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NON-LINEAR ANALYSIS OF CONCRETE FILLED COMPOSITE SHORT COLUMNS

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ABSTRACT

Composite columns offer a number of advantages over conventional reinforced cement concrete (RCC) columns, hence making their application more varied and versatile. Larger cross sections required both, extra space and material. Steel columns in-filled with high strength concrete provide a solution to tackle this problem. In the present study, an effort has been made to reduce the cross-section of composite columns and to achieve higher load carrying capacity. Two methods have been evolved for computing the ultimate strength of concrete in-filled columns. Thickness, length and eccentricity are the constant parameter while perimeter, aspect ratio and grade of concrete are varied. It is assumed that the behavior of reinforcement either inside or outside has no effect on the stress-strain properties of concrete. It is concluded that the load carrying capacity of a concrete filled square column is 15% higher than that of rectangular column of same perimeter. The percentage increase in load carrying capacity of composite steel columns is 10% to 15% with increase in grade of concrete from M-20 to M-40. Further percentage increase in load carrying capacity varies from 73% to 86% for a change in columns perimeter from 800mm to 1200mm. Thus, the desired load carrying capacity of section can be achieved with a lower grade of concrete and lower perimeter by choosing the most efficient aspect ratio making the section more economical.

Keywords: composite columns, ductility, local buckling, reinforced concrete, steel sections and ultimate load

1 INTRODUCTION

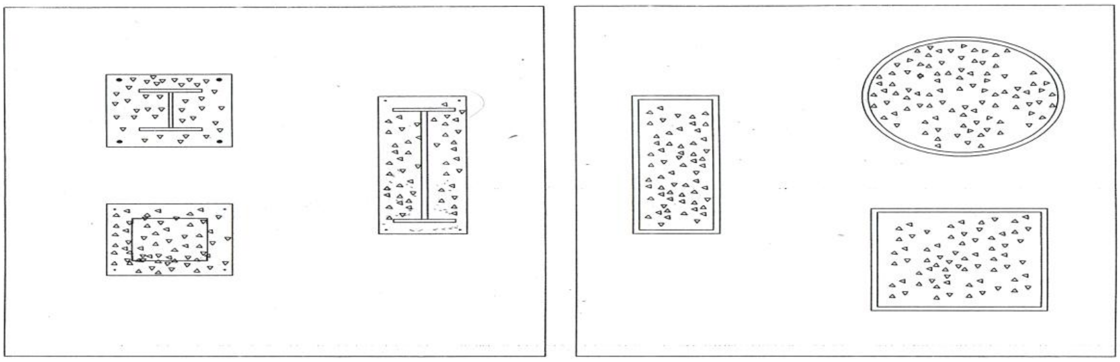
A composite column is a compression member with cross-section comprising either a concrete encased hot rolled steel section or a concrete filled tubular section that act together to resist external forces [1]. In a composite column both the steel and concrete would resist the external loading by interacting together through bond and friction [1,2]. Supplementary reinforcement in the concrete encasement prevents excessive spelling of concrete both under normal load and fire conditions [3,4]. This type of column offers high strength, ductility and large energy absorption capacity as well as provide rapid rate of construction [5,6,7]. Now a day's it is possible to produce concrete with high compressive strength which allow the design for more slender columns, permits more useable floor space by using composite columns consisting of concrete filled steel tubes [8,9,10]. The advantage of tubular columns over reinforced concrete columns is that the core and cover are two different layers where as in the composite section it is considered as homogeneous mass[11,12]. The transverse reinforcement in the form of ties or spirals is eliminated. The box section themselves acts as column forms, so column formwork cost would be eliminated. Concrete filled tubes are especially well suited for precast concrete columns for which a fine control on concreting can be made which is essential in use of high strength concreting[13].

Also inward buckling of the steel tubes is prevented by the concrete core which increases the stability and strength of column as a system [14].

Mainly, there are two types of composite columns:

(a Concrete encased steel sections
(b) Concrete filled steel sections.

