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# Structural Behaviour of Reinforced Concrete Haunched Beam A Study on ANSYS and ETABS

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## Abstract

Beams are the major structural element that is capable of carrying and transferring load which is designed primarily for bending and shear. A careful approach in its design will lead to efficient use of concrete and steel reinforcement. Prismatic beams are commonly used in medium span beams. As span increase such beams become uneconomical due to increase in depth. In such situation non prismatic beams (haunched beams) are good solution. In the present study the structural behaviour of reinforced concrete haunched beam is studied in ANSYS and ETABS. Seismic analysis of RC frames with linear and stepped haunch beams will be studied based on the Time Period, Base Shear and Inter storey Drift. Nonlinear finite element analysis is carried out in both software's. Parametric study is done by varying the haunch angle.

***Keywords:*** *reinforced concrete haunched beam (RCHB), prismatic beam, nonlinear finite element method*

## 1. Introduction

Members those do not have the same cross-sectional properties from one end to the other, those having reinforcement over parts of their lengths and those do not have a straight axis are known as Non-prismatic beams. The most common forms of structural members that are non-prismatic have haunches that are either stepped or tapered or parabolic in shape.Non-prismatic concrete beams can provide steel and concrete savings when used to replace equivalent strength prismatic elements.

The non-prismatic members having varying depths are frequently used in the form of haunched beams. The cross-section of the beams can be made non-prismatic by varying width, depth, or by varying both depth and width continuously or discontinuously along their length. Variation in width causes difficulty in construction. Therefore, beams with varying depth are generally provided. Either the soffit or top surface of the beam can be inclined to obtain varying cross-section, but the former practice is more common. The soffit profile may have triangular or parabolic haunches. Effective depth of such beams varies from point to point and the internal compressive and tensile stress resultants are inclined. It makes the analysis of such beams slightly different from prismatic beams.Reinforced concrete haunched beams (RCHBs) are used in cantilever retaining wall, framed buildings, simply supported and continuous bridges for economic and aesthetic reasons.

They favor more efficient use of materials to clear a given span or to provide a reasonable clear height for the stories of buildings.They provide the following advantages with respect to prismatic beams under lateral loading:

(a) More efficient use of concrete and steel reinforcement,
(b)The weight of the building can be reduced for a given lateral stiffness,
(c)Eases the placement of different facilities or equipment (electrical, air conditioning, sewage, etc.)
(d)Aesthetic reasons.

## 2. Modelling of RCHB and Prismatic Beam Using Finite Element Method in Ansys

A conventional reinforced concrete beam and haunched beam were modelled in ANSYS as volume. Quarter of the total dimension are modelled.

### 2.1 Description of analytical model

Prismatic beam size: 165cmX65cmX11cm.
RCHB size: h max: 45cm
h min: 25cm
Beam thickness: 11cm

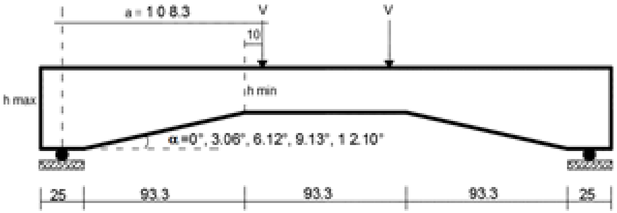

Fig. 1 Geometry, loads and boundary conditions of RCHBs

Table 1: Description of models

| ***Models*** | ***Haunch Angle(∞)*** |
|---|---|
| 1RCHB-$S_{0,}$ RCHB-$S_{1}$ | 3.06° |
| 2RCHB-$S_{0,}$ RCHB-$S_{1}$ | 6.12° |
| 3RCHB-$S_{0,}$ RCHB-$S_{1}$ | 9.13 ° |
| 4RCHB-$S_{0,}$ RCHB-$S_{1}$ | 12.10 ° |

## 2.2 Element Types

Table2: Element types used for modelling

| ***Components*** | ***Element Types*** |
|---|---|
| Concrete | SOLID 65 |
| Steel reinforcement | LINK 180 |
| Loading plate | SOLID 185 |

## 2.3 Meshing

To obtain good result from the solid 65 element, the use of rectangular mesh was done. There for the mesh was set up such that rectangular elements were created. A suitable mesh size is chosen to achieve sufficient accuracy and at the same time not to lengthen the runtime too long.

