

# EFFECT OF WEB OPENINGS OF CONSTANT DEPTH IN BEAMS OF DIFFERENT SHAPE IN PLAN

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**Abstract** – A Reinforced concrete beam with transverse web opening is a facility that allows the services such as telephone lines, air conditioning and ventilating ducts, to pass through the structure. Because of the change in the beam section the corners of the opening are subjected to large concentration of stress, possibly producing oblique cracks in the beam. The regions nearby the openings are measured as the weaker part of the beam. Therefore, a decline in bearing capability and also a change in the load transfer mechanism is experienced. Analytical study is carried out by using ANSYS 16.2. An attempt is made to analyse three beams of 3m span, with different shapes in plan such as curved (semicircular), half-hexagonal, straight beams with and without web openings like circular, rectangular and square openings of constant depth. Beams are analyzed for with and without CFRP wrapping. Provision of CFRP wrapping reduces by 9 to 14% for deformation, stress and resultant reactions in all types of beams.

**Key Words:** Circular beam, half-Hexagonal beam, Straight beam, Circular opening, Rectangular opening, square openings, CFRP wrapping, CATIA, ANSYS.

## 1. INTRODUCTION

Nowadays the RC beam structures are constructed with web openings commonly used for passing of pipes and ducts. These web openings contain mainly building services such as water supplying, electricity; air congaing; Computer & Telecommunication network lines.

The presence of an opening in the web of a RC beam leads to various troubles in the behavior of beam, like decrease the rigidity (stiffness) of beams, unnecessary cracking, unnecessary deformations and decrease in the beam strength. Also rapid change in the dimension of cross section of the beam leads to high stress focus at the corner's of opening. That possibly will direct to cracking, unacceptable from visual and durability viewpoints. The reduced rigidity of the beam may also give increase to unnecessary deflection under service load and result in a considerable redistribution of internal forces and moments in a continuous beam.

Concrete is a brittle material so, number of methods are used to make stronger the structural elements. They consist of surface laminates or wrapping of fiber

reinforced polymers in addition to make stronger with a variety of fibrous materials. The FRP materials are light in weight. It gives the excellent mechanical strength and being good resistant to the corrosive nature of aggressive environment under wide range of temperature. FRP is fine replacement for steel reinforcement in reinforced concrete structure. The openings are classified based on their dimension and positions. Web openings have been established in different shapes, for example rectangular, square, circular, hexagonal, elliptical and irregular shapes. Circular, square and rectangular type of openings is generally used. If the opening dia is  $1/4^{\text{th}}$  of the web depth, that considered as large opening.

## 1.1 Types of Beam and their openings Considered in this Project

### A. Straight beam

Straight beam carries only bending moment and shear force. Some examples of straight beams are ceiling beams, entrance of buildings, hidden or merged beams



Fig -1: Water pipe passing through straight beam

### B. Curved beam

A beam in which the neutral axis in the unloaded condition in curved instead of straight beam or If the beam is originally curved before applying the bending moment are termed as curved beam. A horizontally curved beams loaded transversely to its plane is subjected to torsion in addition to bending and shear. Its C.G always follows a certain curve i.e. axis and the plane of figure is normal to the curve. The curved beam can be an arch but an arch is not necessarily made from a curved beam. A few examples of curved beams uses for; circular water tanks, circular ceiling, balconies,

entrance of public buildings, windows, bridge decks, interior of homes and external decorative purpose



Fig -2: Curved beam of a building under construction

### C. Half Hexagonal beam

These beams are geometrically half hexagonal in shape. These beams are used for a few of the following examples, entrance of buildings, watching towers, windows sill, interior of homes and external decorative purpose



Fig -3: Watch towers in hexagonal beams shape

## 2. OBJECTIVES

1. To study the behavior of straight beam, semicircular beam and half hexagonal shaped beam without openings.
2. To study the behavior of straight beam, semicircular beam and half hexagonal shaped beam with circular, square and rectangular openings for constant depth.
3. To study the effect of strengthening of opening with CFRP laminates for different beams.

## 3. METHODOLOGY

### 3.1 Dimensional Details of Beams

In this work, three different shapes of beams in plan are used. All are having a span of 3m and constant cross sectional area of 120x230 i.e., 27600 mm<sup>2</sup> and subjected to concentrated load of 10kN each at 750mm from the support and application of load is above the web openings. Bearing of 120x50x8 is provided at each side of support section and same sized two steel plates are used to applying the load.

