Evaluation of Ultimate Strength of Reinforced Concrete Deep Beams with Web Openings

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Abstract: The present research investigates the effects of the opening shape and location on the ultimate strength of reinforced concrete deep beam with web openings, while keeping the opening size unchanged. The software ANSYS 14.5 is used to handle the nonlinear finite element analysis. The present work concludes that the opening location has much effect on the structural strength than the opening shape. It was concluded that placing the openings near the upper corners of the deep beam may increase the strength, and the use of a rectangular narrow opening, with the long sides in the horizontal direction gives optimum results.

Keywords: Deep Beams, Finite Element, Opening, Reinforced Concrete.

I. INTRODUCTION

Reinforced concrete deep beams are widely used as transfer girders in offshore structures and foundations, walls of bunkers and load bearing walls in buildings. The presence of web openings in such beams is frequently required to provide accessibility such as doors and windows or to accommodate essential services such as ventilating and air-conditioning ducts. Provision of such openings due to mechanical / architectural requirements and/ or a change in the building’s function would reduce the element shear capacity, thus rendering a severe safety hazard. When such a provision is unavoidable, adequate measures should be taken to strengthen the beam to counteract the strength reduction. In the present research the opening size is fixed, while the opening shape and location are altered to obtain optimal results.

As per IS Code 456-2000 Clause 29.1, A beam shall be deemed to be a deep beam when the ratio of effective span to overall depth L/D is less than:
1) 2.0 for a simply supported beam; and
2) 2.5 for a continuous beam.

Because of the geometry of deep beams, their behavior is different from slender beams or intermediate beams.

II. FINITE ELEMENT

A. Concrete

The eight nodes element “CONCRET65” is used in the present research to model concrete material. The element is also called “SOLID65”. It is used for the 3 solids with or without reinforcing bars (rebar). The element is capable of cracking in tension and crushing in compression. In concrete applications, for example, the solid capability of the element may be used to model the concrete while the rebar capability is available for modeling reinforcement behavior. Other cases for which the element is also applicable would be reinforced composites (such as fiberglass), and geological materials (such as rock). The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y and z directions, as shown in Figure 1(a) and Figure 1(b).

This element has special cracking and crushing capabilities, and its most important aspect is the treatment of nonlinear material properties. The concrete is capable of cracking (in three orthogonal directions), crushing, plastic deformation and creep.

Reinforced concrete deep beams are members in which a significant amount of the load is carried to the support by compression thrust joining the loading and reaction point. Reinforced concrete beams with openings have complex stress and had been investigated by many researchers in the last decade [2], [3], [5], [15]. In the present research, the opening size is fixed, while the opening shape and location are altered to obtain the optimal results. The present work investigates the opening optimum shape and location, rather than studying how to strengthen an opening with fixed shape and location.

Finite element method is a numeric method which can solve complex and difficult physical problems with acceptable approximation. As concrete is a material showing nonlinear behavior during loading, it is modeled in such a way that it will show a nonlinear behavior with (Ansys + Civil FEM) finite element program which is the most advanced comprehensive reputable finite element analysis and design software package.
available for Structural Engineering Projects. The System combines the state of the art general propose structural analysis features of ANSYS with the high and civil engineering specific structural analysis capabilities of Civil FEM, making it a unique and powerful tool for a wide range of civil engineering projects [11].

The rebar are capable of tension and compression, but not shear. They are also capable of plastic deformation and creep. However, the rebar capability of this element was not used in the present work, because the discrete reinforcement model is adopted, in which the reinforcing bars are modeled using the BEAM 188 elements, and then merged with the concrete elements in the proper locations

![Figure 1(a): Geometry of the Element Concrete](image)

![Figure 1(b): 6 node (Prism Option)](image)

**Figure 1:**

**B. Steel Bars**

The BEAM188 element is suitable for analyzing slender to moderately stubby/thick beam structures. This element is based on Timoshenko beam theory. Shear deformation effects are included. BEAM188 is a linear (2-node) beam element in 3-D with six degrees of freedom at each node. The degrees of freedom at each node include translations in x, y & z directions and rotations about the x, y & z directions. Warping of cross sections is assumed to be unrestrained. The beam elements are well-suited for linear, large rotation, and/or large strain nonlinear applications. BEAM 188 includes stress stiffness terms, the stress stiffness terms provided enable the elements to analyze flexural, lateral and torsional stability problems (using Eigen value buckling or collapse studies with arc length methods). Elasticity and isotropic hardening plasticity models are supported (irrespective of cross section subtype) [4].

![Figure 2: BEAM 188 3-D Linear Finite Strain Beam](image)
III. MATERIAL MODELING

A. Concrete

It is not an easy task to establish accurate stress relationship for concrete. Concrete has crushing and cracking possibilities, and behaves differently in compression and tension. Fig. 3 shows the typical stress-strain curve for normal weight concrete [8]. In compression, the stress-strain curve for concrete is linearly elastic up to about 30 percent of the maximum compressive strength. Above this point, the stress increases gradually up to the maximum compressive strength. After it reaches the maximum compressive strength descends into a softening region and eventually crushing failure occurs at an ultimate strain $\varepsilon_{cu}$. In tension, the stress strain curve for concrete is approximately linearly elastic up to the maximum tensile strength. After this point, the concrete cracks and the strength decreases gradually to zero [2].

