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Behaviour of Rectangular Concrete Deep Beams with Hybrid Fibre Reinforced Polymer Reinforcements Considering Web Openings

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Abstract: The use of non-corrosive reinforcements in the place of steel reinforcements has therefore been focused as an alternative to improve the life span of the concrete structures. Fibre Reinforced Polymer (FRP) reinforcements offer many advantages over steel reinforcements including resistance to electrochemical corrosion, high strength to weight ratio and easy in fabrication and electromagnetic insulating properties. Further, the use of hybrid FRP reinforcements, in lieu of conventional steel reinforcements requires better understanding under different parametric conditions. Therefore the present study deals mainly with the behaviour of Concrete Deep beams with and without openings reinforced internally with hybrid type Fibre Reinforced Polymer (FRP) reinforcements under static loading conditions. In structural applications, deep beams are commonly used as large span structures such as transfer girders in buildings, bridges, foundation walls, shear walls and offshore structures. In this study,high strength concrete deep beams are investigated. Among the eight beams, four beams are reinforced internally using conventional reinforcements with and without web opening, four beams are reinforced internally using hybrid FRP reinforcements with and without web openings. Different parameters like, high strength concrete, web opening positions (Top, Middle and Bottom), span sprinkled FRP hybrid reinforcements are considered. Based on this study, static load carrying capacities and their modes of failures of deep beams reinforced internally with FRP hybrid type reinforcements for various web openings positions are compared by finite element modelling using ANSYS software with the existing theories for better under standings. Based on the modelling and theoretical work, final conclusions of the present study are derived.

***Keywords*: Hybrid Fibre Reinforced Polymer (HFRP) reinforcements, Deep beams, modelling, web openings, shear span to depth ratio.**

I. INTRODUCTION

Fibre matrix composites made of different proportions of fibres and resins are now commercially utilized as reinforcing agents in place of conventional ferrous reinforcements for conventional concrete structures.

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The advantages of fibrous reinforcements, when compared with metallic reinforcements, gives a better strength and serviceability [1],[3],[15].

The application of non-metallic reinforcements gains its use both in reinforced concrete and pre-stressed concrete works all over the world.

Most of the studies techniques specially, within the early years had been directed closer to behaviour of concrete deep beams reinforced with conventional reinforcements [8].

However, the application of hybrid non-metallic reinforcements in concrete deep beams with and without web openings in concrete structures, their behaviours under different positions of web openings [4],[6],[20] and the formulation of rational design specifications are not well explored with regard to Indian standards[3].

The non-metallic reinforcements, few decades, have received much attention in structural applications including bridge structures.

Despite their successful introduction into the construction industry, the widespread acceptance of non-metallic reinforcements by the engineering industry depends on timely development of design guidelines and specifications.

Hence, the present work has been proposed to study the behaviour of concrete deep beams reinforced with non-metallic reinforcements with and without web openings and their suitability for codal recommendations [5],[18],[19],[28],[29].

Although an extensive research has been carried out on the behaviour of FRP reinforced structural elements in other countries very limited studies have been carried out in India.

There is a need for modelling and analytical study that accounts for the fundamental issue related to the hybrid FRP reinforcements and their interaction with the concrete under static loading conditions with and without web openings [9],[16],[17].

II. FINITE ELEMENT MODELLING

This Chapter introduces the finite element modelling and analysis of conventional and Hybrid reinforced concrete beams under static loading.

In this, the details of finite elements used in this study are explained and then the method of modelling of concrete deep beams is explained.

Then, the type of analysis to be performed is explained. Finally the result of the study is compared with the theoretical values.

Table- I: Material properties of Steel/Hybrid reinforcements

Properties	Steel(F_e)	Hybrid (H_f)
Modulus of elasticity E_s, (GPa)	210	64.70
Bar size (mm)	12	12
Tensile strength, for main reinforcement	520	518
Tensile strength, for stirrup reinforcement	520	147
Compressive strength, f_{Hybrid} (MPa)	660.98	760.05
Poisson's ratio	0.3	0.23

Table- II:Material properties for concrete

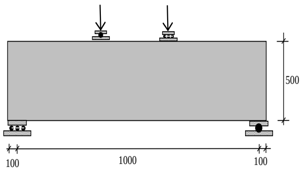
Properties	M60 Grade
Elastic modulus E_c (GPa)	32000
Poisson's ratio	0.2
Ultimate compressive stress f_{cu}(MPa)	76.00
Tension stiffening coefficient, α	0.6
Tension stiffening strain coefficient, ε_m	0.0016