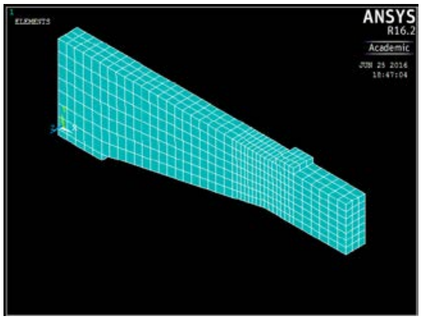

Fig. 2 Meshed model of RCHB

## 2.4 Boundary Conditions and Loading

Instead of modelling the total structure, quarter portion was modelled. At a plane of symmetry, the displacement in the direction perpendicular to the plane was held at zero. A single line of nodes on the plate were given constraint in the y and z directions. Four point loading system and loading plates are established to make actual loading system. The introduction of loading plates will increase the distribution of load throughout the structure

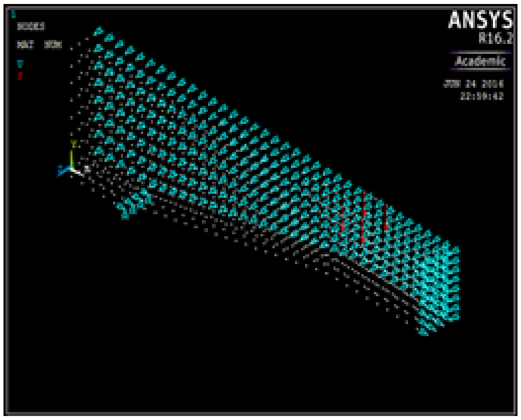

Fig. 3 Boundary condition and loading

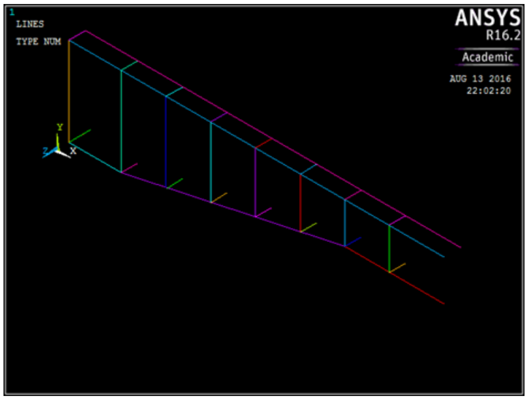

Fig. 4 Flexure and shear reinforcement configuration

## 3. Modelling of prismatic and haunched frame buildings in ETABS

In ETABS Nonlinear version 13.1.2, one can model non prismatic beams by dividing the element length into any number of segments; these do not need to be of equal length. Non prismatic properties are interpolated along the length of each segment from the values at the two ends. The variation of bending stiffness may be linear, parabolic or cubic over each segment of length.

### 3.1 Material Properties

Density of concrete is 25 KN/ m3. M-25 grade of concrete and Fe 415 grade of reinforcing steel are used for all the frame models considered in this study. The modulus of elasticity for concrete is taken as 25000Mpa

### 3.2 Geometry and Loading Conditions

In the present study, Bare frames situated in seismic zone 3 are considered with variations of heights (G+2), (G+4), (G+6), (G+8),Depth of foundation is taken as 1.5m .The storey height taken is 3m.Two types of non-prismatic members are developed which includes linear haunch (LH) and stepped haunch (SH). The size of prismatic beam is taken as 500mmx300mm and size of non-prismatic beam at the support as 1000mm and 750mm at the mid-section with a width of 300mm. Sizes of columns have been taken as 500mmx 300mm. Thickness of slab is taken as 150 mm; floor finish load is 1 KN/m2, Live load on floor slabs is 4 KN/m2.