The two types of composite columns have been shown in Fig. Below:



(a) Concrete encased steel section (b) Concrete filled steel section

Fig. 1 various types of composite column

2 Methodology Used

In the present study concrete filled steel column sections are analyzed by

a) Load and Resistance Factor Design (LRFD) Method
b) Design based on Euro-code 4

2.1 Load and Resistance Factor Design (LRFD) Method

This method [15] has been used for calculating the ultimate load carrying capacity of concrete filled steel tube sections. The Elastic critical load (P_{cr}) is worked out by Euler's formula. On the basis of factored axial strength (ϕN_0), the elastic critical 1oad (P_{cr}), eccentricity and the coefficients a_1, a_2, a_3, a_4, the axial strength of composite column section has been found out by using Newton Rapson Method [16,17]. The ultimate load carrying capacity is then worked out by number of trials. A series of exercises were carried out by varying the cross section and grade of concrete.
Concrete has an ultimate strain of 0.003 corresponding to an ultimate strength of 0.85 f_{ck} uniformly distributed over a depth of $\gamma(k_u d - t)$, a reasonable approximation of which is

$$\gamma = 0.85 - 0.007(f_{ck} - 28) \quad (1)$$

$$0.65 \le \gamma \le 0.85$$

The strain $\in$ at a distance y from the top reference fiber is given by

$$0.003\left\{\frac{k_u d - y}{k_u d - t}\right\} \quad (2)$$

The balanced condition is obtained by substituting $\in = \in_y$

At y = d

$$k_u d = \frac{d(600 + \sigma_y t / d)}{600 + \sigma_y} \quad (3)$$

$$T_2 = d(1 - k_u) t \sigma_b \quad (4)$$

$$T_f = (b2t) t \sigma_b \quad (5)$$

$$C_c = 0.85 f_{ck}\, \gamma (b - 2t)(k_u d - t) \quad (6)$$

The value of P_{cr} calculated at particular section may be assumed to be constant for a distance equal to d/2 , measured in the direction of increasing moment, from the particular section.

$$\phi N_0 = \phi_c (b - 2t)(d - 2t) 0.85 f_{ck} + 2\phi(b + d - 2t) t \sigma_y \quad (7)$$

Design strength in pure bending,

$$\phi M_0 = \phi_s z_s \sigma_y + \phi_s b t \sigma_y \left(\frac{d}{2} - \frac{t\sigma_y}{2 \times 0.85 \phi f_{ck}}\right) \quad (8)$$

$$\frac{\phi M_s}{\phi M_0} = 1 + 2\left(\frac{\phi N_s}{\phi N_0}\right) - 3\left(\frac{\phi N_s}{\phi N_0}\right)^a \quad (9)$$

$$\lambda = \frac{0.85(b - 2t)(d - 2t) f_{ck}}{2(b + d - 2t) t \sigma_y} \quad (10)$$

$$\alpha = 1.0 + 0.5\lambda \quad (11)$$

$$\phi M_s = \frac{(\phi N_s) e_0}{1 - \frac{\phi N_s}{P_{cr}}} \quad (12)$$

$$P_{cr} = \frac{\beta \pi^2 E_c I}{L^2} \quad (13)$$

$$\beta = 0.43 + 0.14\left(\frac{e_b}{e_0}\right) \le 1.0 \quad (14)$$

$$e_b = \frac{(\phi M_s)_b}{(\phi N_s)_b} \quad (15)$$

$$(\phi N_s)_b = \phi N_0 \left(\frac{2}{3\alpha}\right)^{1/\alpha - 1} \quad (16)$$

$$P_{cr} = \frac{\beta\pi^2 E_c I_c}{L^2}$$

$$\beta = (1 + \gamma + \gamma^2)^{1/2}$$

$$\alpha = \frac{0.45 A_c f_{ck}}{N_u}$$

$$N_u = A_s \frac{f_y}{\beta} + A_c(\sigma_u + 2\mu\gamma(\frac{t}{d})(\frac{f_y}{\beta})$$