### 3.2 Cross Section of Beams

Beams are having constant cross sectional area. A Concrete beams of 120x230 i.e., 27600 mm<sup>2</sup>, And beam with 2mm thick CFRP wrapping is provided at opening zone on top surface of the beam up to 500mm in length. Area of CFRP is 1416mm<sup>2</sup> used.

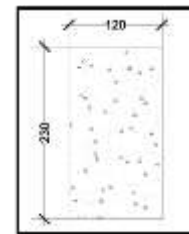


Fig -4: Cross section of concrete beams

### 3.3 Curved Beam (Semi-Circular)

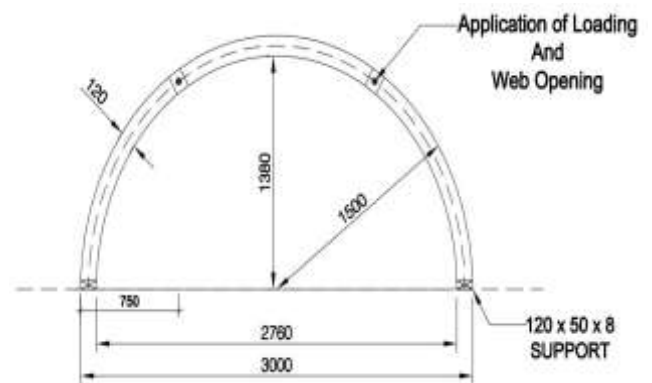


Fig -5: Curved beam in plan

### 3.4 Straight Beam

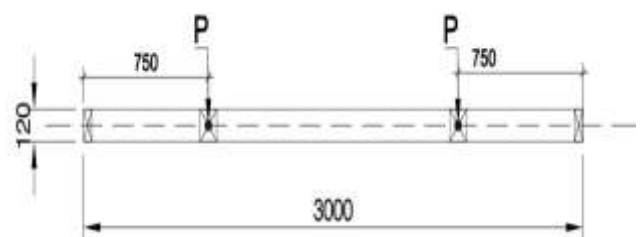


Fig -6: Straight beam in plan

### 3.5 Half Hexagonal Beam

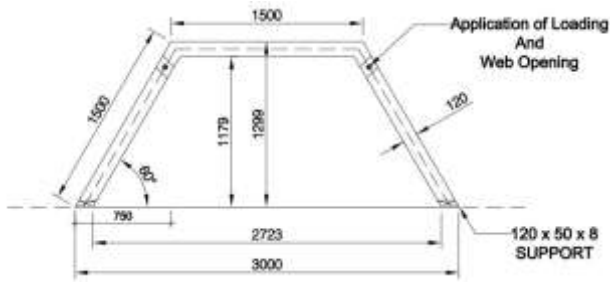


Fig.7: Half-hexagonal beam in plan

### 3.6 Sizes of different web openings for constant depth of opening

- A. Circular opening
- B. Rectangular opening
- C. Square opening

The openings are provided in the center of beam web for constant depth, 100mm deep web opening is provided.

### 3.7 Modeling by CATIA

All shape of beams are modeled by using CATIA and analysed by ANSYS forward.