Table- III:Various Parameters Considered In Deep Beams

Parameters	Description	Designation
Type of reinforcements	Hybrid FRP	H
	Conventional steel	C
Positions of duct	No Duct	ND
	Middle	MD
	Top	TD
	Bottom	BD

A. *Finite Element Discretization*

An important step in finite element modelling is the selection of solid and link elementsFig. 2(a), 2(b), 2(c). The solid elements in ANSYS can be used for linear analysisand for complex nonlinear analyses involving contact, plasticity and large deformations.



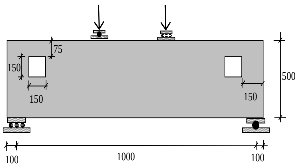
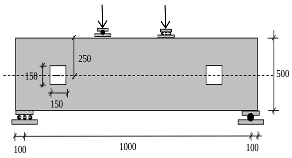


Fig. 1(a) Model of beam with loading (Non Duct) **Fig. 1(b) Model of beam with loading (Top Duct)**



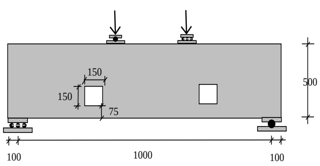
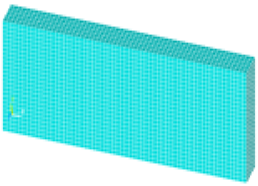


Fig. 1(c) Model of beam with loading (Middle Duct) **Fig. 1(d) Model of beam with loading (Bottom Duct)**



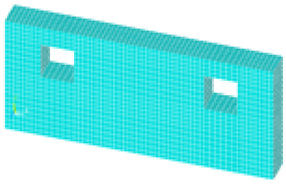


Fig. 2(a) Deep beam Model without web openings (Solid elements) **Fig. 2(b) Deep beam Model withweb openings (Solid elements)**

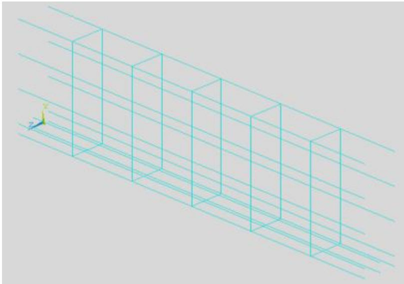


Fig. 2(c) Deep beam Model Reinforcement (Link elements)

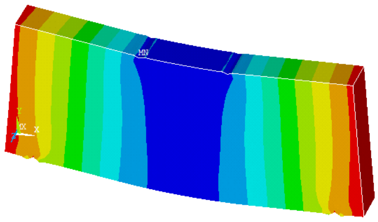


Fig. 3(a) without opening

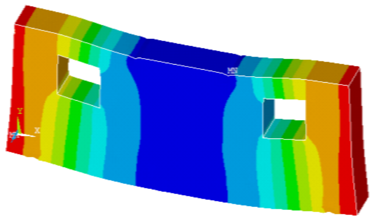


Fig. 3(b) Top openings

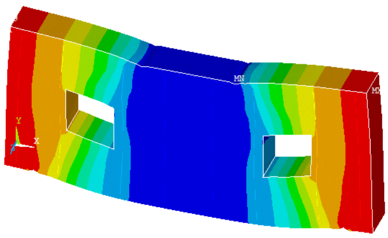


Fig. 3(c) Middle openings

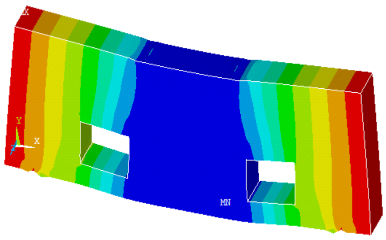


Fig. 3(d)Bottom openings

Fig. 3 Displacement contour diagram for Deep Beam obtained from ANSYS

III. ANALYTICAL INVESTIGATIONS

Proposed design equation from Kong & Sharp (1973):