$$\mu = 0.25(25 - \frac{L}{D})$$

$$\gamma = 0.02(25 - \frac{L}{D})$$

For perfectly elastic pin ended columns the elastic critical load 'P_{cr}'

is equal to the Eular load 'P_E

$$\therefore f(\phi N_u) = \phi N_u a_1 + (\phi N_u)^2 a_2 + (\phi N_u)^\alpha a_3 + (\phi N_u)^{\alpha+1} a_4 \quad (17)$$

$$a_1 = \frac{2}{\phi N_o} - \frac{1}{P_{cr}} - \frac{e_0}{\phi M_0} \quad (18)$$

$$a_2 = \frac{-2}{\phi N_o (P_{cr})} \quad (19)$$

$$a_3 = \frac{-3}{(\phi N_o)^\alpha} \quad (20)$$

$$a_4 = \frac{3}{(\phi N_o)^\alpha P_{cr}} \quad (21)$$

By Newton Raphson Method

$$(\phi N_u)^{r+1} = (\phi N_u)^r - \frac{f\{(\phi N_u)^r\}}{f'\{(\phi N_u)^r\}} \quad (22)$$

$$f'\phi N_u = a_1 + a_2(\phi N_u) + \alpha a_3(\phi N_u)^{\alpha-1} + (\alpha+1)a_4(\phi N_u)^\alpha \quad (23)$$

The final value is worked out by Newton Raphson method. This method gives an accurate approximate value. Initially the coefficients a_1, a_2, a_3, a_4 are worked out by the Equations 18 to 21. For iteration purpose, first the value of $f(\phi N_u)$ is assumed, then the value of $f'(jN_u)$ is worked out. Similarly the next approximate value is calculated. By making numerous trials so that there is no change in final trial value, the accurate value is calculated.

2.2 Design based on Euro-code 4

As per the specifications given by Euro-code 4[13], the load carrying capacity of concrete

filled steel tube columns has been found out based on the phenomenon that structural adequacy, the internal forces and moments resulting from the most unfavorable load combination should not exceeds the design resistance of the composite cross sections, while local buckling of the steel sections may be eliminated. Besides this "Institute for Steel Development and Growth"(INSDAG), [18,19,20] has given out specifications and guidelines for designing the composite concrete structure based on Euro-code 4 which has been used for the design of composite columns.
The ultimate load carrying capacity has been worked out analytically. A series of exercises were carried out by varying the cross section and grade of concrete and to obtain the results**.**

Plastic Resistance of composite columns is calculated by:

$$P_p = A_a.f_y / \gamma a + \alpha_c A_c.(f_{ck})_{cy} / \gamma_c + A_s.f_{ck} / \gamma_s$$

$$P_p = A_a.f_y / \gamma a + \alpha_c A_c[0.80 \times f_{ck})_{cu}] / \gamma_c + A_s.f_{sk} / \gamma_c \quad (24)$$

Extension of IS: 456-2000 to composite columns will result in the following equation:

$$P_p = A_a.p_y + A_c p_{ck} + A_s.p_{ck} \quad (25)$$

Where

$$p_y = 0.87 f_y ; p_{ck} = 0.4(f_{ck})_{cu} \text{ and } p_{sk} = 0.67 f_y$$

Design parameter $\beta_{\mathbf{a}}$ is given by:

$$\beta_a = \frac{A_a \times p_y}{p_p} \quad (26)$$

The eccentricity, *e*, is defined as follows

$$e = \frac{M}{P} \leq \frac{D}{10}$$

The plastic compression resistance of concrete filled circular tubular sections is calculated by using

two coefficients η_1 and η_2 as given below.

$$P_p = A_a \eta_2 p_y + A_c p_{ck}[1 + \eta_1 \frac{t}{D} \frac{f_y}{f_{ck}}] + A_s p_{sk} \quad (27)$$