#### A. Curved Beam Models by CATIA

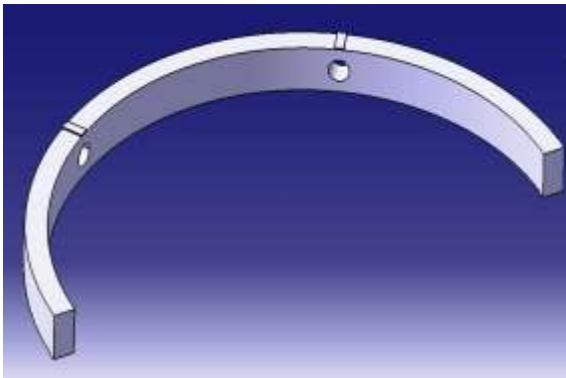


Fig -8: Curved beam with circular web opening

#### B. Half hexagonal Beam Models by CATIA

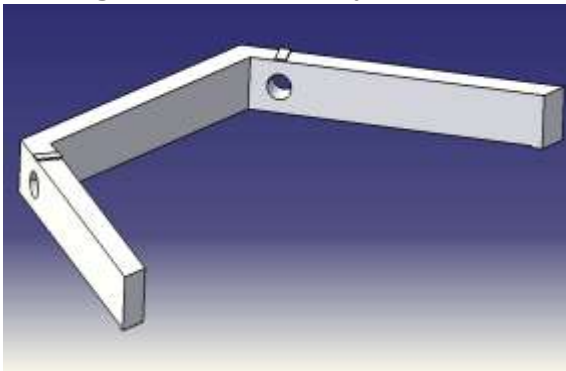


Fig -9: Half-hexagonal beam with circular web opening

### C. Straight Beam Models by CATIA

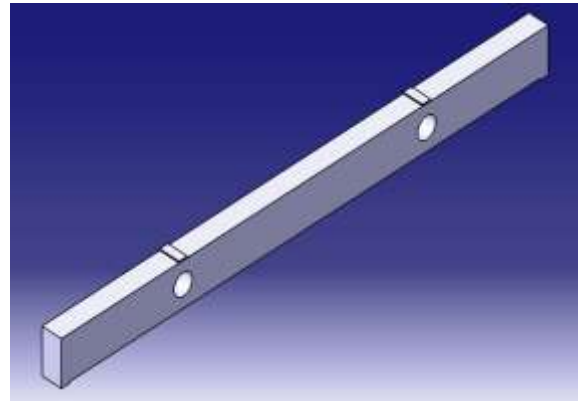


Fig -10: Straight beam with circular web opening

### 3.8 Material properties

#### A. Concrete

For concrete isotropic materials was used as fallow, M-25 Concrete is considered  
 Density is  $2400 \text{ kg/m}^3$   
 Young's modulus is  $25 \times 10^3 \text{ MPa}$   
 Poisson's ratio is 0.18.

#### B. CFRP wrapping

For CFRP orthotropic elasticity was used and it is a good strengthening material. In this study, 2mm thick CFRP wrapping at opening zone is provided. Properties of CFRP wrapping materials are in Table -1.

Table -1: Properties of CFRP

| Properties of Outline Row 3: CFRP |                             |          |                    |
|-----------------------------------|-----------------------------|----------|--------------------|
|                                   | A                           | B        | C                  |
| 1                                 | Property                    | Value    | Unit               |
| 2                                 | Density                     | 1.55E+05 | kg m <sup>-3</sup> |
| 3                                 | Orthotropic Elasticity      |          |                    |
| 4                                 | Young's Modulus X direction | 2.3E+05  | MPa                |
| 5                                 | Young's Modulus Y direction | 17900    | MPa                |
| 6                                 | Young's Modulus Z direction | 17900    | MPa                |
| 7                                 | Poisson's Ratio XY          | 0.22     |                    |
| 8                                 | Poisson's Ratio YZ          | 0.22     |                    |
| 9                                 | Poisson's Ratio XZ          | 0.3      |                    |
| 10                                | Shear Modulus XY            | 11790    | MPa                |
| 11                                | Shear Modulus YZ            | 11790    | MPa                |
| 12                                | Shear Modulus XZ            | 6880     | MPa                |

### 3.9 Meshing Properties Considered

The meshing used is tetrahedron of 25mm element size.

### 3.10 Analysis

Analysis of beams is carried out by ANSYS 16.2 software.

All beams are analyzed and solutions are obtained for the following,

- A. Total Deformation in mm
- B. Equivalent (Von-Mises) stress in Mpa
- C. Forced Reactions at each support ends of beams in kN

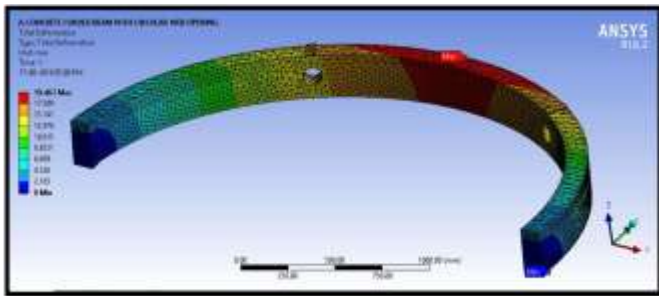


Fig -11: Deformation of Concrete curved beam for constant depth of circular web opening