FromV_u Kong & Sharp [12] noting the scarcity of literatures on deep with web openings, [12]they tested 24 reinforced light weight concrete deep beams with web openings. The results indicated that web reinforcement did considerable strength of deep beams with web openings were comparable to solid deep beams. From this study two design equations for these beams were proposed. When the opening is reasonably clear of the load path joining the support with the bearing plate, the beam may be considered as not having an opening, therefore the ultimate load capacity

$$V_u = c_1\left(1 - 0.35\,\frac{x}{D}\right) f_t bD + c_2 \Sigma A \frac{y}{D} sin^2\alpha \qquad (1)$$

The various parameters involved in the above equation are clearly explain in Fig.3

Fig. 3

Proposeddesign equation from Kong & Sharp (1990):

The proposed design equation is based on the equations recommended by Kong and Sharp[12]. The present study focuses on identifying the effect of opening especially location and effect of Hybrid reinforcements on the behavior of deep beams with web openings. The equation regarding main steel and/or web reinforcement is adopted from the proposal of Kong and Sharp[12].

$$V = V_C + V_S \qquad (2)$$

Where V is the ultimate strength of deep beams with openings, $V_C$and $V_S$are respectively the ultimate strength of concrete and steel. The ultimate strength of concrete, $V_C$by Kong (1990) was

$$Vc = C_1 . \lambda c . D . b . ft$$

(3)

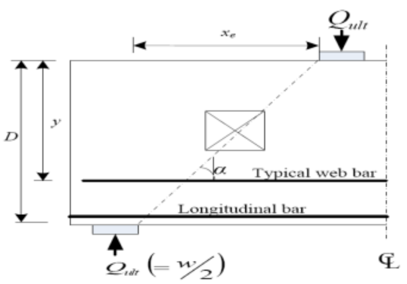


Fig. 3 Parameters involved in deep beam with web openings

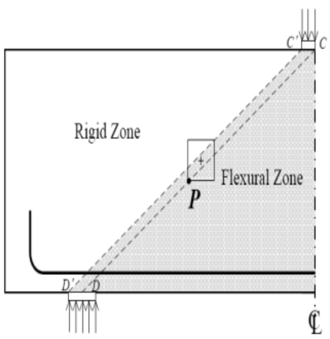


Fig. 4(a) Zone identificationin deep beams bydiagonal strut

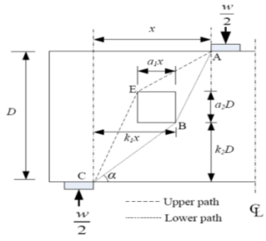


Fig. 4(b) Load paths in deepbeam with web opening

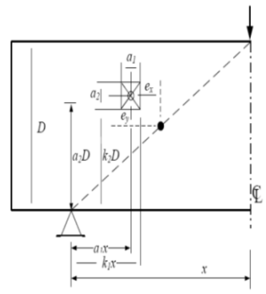


Fig. 4(c) Various parameters involved deep beams with web openings

Where C_1 is a parameter for high strength concrete,$\lambda_C$is a parameter of opening location and size, D is the overall depth of the deep beam, b is the thickness of deep beam and $f_t$is the calculated tensile strength.

$$\lambda_c = (1 - m) \quad (4)$$

Where, m = ratio of strength reduction of opening location and size $\frac{\Psi x}{\Psi y}$multiplied by shear span to depth ratio $\left(\frac{x}{D}\right)$.

$$\lambda_c = 1 - \frac{\Psi_x}{\Psi_y}\frac{x}{D} \qquad (5)$$

where$\Psi_x$is the strength reduction ratio of opening location and size in the horizontal direction and Ψ_y is that in the vertical direction.

$$\Psi_x = 1 - \frac{e_x}{x} \qquad (6)$$

$$e_x = 1 - (2k_1 - t_3 a_1)x$$

$$e_x = 1 - 2k_1 x - t_3 a_1 x \qquad (7)$$

Similarly,

$$\Psi_y = 1 - \frac{e_y}{D} \qquad (8)$$

Where the eccentricity of opening in vertical direction,

$$e_y = 1 - (2k_2 - t_4 a_2)D$$

$$e_y = 1 - 2k_2 D - t_4 a_2 D \qquad (9)$$

Substituting the equations, we get

$$\lambda_C = 1 - t_2 \frac{(2k_1 - t_2 a_1)}{(2k_2 - t_4 a_2)}\left(\frac{x}{D}\right) \qquad (10)$$

Thus we get,

$$V_C = C_1\left(1 - t_2 \frac{(2k_1 - t_2 a_1)}{(2k_2 - t_4 a_2)}\frac{x}{D}\right) f_t b k_2 \qquad (11)$$

The ultimate strength related to steel is given by

$$V_S = C_2 \Sigma \lambda \frac{A y_1}{D} sin^2\theta \qquad (12)$$

The coefficients of parameters (C_1,t_2,t_3 andt_4) are obtained by linear analysis based on least square method using parametric study results for best fit.

