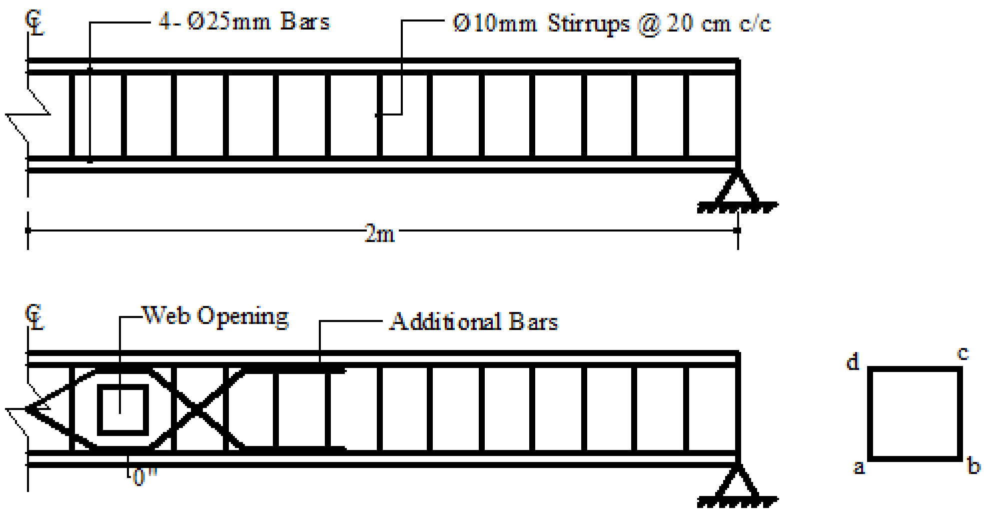

Fig. 1: Details of Beam, Web Opening and Additional Reinforcement

Beam Specification

To observe the effect of the opening in the web of a beam, 12 simply supported beams were modelled and analyzed in COMSOL. Specification of the beam is shown in Table 1 with reinforcement detailing (Fig. 1). 25 mm bar was used as longitudinal main bar with clear cover of 3.25 cm and 10 mm bar was used as stirrups with a spacing of 20 cm c/c distance. Plastic strain increased near the hollow with the increase of web opening. Strain localization was observed in the top of the web opening and in higher opening areas. So, two additional reinforcements were provided to cope up with strain localization and huge strain.

Table 1: Solid Beam Specification

Specifications	Beam
Length	4 m
Width	30 cm
Depth	50 cm
Main Reinforcement	25 mm (4, in each corner with 3.25 cm clear cover)
Additional Reinforcement (25 × 25 cm)	10, 12, 14, 16 mm (2, spacing 10 cm c/c)
Stirrups	10 mm (spacing 20 cm c/c)
Load Applied	200,000 N/m^2 (Pressure)
Support Condition	Simply Supported

Material Properties

In this study, 12 beams were analyzed. Two materials were used- concrete and structural steel. The uniaxial compressive and tensile strength of concrete were assumed to be 30 MPa and 3 MPa, respectively. The density, modulus of elasticity, and Poison's ratio of concrete were assumed to be 2400 kg/m^3, 26 GPa, and 0.25, respectively. Density, modulus of elasticity, and Poison's ratio of steel were assumed to be 7850 kg/m^3, 200GPa, and 0.3, respectively.

RESULTS AND DISCUSSIONS

Both elastic and plastic deflections at mid span increase with the increment of the size of the web opening (Fig. 2). It has been observed that additional reinforcements have reduced both elastic and plastic deflections. The mid-span deflection of beam with 25 mm square web opening reduces gradually from 2.3796 mm to 2.31854mm (elastic) and 3.38365 mm to 3.2083 mm (plastic) as the diameter of additional reinforcement increases up to 16 mm.