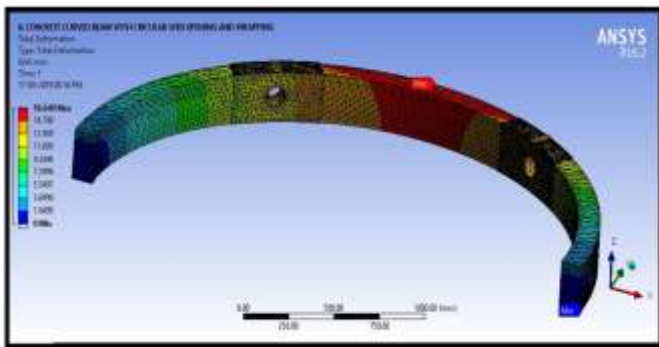


Fig -12: Deformation of Concrete curved beam for constant depth of circular web opening with wrapping

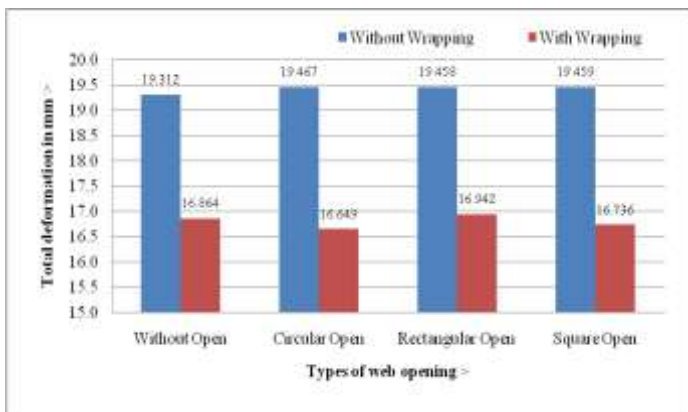


Fig -13: Deformation in curved beam for constant depth of different web opening with and without wrapping

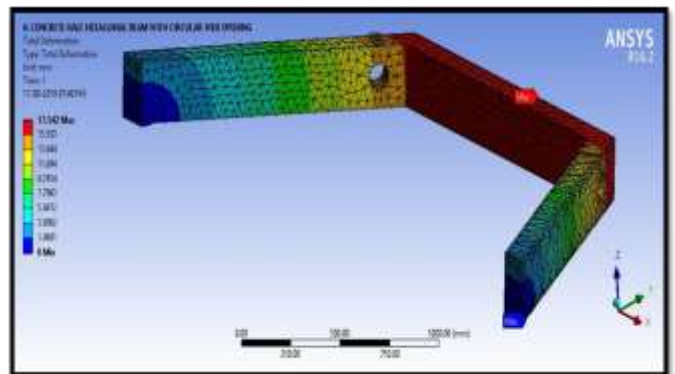


Fig -14: Deformation of Concrete half hexagonal beam for constant depth of circular web opening

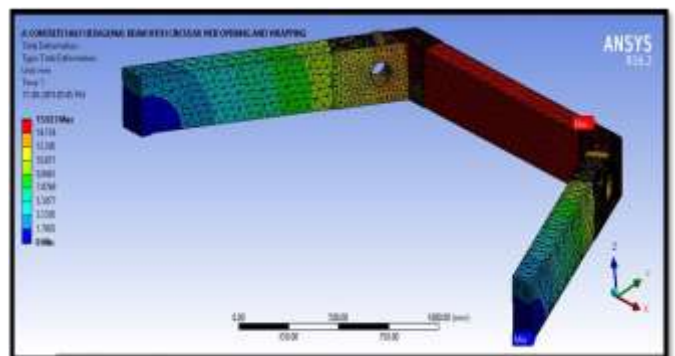


Fig -15: Deformation of concrete half hexagonal beam for constant depth of circular web opening with wrapping

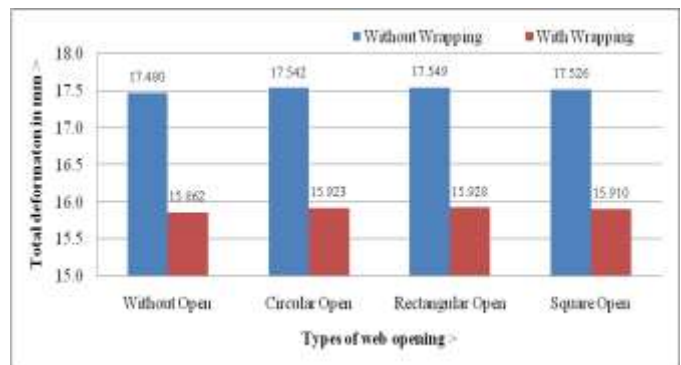


Fig -16: Deformation in half hexagonal beam for constant depth of different web openings with and without wrapping