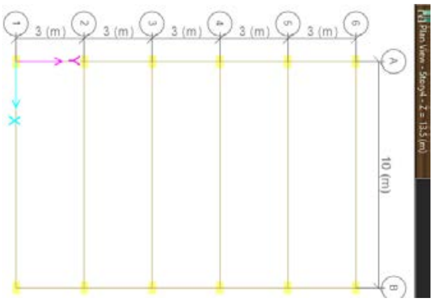

Fig. 5 Plan of building

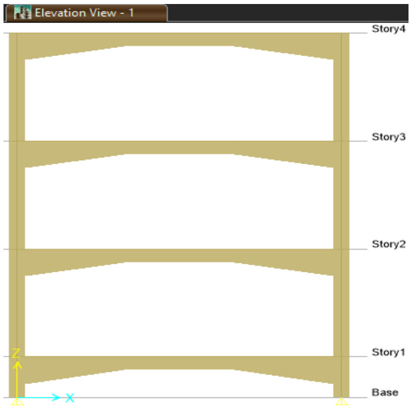

Fig. 6 Elevation of frame with linear haunch

### 3.3 Methodology

Nonlinear static Pushover analysis: pushover analysis is a useful tool for assessing inelastic strength and deformation demands in the structure, and for exposing design weaknesses .its foremost advantage is that it facilitates the design engineer to recognize important seismic response quantities and to use engineering judgement to alter suitably the force and deformation demands and capacities that controls the seismic response close to failure. The main output of pushover analysis is in the form of a force-displacement curve, called pushover curve

## 4. Analysis Results

### 4.1 Ansys

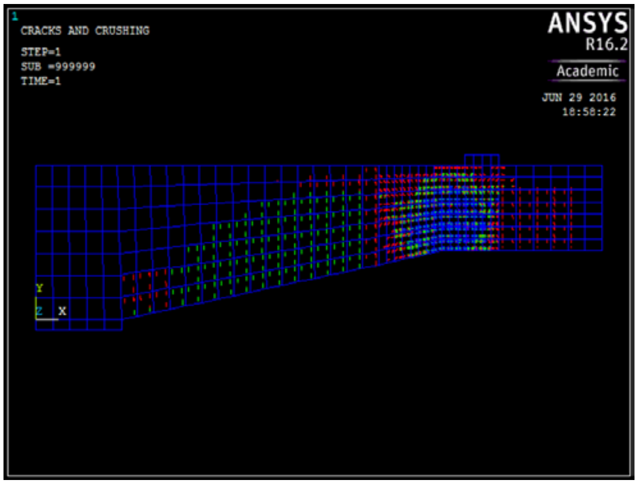
CRACKS AND CRUSHING
STEP=1
SUB =999999
TIME=1

Fig. 7 Crack pattern of reinforced concrete haunched beam

The reason for such crack pattern is supposed to be that , the bending shape of tensile rebars caused the stress concentration near the bending position, while the tensile force tended to straigten the bent rebars and push over the concrete cover.

When ever there is a change of direction in a main reinforcing bar , a resultant radial force is generated at the location of the kink. If the radial force acts outwards, this force tends to push out the cover concrete causing splitting. Moreover , as a staight length is shorter than the bent length of the bar, the spalling will lead to a relieving of the bar stress resulting in lowering of the resistance of the section against cracking and possible failure. when the angular change is small (say < $15^{o}$) the radial force resultant is small and can be carried and transffered to the

compression zone by providing adequate number of stirrups at the location of the kink .
The most demanded stirrups were those that were located between the vertex and the midsection of the haunched length.

The FE-analysis demonstrates that the shear forces are transferred in uncracked compression zone mainly. Therefore crack friction and dowel action plays no significant role on shear bearing capacity at the ultimate limit state. As a result of the FE-analysis and the test program, a shear resistance action of uncracked concrete part in the tension zone is firstly introduced to be one of the two main shear bearing actions of concrete structures without stirrups.