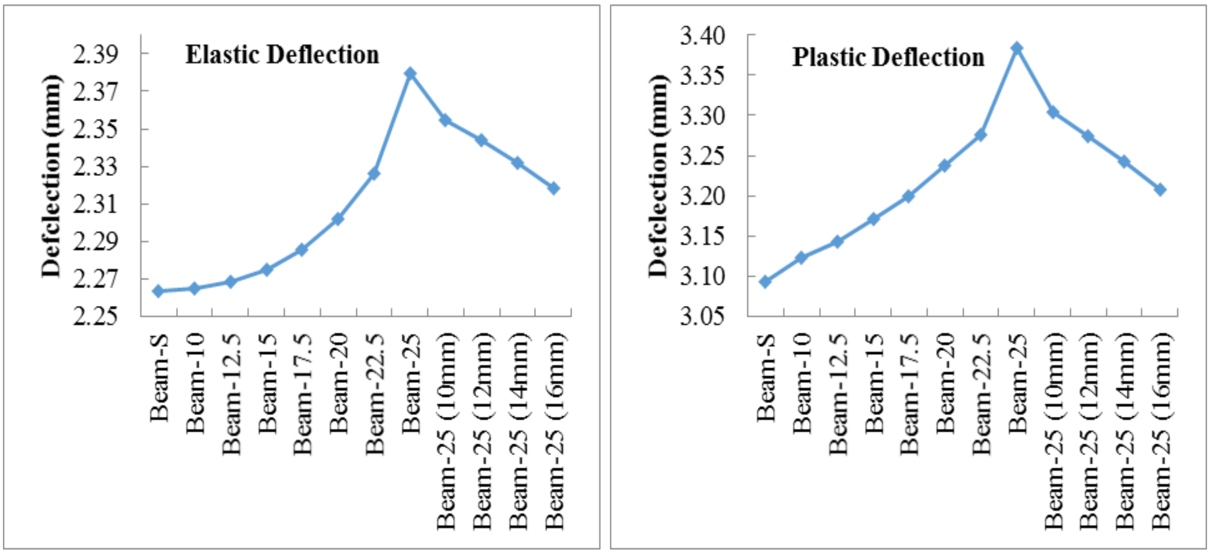

Fig. 2: Elastic and Plastic Deflection of Beams at Mid-Span

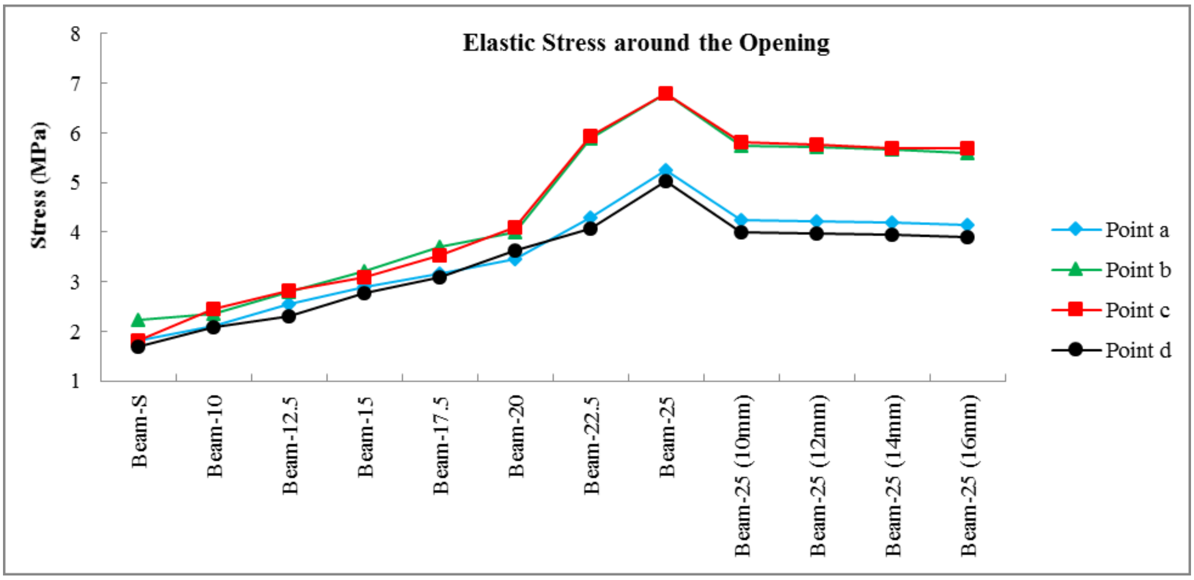

Fig. 3: Elastic Stresses of Beam around Web Opening

It has been observed from Fig. 3 that elastic stresses gradually increases as the dimension of the square web openings increase from 10 mm to 25 mm. Stresses at points ‘a’ and point ‘d’ as well as stresses at points ‘c’ and point ‘b’ are almost similar (Fig. 1). It should be noted that points (a, d) and points (b, c) are located at the same horizontal distance from centerline. After the inclusion of 10 mm additional reinforcements to the model, elastic stress decreases sharply. As the diameter of additional bars increases, elastic stresses decrease, though the change is not as prominent as that of the model with 10 mm additional bars.