This yields for Rigid zone, C_1= 1.4, t_2= 0.7, t_3= -0.6 and t_4=0.4 and for flexure zone, C_1= 1.3, t_2= 0.15,t_3= -0.1 and t_4=0.9.

Thus the proposed design equation for high strength concrete deep beams with web openings is expressed as

$$V_u = C_1\left(1 - t_2\frac{(2k_1 - t_2a_1)}{(2k_2 - t_4a_2)}\frac{x}{D}f_t bk_2D\right) + C_2\Sigma\lambda\frac{Ay_1}{D}sin^2\theta \quad (13)$$

For opening located in Flexural zone the equation is expressed as

$$V_u = 1.3\left(1 - t_2\frac{(2k_1 - t_2a_1)}{(2k_2 - t_4a_2)}\frac{x}{D}f_t bk_2D\right) + C_2\Sigma\lambda\frac{Ay_1}{D}sin^2\theta (14)$$

For opening located in Rigid zone the equation is expressed as

$$V_u = 1.4\left(1 - t_2\frac{(2k_1 - t_2a_1)}{(2k_2 - t_4a_2)}\frac{x}{D}f_t bk_2D\right) + C_2\Sigma\lambda\frac{Ay_1}{D}sin^2\theta (15)$$

To verify the proposed design equation, a comparison of proposed equation and other existing equations is made utilizing the experimental results.

IV. RESULT AND DISCUSSION

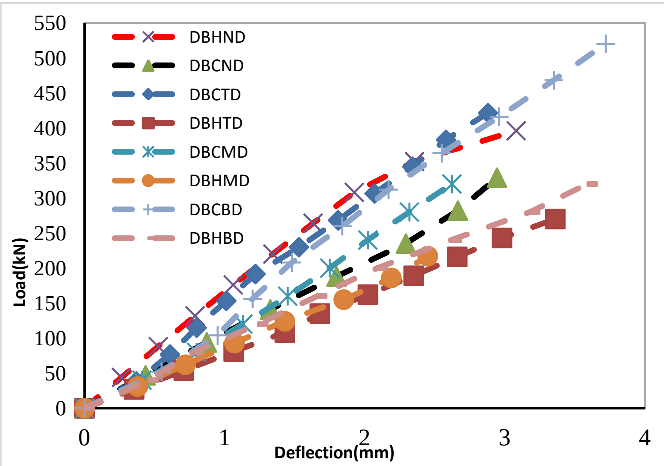


Fig. 5 Load vs Deflection of FEM

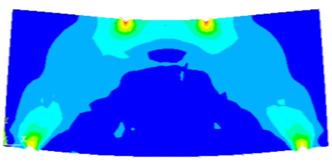


Fig. 6(a) Stress contour diagram obtained from ANSYS for the specimen without opening

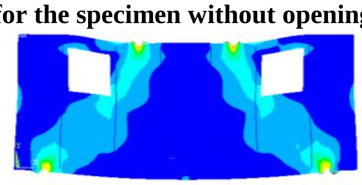


Fig. 6(b) Stress contour diagram obtained from ANSYS for the specimen with opening(Top)

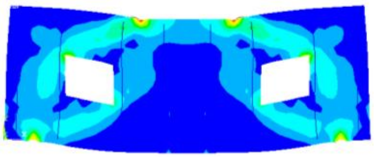


Fig. 6(c) Stress contour diagram obtained from ANSYS for the specimen with opening(Middle)

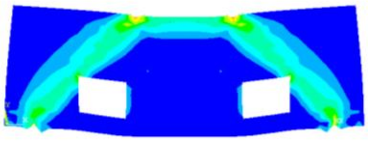


Fig. 6(d) Stress contour diagram obtained from ANSYS for the specimen with opening(Bottom)

Table-IV: Results compared with Theoretical and Experimental values

Beam	Vu(kN)			Vu (FEM) / Vu (Theo) (Kong 1973 and 1990)
	FEM	Theo. (Kong 1973)	Theo. (Kong 1990)	
DBCND60	461	451	-	1.02
DBHND60	431	404	-	1.07
DBCTD60	442	-	407	1.09
DBHTD60	267	-	223.5	1.19
DBCMD60	388	-	365	1.06
DBHMD60	293	-	292.5	1.00
DBCBD60	510	-	450	1.13
DBHBD60	396	-	359	1.10

The results of the finite element study are compared with experimental study to get better improvement in the finite element modelling.