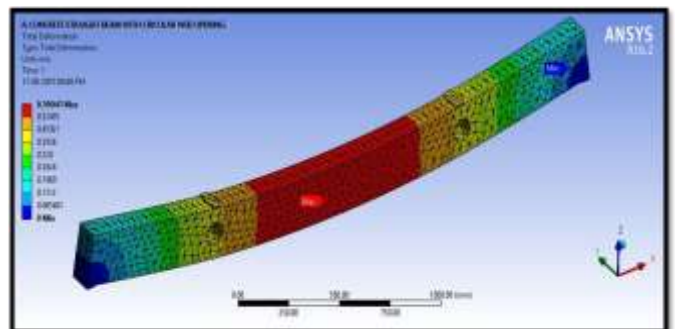


Fig -17: Deformation of concrete straight beam for constant depth of circular web opening

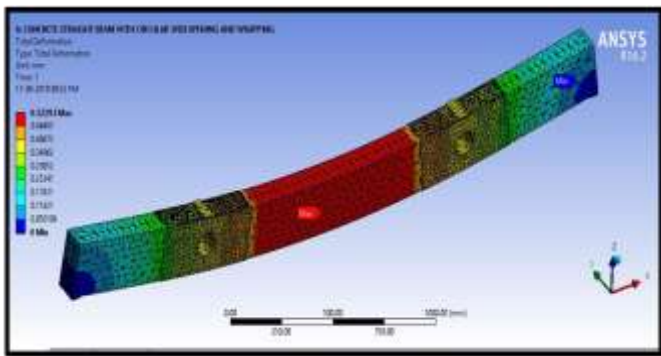


Fig -18: Deformation of concrete straight beam for constant depth of circular web opening with wrapping

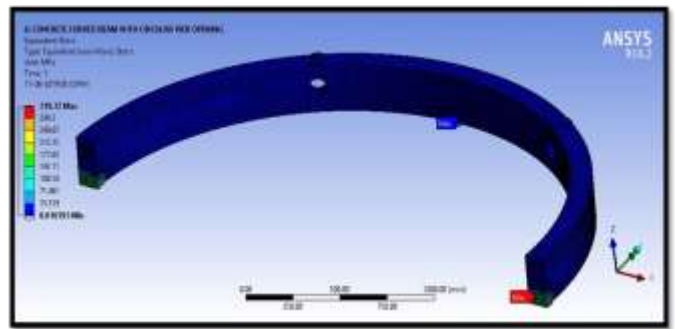


Fig-20: Stress for concrete curved beam for constant depth of circular web opening

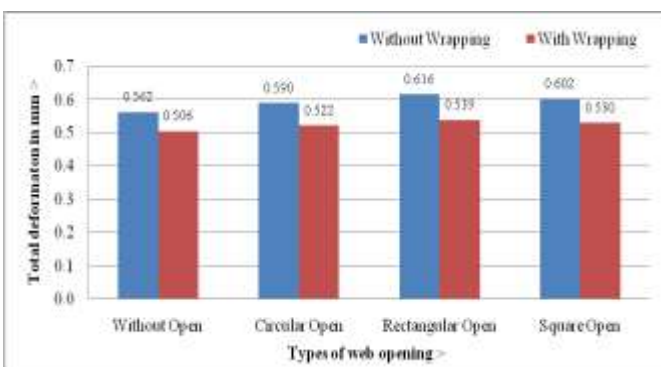


Fig -19: Deformation in straight beam for constant depth of different web openings with and without wrapping

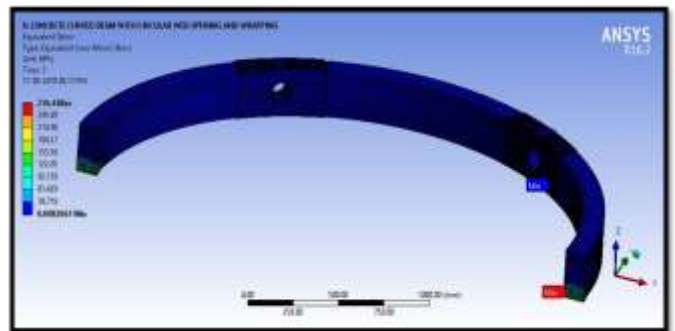


Fig-21: Stress for concrete curved beam for constant depth of circular web opening with wrapping

- Increase in deformation with the provision of web openings is negligible for constant depth of openings in all shape of beams.
- Deformation reduces by providing CFRP wrapping.
- Deformation reduces by 12.68% to 14.48% by providing CFRP wrapping for all type of web openings of constant depth in curved beam.
- Deformation reduces by 9.14% to 9.24% by providing CFRP wrapping at opening zone for all type of web openings of constant depth in half hexagonal beam.
- Deformation reduces by 9.96% to 12.50% by providing CFRP wrapping at opening zone for all type of web openings for constant depth in straight beam.