### 4.2 Etabs

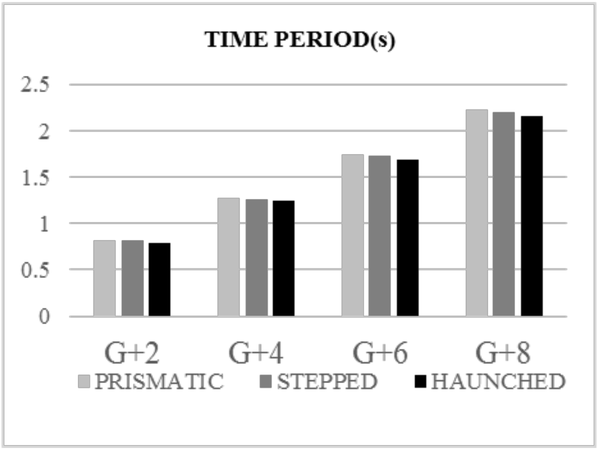

Fig. 8 Variation of Time Period in seconds

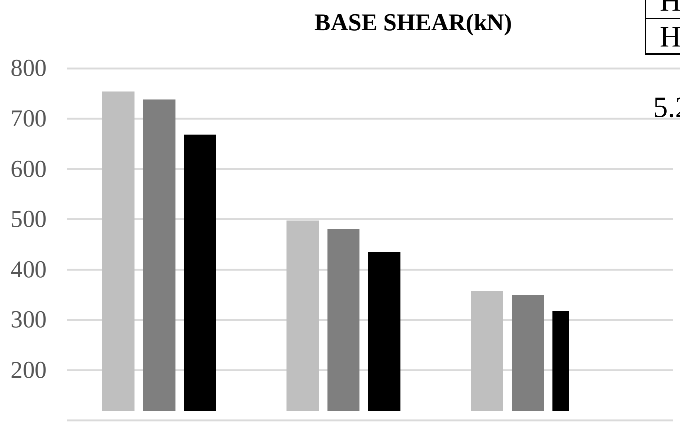

Fig. 9 Variation of Base Shear in kN

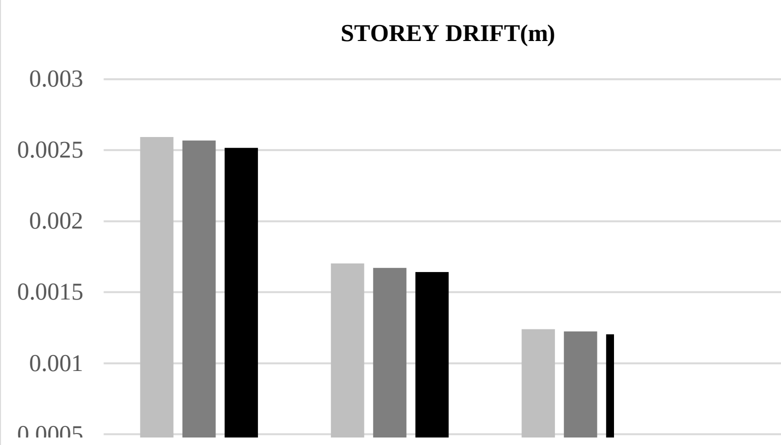

Fig. 10 Variation of Interstorey Drift in mm

## 5. Parametric Study

### 5.1 Description of analytical model

$h_{max}$ = 1000mm, thickness of beam: 300mm,
Haunch length= 3.3m Span length: 10 m

Table 3: Description of Models

| *HA MODELS* | *Haunch angle(∞)* | *H min(mm)* |
|---|---|---|
| HA 1 | $6.54^o$ | 750 |
| HA 2 | $7.47^o$ | 600 |
| HA 3 | $8.39^o$ | 550 |
| HA 4 | $9.30^o$ | 500 |
| HA 5 | $10.22^o$ | 450 |
| HA 6 | $11.12^o$ | 400 |
| HA 7 | $12.03^o$ | 350 |
| HA 8 | $12.92^o$ | 300 |