η_1 and η_2 two coefficients given by

$$\eta_1 = \eta_{10}[1 - \frac{10e}{D}]$$

$$\text{and } \eta_2 = \eta_{20} + (1 - \eta_{20})\frac{10e}{D}$$

Table 1. Basic value of η_{10} and η_{20} to allow for the effect of tri-axial confinement in concrete filled circular tubular sections, as provided in Euro-code 4 applicable for concrete grades ($(f_{ck})_{cy}$ = 25 to 55 N/mm^2

	$\bar{\lambda}$ =0.0	$\bar{\lambda}$ =0.1	$\bar{\lambda}$ =0.2	$\bar{\lambda}$ =0.3	$\bar{\lambda}$ =0.4	$\bar{\lambda}$ =0.5
η_{10}	4.90	3.22	1.88	0.88	0.22	0.00
η_{20}	0.75	0.80	0.85	0.90	0.95	1.00

The non-dimensional slenderness of the column should be first evaluated as follows

$$\bar{\lambda} = \sqrt{\frac{p_{pu}}{p_{cr}}} = \sqrt{\frac{f_y}{\pi^2 E}}\frac{l}{r} \tag{28}$$

$$\frac{d}{t} \le 85 \in^2 \quad \text{For concrete filled circular tubular section} \tag{29}$$

$$\frac{h}{t} \le 50 \in \quad \text{For concrete filled rectangular tubular section} \tag{30}$$

$$\frac{b}{t_f} \le 43 \in \quad \text{For partially encased I section} \tag{31}$$

where

$$\in = \sqrt{\frac{250}{f_y}}$$

Effective elastic flexural stiffness

load (Euler Load), $\mathbf{P_{cr}}$, which is defined as follows

$$p_{cr} = \frac{\pi^2 (EI)_e}{l^2}$$

Short term loading

The effective elastic flexural stiffness, (EI)e , is obtained by adding up the flexural stiffness of the

individual components of the cross-section:

$$(EI)_e = E_a I_a + 0.8 E_{cd} I_c + E_s I_s \tag{32}$$

Where

0.8 Ecd Ic is the effective stiffness of the concrete; the factor 0.8 is an empirical multiplier (determined by a calibration exercise to give good agreement with test results).

$$E_{cd} = E_{cm} / \lambda^*{}_c$$

λ^{*}_{c} is reduced to 1.35 for the determination of the effective stiffness of concrete according to Euro-code 2

Partial safety factor for materials

The Partial safety factor γ_m * for structural steel, concrete and Reinforcing steel is given in table 2

Table 2. Partial safety factor for materials

Material	γ_m *
Steel section	1.10
Concrete	1.50
Reinforcement	1.15

For each of the principal axes of the column, the design should be checked that $p < \chi_x \, p_p$

3 Observations and Calculations

In the present study ultimate load carrying capacity of composite columns with variable parameters has been worked out by two following methods.

a) By LRFD method
b) Design based on Euro-code 4

The aspect ratio (D/B), grade of concrete and perimeter are the variable parameters. Whereas the thickness of the steel section, grade of steel and length of column section are kept constant in all the trials. The ultimate load carrying capacity has been obtained from both the methods for three different perimeters of 800mm, 1000mm and 1200mm and five different grades of concrete i.e. M20, M25, M30, M35, and M40. The results obtained from these methods have been plotted graphically with aspect ratio (D/B) versus ultimate load carrying capacity for different perimeters and grades of concrete.

The results obtained by both the methods have been tabulated for three different perimeters of 800mm,1000mm.,1200mm with single grade of concrete.