1. The crack propagations is observed and the first cracks observed by FE are flexural, subsequently by shear cracks and then leads to main diagonal cracks. These cracks which are formed above the longitudinal reinforcements extend from support to loading point. Vertical cracks are also observed on the top surface of the models above the reaction points.
2. In FE analysis, the web opening considered at top and middle interferes the load path causes the compression struts into two paths which results approximately about 14% to 32% reduction in the load carrying capacity while the other positions of web openings does not interfere with the load path or compression struts, the observed reduction the load carrying capacity ranged from 6% to 8% depending on the opening dimensions.
3. In FE analysis, the anchorage cracks at the level of longitudinal reinforcements beyond the supports are observed.
4. In the FE results slightly over estimated the deflection corresponding to ultimate and service load results, but can simulate comparable observations at ultimate load stages with a mean analytical to FE for all simulated specimens of 1.13 with a coefficient of variation of 3%.

5. The most accurate simulations are found for the specimens without web openings, while specimens with web openings lead to slightly unconservative predictions the results show more consistent findings for beams having no web openings, clarifying that the path of compression strut crack models can accurately simulate the behaviour.
6. The results depict that the simulation procedures are stable and are provided reasonably accurate simulation of the behaviour, especially with regard to load–deflection response, crack patterns at different load stages, failure mode. All these indicate that the constitutive models used for modelling concrete and Hybrid reinforcements in ANSYS software are able to capture the behavior of deep beams at ultimate stage accurately. Consequently, this method may be used for the nonlinear analysis and design more precisely. The load versus deflection plots observed from finite element model at mid span across depth of the deep beams simulate well with the observations.
7. Based on Finite Element (FE) analysis, it is observed that the modelling approach in software can simulate the shape and propagation of load path upto ultimate. The observed load path for all the beams by FE approach agree well with the observations.
8. Each beam is analyzed under increasing incremental load of 10 kN up to failure. The ultimate load is assumed to occur when the solutions are not converged.
9. The load versus deflection shows good agreement with the data. However, the finite element models show higher load capacity than the experimental study and is primarily due to higher stiffness from FE modelling.
10. Concrete strain distribution in hybrid FRP reinforced concrete deep beams is nonlinear, and they do not conform to Bernoulli's assumptions for strain and stress distribution. This nonlinearity of strain distribution is due to the shear deformations that are often less obvious in FRP reinforced shallow beams, but that are significant in hybrid FRP reinforced deep beams

V. CONCLUSION

All concrete Deep Beam specimens with and without web openings and is reinforced internally with conventional reinforcements using a higher concrete grade (60MPa) have shown higher strength than that of hybrid reinforced specimens.

It is primarily due to the fact that hybrid FRP reinforcements reach their ultimate tensile strength without exhibiting strain hardening of material. Unlike steel, the tensile strength of hybrid FRP reinforcements show milder slope in the strain hardening region.

All specimens with and without web openings inferably show the ultimate deflection at the mid span of the specimens lower than that of specimens with hybrid reinforced. It is primarily due to the fact that the modulus of elasticity of hybrid FRP reinforcements is approximately 25% to 30% that of steel.

Deep beam shows predominant compression load along the strut path. The two dimensional state of stress and their strain distributions are non-linear.

It is observed that nearly 30 to 60 % strains across the depth of deep beam at mid span are under tension.

The deflection of a concrete member reinforced with Hybrid specimens is a major design consideration.

The existing theoretical load based on Kong and Sharp model for various parametric of deep beams with and without web openings is utilized for hybrid FRP reinforced concrete deep beams. A summary of the predictions by the proposed equations with respect to the FEM modelling results are presented. The predicted equations for steel/hybrid FRP reinforced deep beams with and without web openings show a more in-depth and nearly comparable range whilecompared. Consequently the present theories are more reliable to predict the behaviour of deep beams with and without web openings.

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