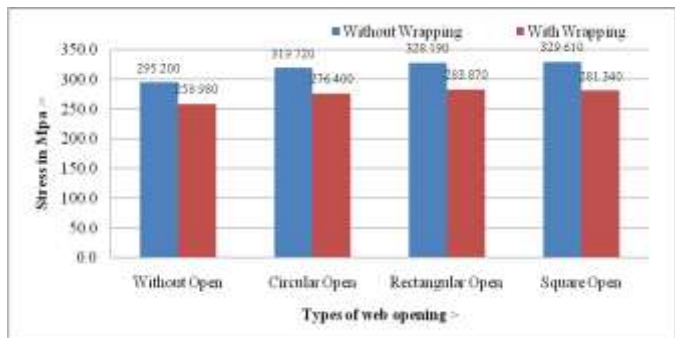


Fig -22: Stress in curved beam for constant depth of different web openings with and without wrapping

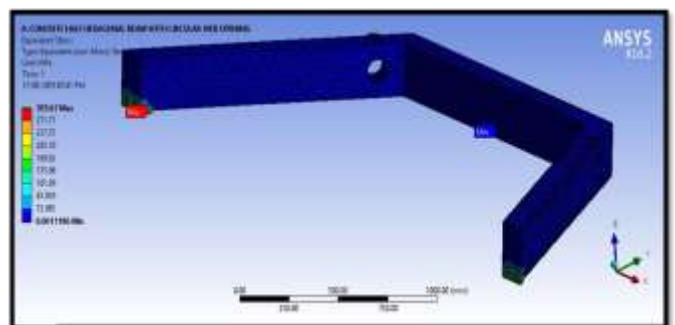


Fig -23: Stress for concrete half hexagonal beam for constant depth of circular web opening

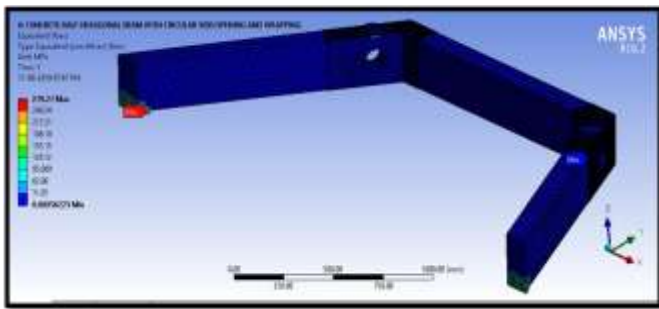


Fig -24: Stress for concrete half hexagonal beam constant depth of circular web opening with wrapping

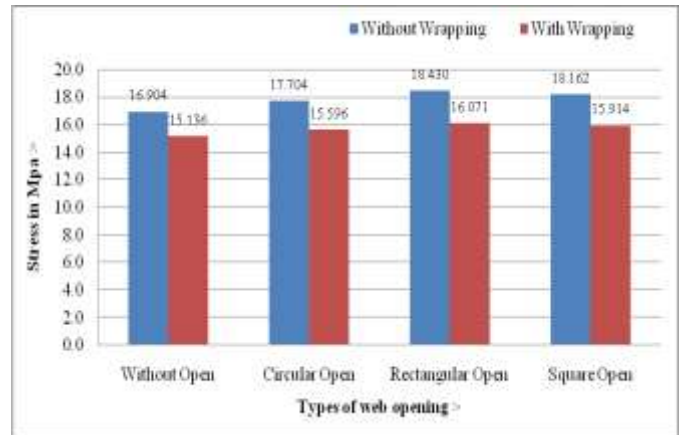


Fig -28: Stress in straight beam for constant depth of different web openings with and without wrapping