The Poisson ratio for concrete is usually taken as 0.2 [4], [5].

$$f_c = 0.62\sqrt{f'_c}$$  \hspace{1cm} (1)

Figure 3: Typical stress-strain curve for concrete [8]

The following equations are used to obtain a simplified stress-strain relationship for concrete [6] & [8]:

$$f = E_c \varepsilon / [1 + (\varepsilon / \varepsilon_0)^2]$$ \hspace{1cm} (2)

$$\varepsilon_0 = 2f'_c / E_c$$ \hspace{1cm} (3)

$$E_c = f / \varepsilon$$ \hspace{1cm} (4)

$f$ : Stress at any strain $\varepsilon$

$\varepsilon$ : Strain at stress $f$

$\varepsilon_0$ : Strain at the ultimate compressive strength $f'_c$

Figure 4 shows this simplified relationship which is used in the present research:

Figure 4: Simplified compressive stress-strain curve for concrete [8]

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B. Steel Bars

The bilinear model is used in the present work to represent the stress-strain relationship for steel bars in the ANSYS 14.5 software. This elastic-perfectly plastic model is shown in Fig.5. Stress-strain curve for steel bars [8]

![Stress-strain curve for steel bars](image)

Figure 5: Stress-strain curve for steel bars [8]

IV. PARAMETRIC STUDIES

Many techniques were suggested in the previous researches to enhance the structural behavior of R.C deep and ordinary beams with opening [2], [5], [9] and [10]. However, the present work focuses on the effects of both opening location and shape, on increasing the structural strength of the reinforced concrete deep beam with opening. The following cases were studied to enhance the structural behavior of the deep beam, while keeping its opening having area 22,500 mm².

A. Square Opening

In this case, the original beam has 150 mm x 150 mm square opening. Three locations in the shear zone, one near the top, one at the mid depth of beam and one near the bottom of the beam are considered for strength of the beam versus the distance d.

B. Rectangular Opening 1

In this case, the square opening is replaced with a rectangular one (225 mm x 100 mm), (i.e. the one having same area of cross section) with the long sides of the opening extended in the horizontal direction.

C. Rectangular Opening 2

In this case, the rectangular opening 1 is replaced with rectangular opening 2, which has the same dimensions but long sides extended in the vertical direction.

V. MODELING DATA

The beam is modeled with length of the beam = 1750 mm, overall depth = 1167 mm and thickness = 150 mm having a square opening of size 150 mm X 150 mm reinforced with 2 Nos. 20 mm diameter bars at a clear cover of 25 mm.
Figure 6(a), Figure 6(b), and Figure 6(c): Beam Models with openings

Table 1: Beam Modeling Data

<table>
<thead>
<tr>
<th>Length of span</th>
<th>L/D ratio</th>
<th>Overall depth of beam</th>
<th>Thickness of beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>1750 mm</td>
<td>1.50</td>
<td>1167 mm</td>
<td>150 mm</td>
</tr>
<tr>
<td>1750 mm</td>
<td>1.75</td>
<td>1000 mm</td>
<td>150 mm</td>
</tr>
<tr>
<td>1750 mm</td>
<td>2.00</td>
<td>875 mm</td>
<td>150 mm</td>
</tr>
</tbody>
</table>

Figure 7: Meshed Model of Beam
V. CONCLUSION

The finite element analysis implemented in the present work shows fair agreement with previous researches. Despite the complexity of the problem of irregular stress, this software was found completely efficient in handling such analysis. The best shape for the opening, in the deep beam considered, is the narrow rectangular one, with the long sides extended in the horizontal direction. The best location of the opening, regardless of its shape, is far from the arching action and the flexure region, which is near the upper corners of the beam.

Table 2: Ultimate Strength of RC deep beam with shape and location of opening for L/D=1.5, L/D=1.75 and L/D=2.0

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Shape Of Opening</th>
<th>Location of Opening in the shear zone</th>
<th>Ultimate Strength (in kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>L/D=1.5</td>
<td>L/D=1.75</td>
</tr>
<tr>
<td>1</td>
<td>Square</td>
<td>At near the top</td>
<td>173.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>At Mid height</td>
<td>161</td>
</tr>
<tr>
<td></td>
<td></td>
<td>At near the bottom</td>
<td>117.45</td>
</tr>
<tr>
<td>2</td>
<td>Rectangular Opening With Length Parallel To The Horizontal</td>
<td>At near the top</td>
<td>186.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>At Mid height</td>
<td>--</td>
</tr>
<tr>
<td>3</td>
<td>Rectangular opening With Length Parallel To The Vertical</td>
<td>At near the top</td>
<td>163.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>At Mid height</td>
<td>--</td>
</tr>
</tbody>
</table>

Figure 9: Ultimate Crushing Strength in kN v/s L/D ratio

VI. REFERENCES


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