3.1 Effect of grade of concrete on ultimate load carrying capacity:

The composite columns have been analytically designed by both the methods i.e. by L.R.F.D.method [15] and Euro-code 4 methods [13] for various perimeters and the results computed have been tabulated and represented graphically as given below:

Perimeter 800 mm:

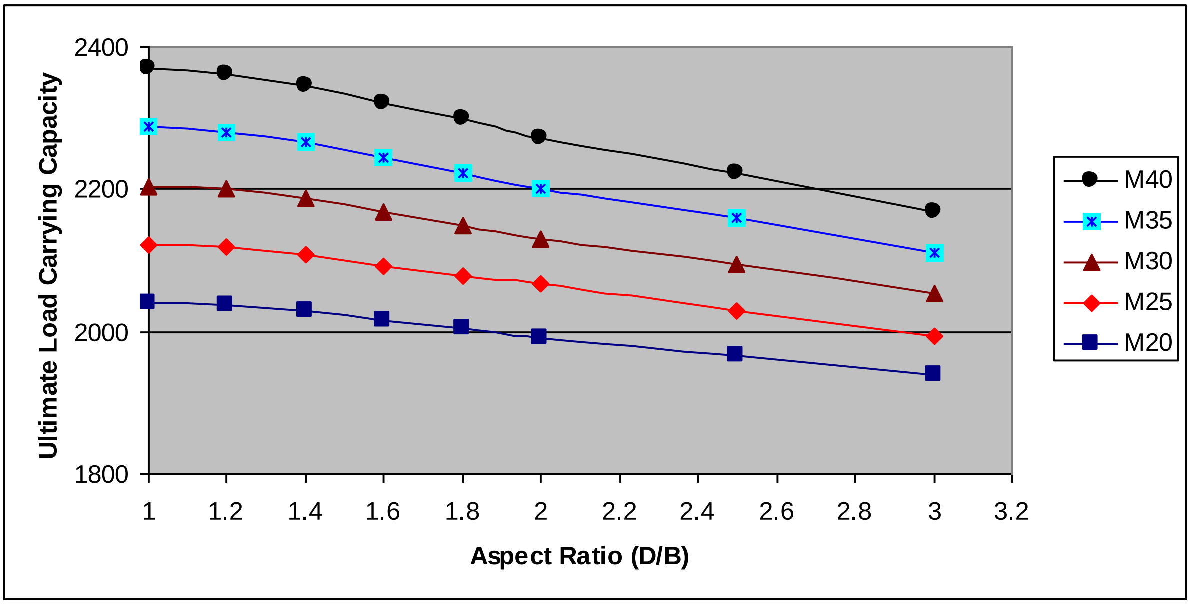


Fig 2. Effect of Aspect Ratio (D/B) on Ultimate Load Carrying Capacity for perimeter 800mm (Grade of concrete M-20, M-25, M-30, M-35, M-40) using LRFD method