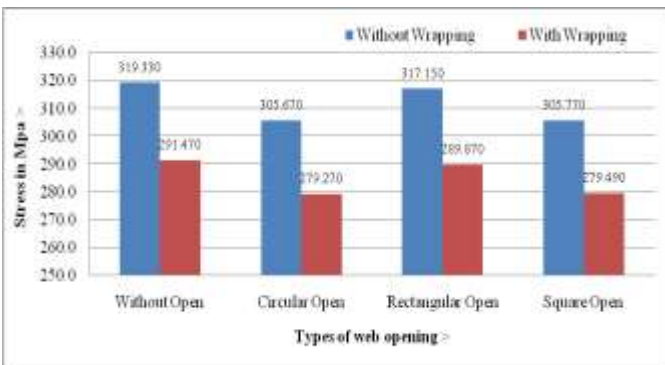


Fig -25: Stress in half hexagonal beam for constant depth of different web openings with and without wrapping

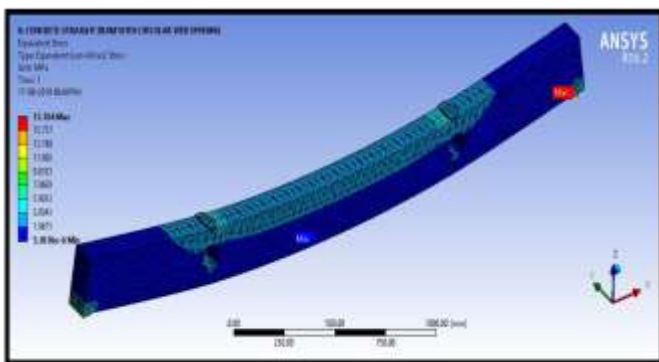


Fig -26: Stress for concrete straight beam for constant depth of circular web opening

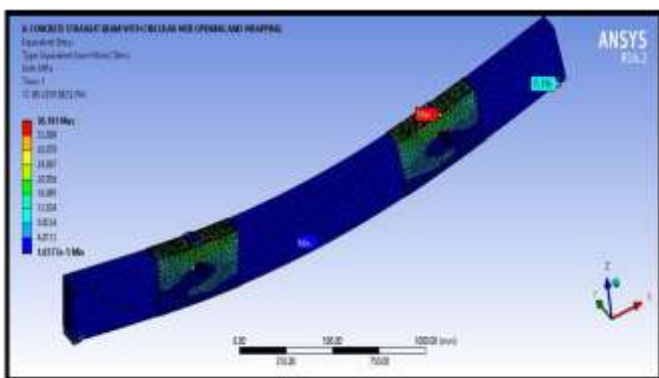


Fig -27: Concrete straight beam for constant depth of circular web opening and with wrapping

- Maximum stress is observed in square and rectangular opening for without wrapping beam in all shape of beams.
- Due to provision of opening in concrete beam stress will increase by 7.50-10.50% for constant depth of web openings compared to without openings in curved beam.
- Due to provision of opening in concrete beam stress will increase by 4.50-8.30% for constant depth of web openings compared to without openings in straight beam.
- Stress reduces with the provision of CFRP wrapping.
- Stress reduces by 12.27 to 14.64% for constant depth of web openings by the introduction of wrapping at opening zone in curved beam.
- Stress reduces 8.60 to 8.72% for constant depth of web openings by the introduction of wrapping at opening zone in half hexagonal beam.
- Stress reduces 10.46 to 12.80% for constant depth of web openings by the introduction of wrapping at opening zone in straight beam.
- Minimum stress is observed for curved beam, half hexagonal beam and straight beam with circular web opening with CFRP wrapping than other openings.