### 5.2 Analysis Results

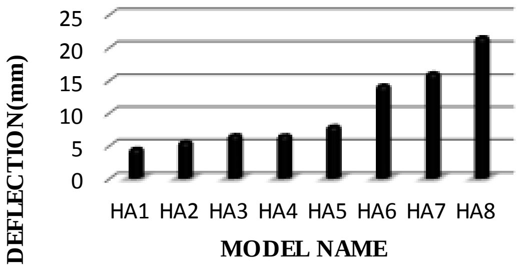

Fig. 11 Deflection chart

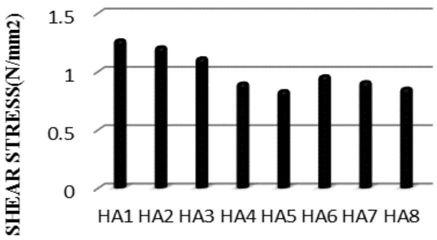

Fig.12 Shear stress chart

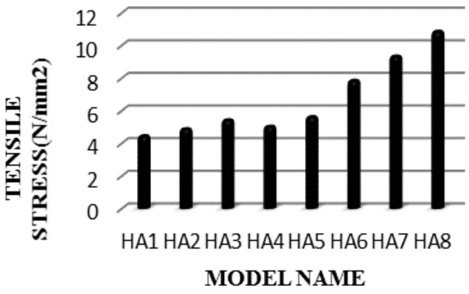

Fig.13 Tensile stress chart

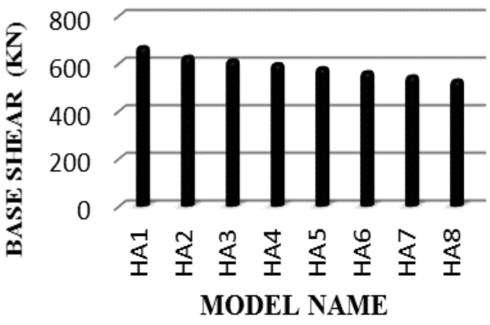

Fig. 14 Base shear chart

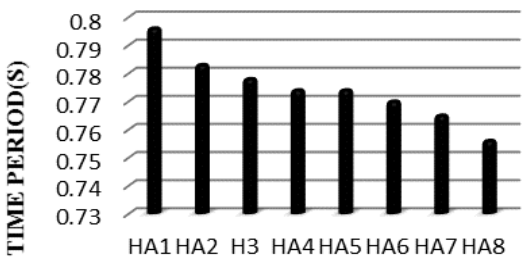

Fig. 15 Time Period chart

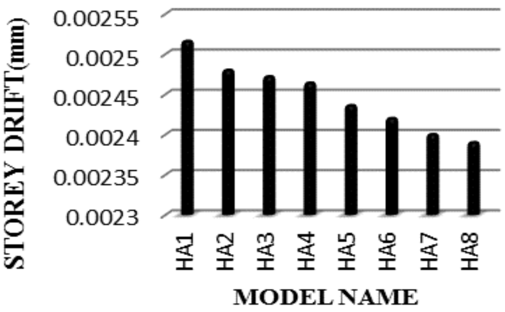

Fig. 16 Storey Drift chart

## 6. Conclusions

The existence of vertical shear resistance component due to inclination of the concrete compression chord reduces the design shear force .Shear forces are transferred in uncracked compression zone mainly. RCHBs have the ability to redistribute cracks along haunch length so brittle and sudden shear failure of prismatic elements is reduced in RCHBs due to this behaviour.

1. Fundamental natural period T is an inherent property of a building. Any alterations made to the building will change its T. Time period of prismatic beams are close to the haunched beams.
2. The presence of non-prismatic member can affect the seismic behaviour of frame structure i.e. it decreases the

stiffness of the structure which in turn reduces the base shear.
3. The presence of non-prismatic member Increase the lateral stiffness of buildings substantially, control the code drift limits.

## 6.1 Conclusions on parametric study

Deflection: Deflection increases as haunch angle increases
Shear stress: Shear stress values are within the permissible limit and it decrease in both H4 and H5 models.
Tensile stress: Tensile stress increase as haunch angle increases
Time period: Time period is decreasing with haunch angle.
Base shear: Base shear values have less percentage of difference in all the models.
Storey drift: Storey drift is decreasing with increase in the haunch angle.

From the parametric study, for the models HA4 and HA5 give good result for the whole studied factors. The optimum HAUNCH ANGLES that can be taken for RCHBs in the parametric study are:

- H4 = $9.30^{o}$
- H5 =$10.22^{o}$

**Acknowledgments**

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