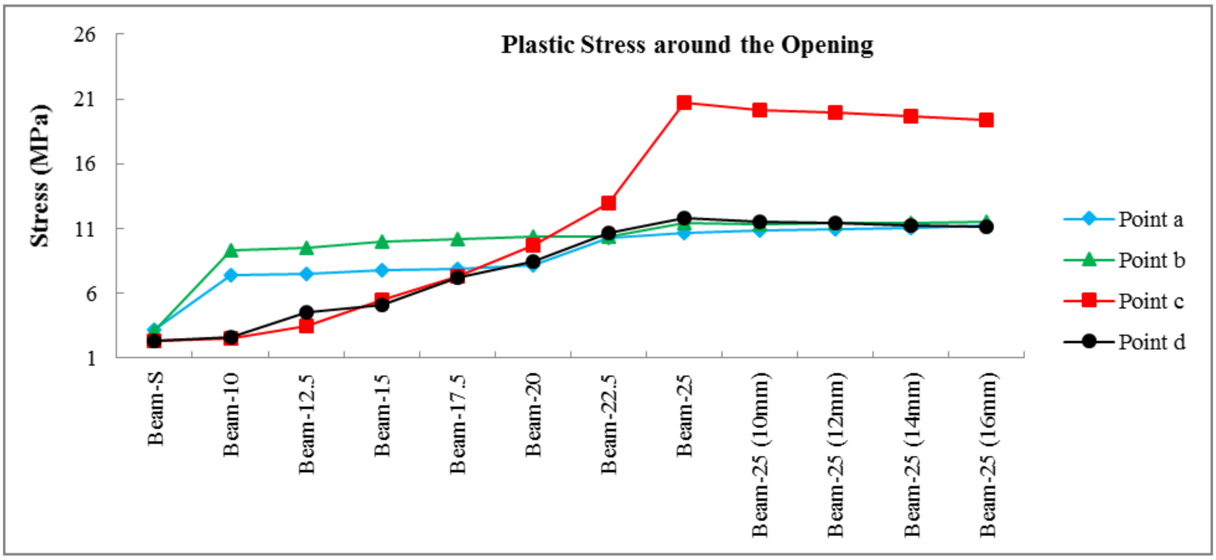

Fig. 4: Plastic Stresses of Beam around Web Opening

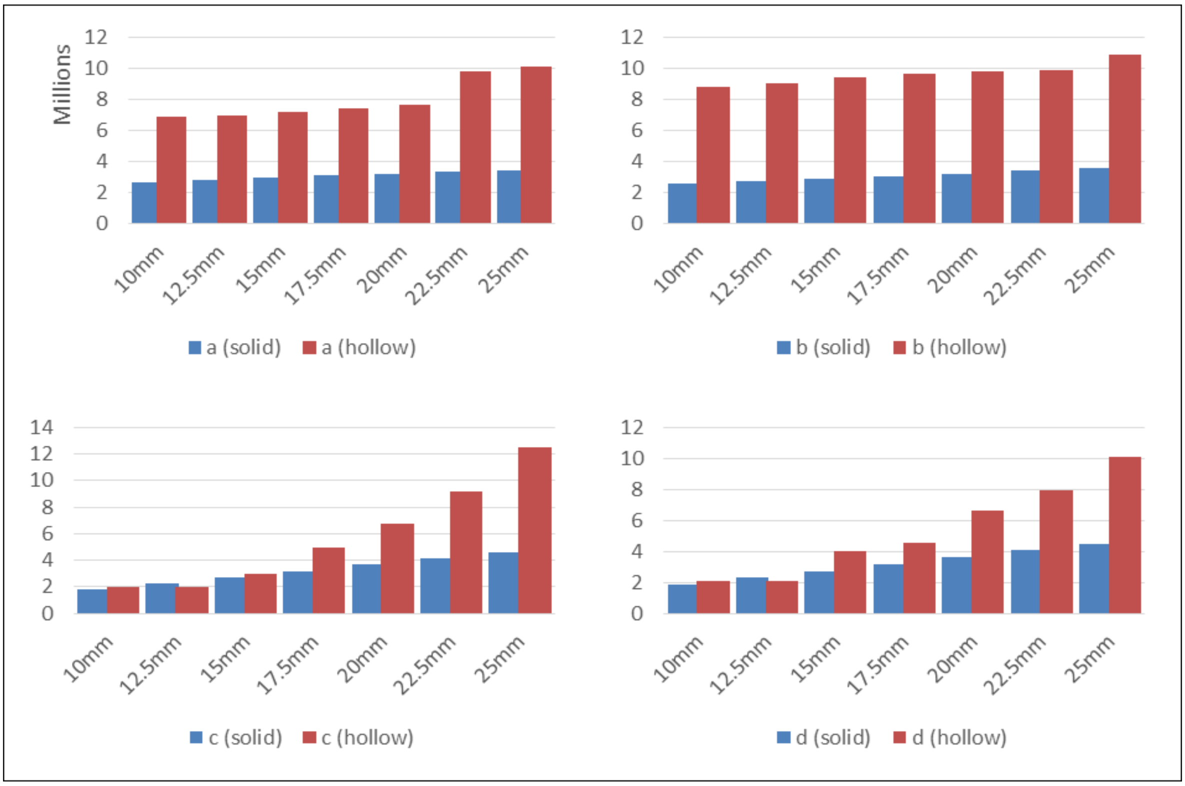

Fig. 5: Plastic Stress at Points a, b, c and d for both Solid and Hollow Beams (MPa)

For plastic stress, as shown in Fig. 4, stresses increase as the dimension of the opening increases. Plastic stresses at points ‘a’ and ‘b’, both of which are below neutral axis, increases sharply as the opening has been introduced. After that, stresses increase gradually for points ‘a’, ‘b’ and ‘d’. Point ‘c’ undergoes excessive plastic stress compared to other three points. Additional bars have decreased plastic stress, similar to elastic stresses, though increasing diameter has very negligible effect.

It should be noted that as the dimension of web opening increases, distance of four points (a, b, c and d) from neutral axis is also increased. So, for better understanding, graphs in Figure 5 compare the plastic stresses in solid beam and plastic stresses in hollow beams at the same four points mentioned above. All four graphs in Figure 5 show that each of the four points undergoes significant plastic stresses due to web openings, which gradually increases as the size of openings has been increased.

CONCLUSIONS

In this study, 12 simply supported beams, with different size of web opening, were analysed by commercially available software COMSOL 4.3b. For all beams, the elastic and plastic deflection and stresses were recorded and compared. It can be concluded that

1. Beams with web opening undergo excessive elastic and plastic deflection under service load. The deflection gradually increases with the increment of cross sectional area of beam web opening.
2. Maximum deflection was found to be 3.38365 mm at 25 cm square opening.