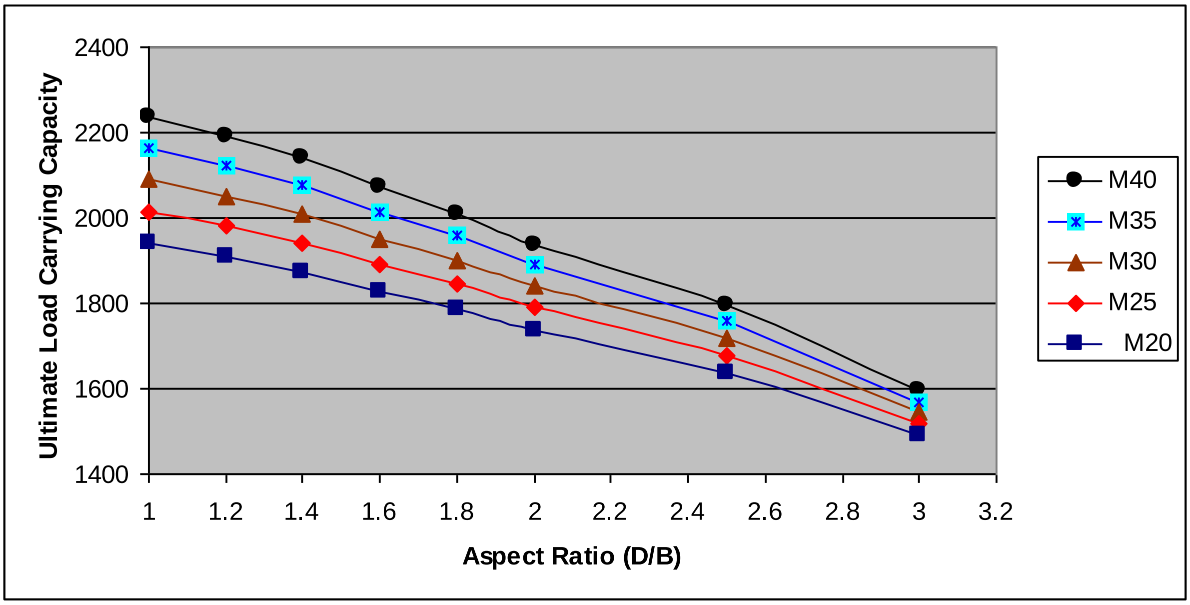


Fig. 3. Effect of Aspect Ratio (D/B) on Ultimate Load Carrying Capacity for perimeter 800mm (Grade of concrete M 20,M-25, M-30, M-35, M-40) using Euro-code 4 method

Perimeter 1000 mm:

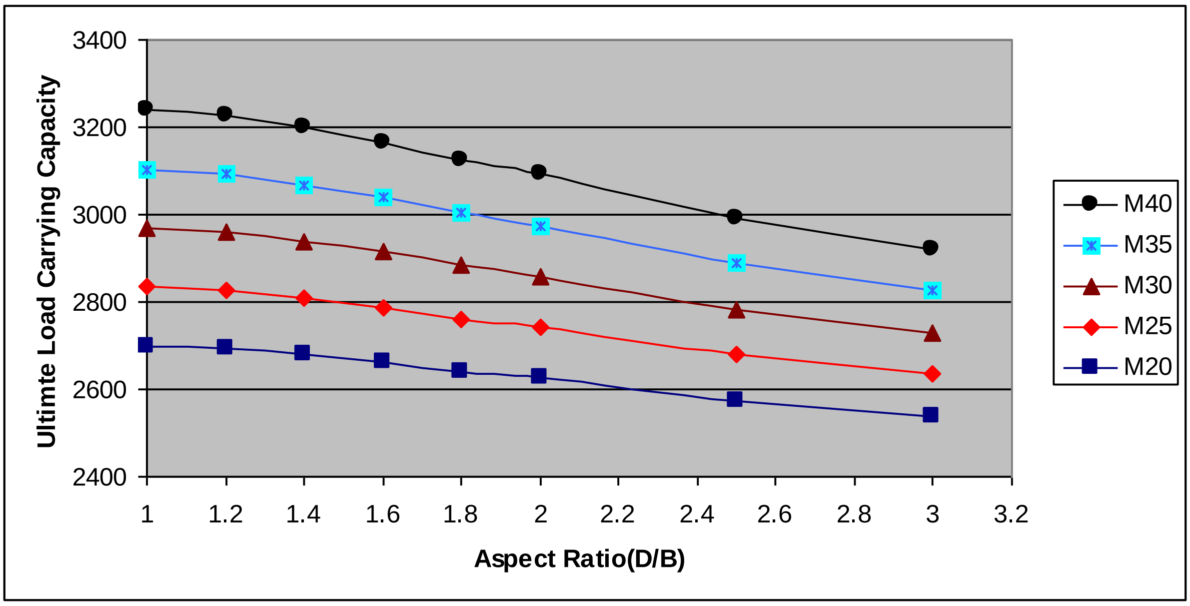


Fig.4. Effect of Aspect Ratio (D/B) on Ultimate Load Carrying Capacity for Perimete1000mm (Grade of Concrete M-20, M-25,M-30 M-35,M-40)Thickness=10mm, using LRFD method