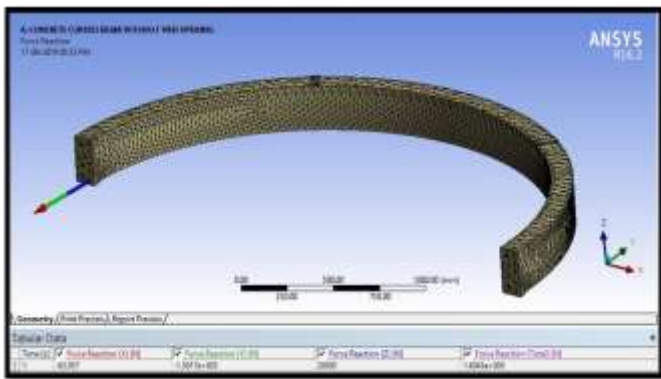


Fig -29: Resultant forced reaction for curved beam

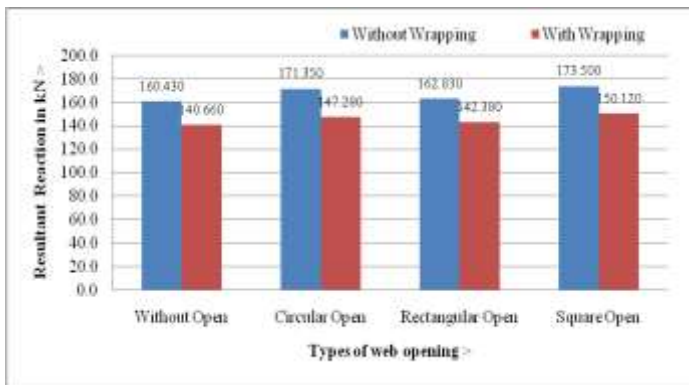


Fig -30: Total resultant forced reaction in curved beam for constant depth of different web openings with and without wrapping

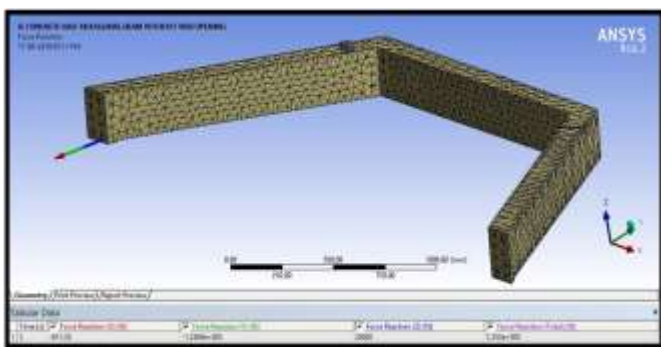


Fig -31: Resultant forced reaction for half hexagonal beam

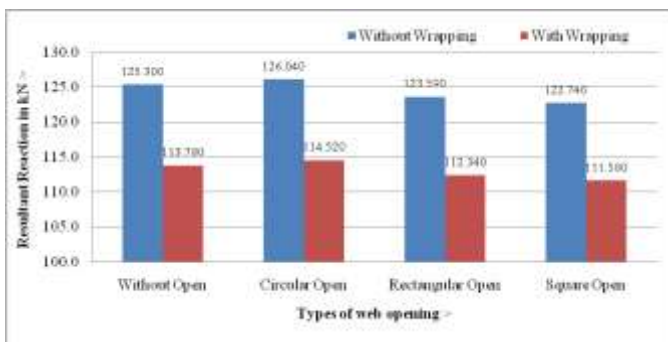


Fig -32: Total resultant forced reaction in half hexagonal beam for constant depth of different web openings with and without wrapping

- Due to provision of opening in concrete beam total resultant reactions will increase by 1.47 to 7.53% for constant depth of web openings compared to without openings in curved beam.
- Resultant forced reactions decrease by providing CFRP wrapping at opening zone for all types of web openings.
- A reduction of forced reaction 12.32 to 14.05% for constant depth of web openings due to CFRP wrapping in curved beam.
- Maximum resultant forced reactions in half hexagonal beam with circular web opening are observed for constant depth of opening in half hexagonal beam.
- Reduction of total resultant forced reactions is by 9.09-9.19% for constant depth of web openings due to CFRP wrapping in half hexagonal beam.
- Straight beam shows almost same resultant reactions for with and without openings and wrappings.
- No variations are observed in this type of straight beam.

#### 4. CONCLUSIONS

In this study attempt has been to check the behavior of different shapes of beams in plan such as curved beam, half hexagonal beam, and straight beam with different openings such as circular, square, and rectangular opening. The static analysis is carried out by ANSYS. Totally 18 models are analyzed. The analysis results are tabulated and compared i.e., 12 models each in 3 different shape of beams with and without opening and external surface wrapping at opening zone.

- Increases in deformation with the provision of web openings web openings are negligible for both constant depths of openings in all type of beams.
- Deformation reduces by providing CFRP wrapping for constant depth of opening in all the types of beams.
- 9 to 14% deformations are reduces by providing CFRP wrapping.
- Stress increases with the provision of web openings for constant depth of opening in all the types of beams.
- CFRP wrapping reduces stress in all beams of web openings with constant area and constant depth.
- 8 to 14% stress are reduces by providing CFRP wrapping.

- vii. Resultant reactions increase in curved beam whereas for half hexagonal beam resultant reactions reduce by providing web openings.
- viii. A resultant reaction reduces by providing CFRP wrapping in all types of beams.
- ix. 9 to 14% resultant reactions are reduced by providing CFRP wrapping.

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