3. Maximum elastic and plastic stresses were found to be 6.3 MPa and 20.3 MPa respectively, at the corner of 25 mm square web opening.
4. After providing two additional reinforcement with 10, 12, 14, 16 mm diameter bars, the deflections were found to be decreased significantly.
5. Stresses were found to be decreased significantly for two 10 mm additional reinforcement. But for 12, 14 and 16 mm bars, stresses were found to be similar and deflection were reduced significantly. So, addition of bars with higher diameter increases the local stiffness of the beam.
6. Stresses induced in four corners were found to be much higher than that of the solid beam. It happens due to stress concentration.

So, as the area of web opening was increased, deflection at mid-span and stresses (elastic and plastic) at four corners of the opening were also increased. To overcome excessive deflection, additional reinforcements should be provided with proper arrangement.

REFERENCES

Amiri, S; Masoudnia, R; Pabarja, AA. 2011. The study of the effects of web openings on the concrete beams. Australian Journal of Basic and Applied Sciences, 5(7): 547-556, 2011 ISSN 1991-8178.

Chen, CC; Li, CY; Kuo, MC. 2008. Experimental study of steel reinforced concrete beams with web openings. The 14th World Conference on Earthquake Engineering, October 12-17, 2008, Beijing, China.

Mansur, MA. 2006. *Design of Reinforced concrete beams with web openings.* 6th Asia-Pacific Structural Engineering and Construction Conference (APSEC 2006), 5 – 6 September, 2006. Kuala Lumpur, Malaysia.

Vasehiamiri, J; Alibygle, MH. 2004. Effect of small circular opening on the shear and flexural behavior and ultimate strength of reinforced concrete beams using normal and high strength concrete. 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada, August 1-6, 2004, Paper No. 3239.