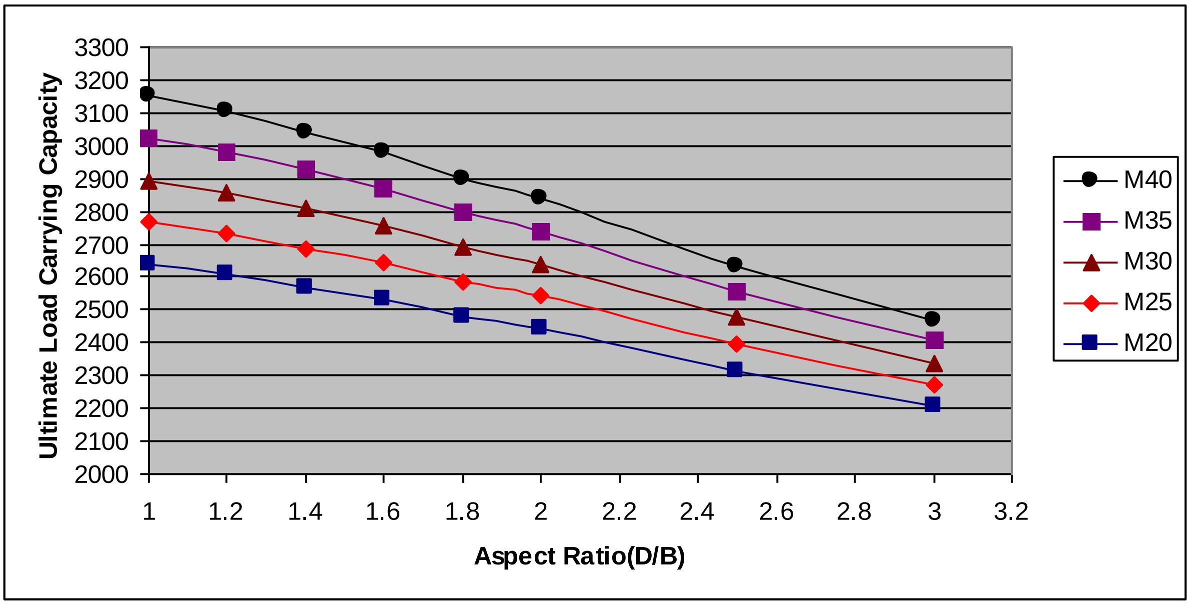


Fig. 5.Effect of Aspect Ratio (D/B) on Ultimate Load Carrying Capacity for perimeter1000mm (GradeofconcreteM-20, M-25,M-30 M-35,M-40) using Euro-code 4 method

Perimeter 1200 mm:

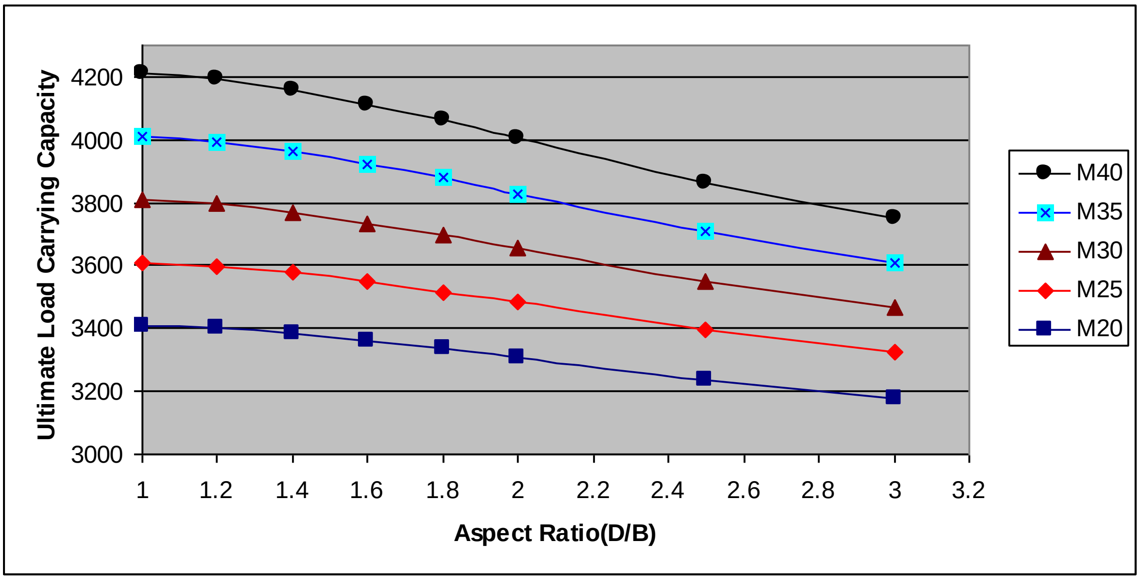


Fig.6. Effect of Aspect Ratio(D/B) on Ultimate Load Carrying Capacity for perimeter 1200mm (GradeofconcreteM-20 M-25,M-30,M-35,M-40), using LRFD method

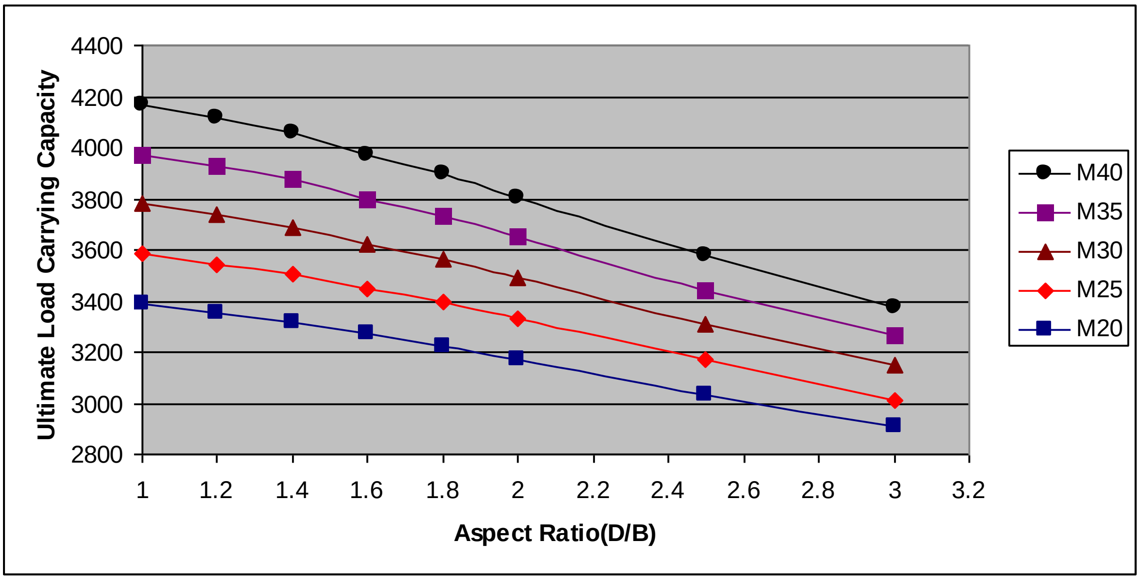


Fig.7. Effect of Aspect Ratio (D/B) on Ultimate Load Carrying Capacity for perimeter 1200mm (GradeofconcreteM-20,M-25,M-30,M-35,M-40) using Euro-code 4 method.

CONCLUSIONS

1 The load carrying capacity of a concrete filled square column is 15% higher than that of rectangular column of same perimeter.

2 With increase in aspect ratio (D/B), the load carrying capacity of a composite column decrease. For an increase in aspect ratio from 1.0 to 3.0, the load carrying capacity decreases by 4.5% to 14.5% respectively.

3 Grade of concrete has a direct bearing on the strength of the composite columns. The percentage increase in load carrying capacity of composite steel column is 10% to 15% with increase in grade concrete from M-20 to M-40.

4 The desired load carrying capacity of section can be achieved with a lower grade of concrete and lower perimeter by choosing the most efficient aspect ratio thus making the section economical.

5 The load carrying capacity of composite column is directly proportional to the perimeter of the section.Percentage increase in load carrying capacity varies from 73% to 86% for a change in column perimeter from 800mm to 1200mm

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