International Journal of Latest Engineering and Management Research (IJLEMR)
ISSN: 2455-4847
www.ijlemr.com || Volume 03 - Issue 02(S) || PP.31-42

Design Comprasion of Encased Composite Column under Bi Axial Loading as Per Eurocode-4 and Aisc.Lrfd Code

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Abstract: The Encased composite column is one of the best option in the design of high-rise building where building load is heavy and architect restrict the increase the size of column. That is highly resist fire load and blast load. Rolled I-section is used in composite column because in built-up section there is more cost in fabrication and the cost of connection between the beam and column is very high. In a country where this technology is developed, it is used in design of important structure. In this paper analytical equation are using to design the Encased composite column under biaxial loading for comparison between the design codes Eurocode-4 and AISC.LRFD code that is more economical and serviceable.. This study further present a investigation of design by using Etabs the analytical design is compare with the design of Etabs . In this study 3 size of composite column is used with different encased I- section.

I. Introduction

A steel concrete composite column is a compression member, comprising either a concrete in case hot rolled steel section or a concrete filled tubular section of a hot rolled steel and is generally used as a load bearing member in a composite framed structure. Composite column represent a combination of one or more steel sections and concrete in a compression member. In a Composite column both the steel and concrete would resist the external loading by interacting together by bond and friction. Supplementary reinforcement in a concrete encasement prevent excessive spalling of concrete under both normal load and fire condition.

In the composite column we utilize both the property of concrete and steel section more efficiently as compared to individually. Concrete is rigid, economical, fire resistance and durable. In other hand structural steel is fire resistance, ductile, easy to assemble and fast to erect. Hence in composite column we take the advantage of both the property of concrete and steel and the overall structure is very efficient and economical too and also provide excellent seismic property and other structural property like high strength, high ductility and large energy absorption capacity.

Three types of composite section: concrete encased section, partially encased section and concrete filled section.

Encased composite column section has high bearing resistance, high fire resistance and economical solution with regard to material costs. Encased composite column is better than shear wall in hazards seismic zone and it reduces the construction cost and saves time. It proves to be more economical where area is restricted and load is heavy because section size is reduced. Encased composite column is also provided in high rise building, airport structure, stadiums and the structure design for defense.

The precise analytical calculations involve hectic non linear three dimensional modeling of such structures .So designers prefer to adopt design mechanism provided in different codes like Eurocode-4, ACI, AISE-LFRD, BS 5400-5:1979 etc.

The concrete filler tubular columns have many advantages than conventional reinforced concrete columns which make them stronger and economical. In concrete encased composite columns the steel ratio is higher. Hence, it provide more ductility to the structure.

Concrete encasement of a steel core shall be reinforced with longitudinal load carrying bars, longitudinal bars to restrain concrete and lateral ties. Typical section of encased composite column section is in fig 1 and table of column schedule which is used in this paper.

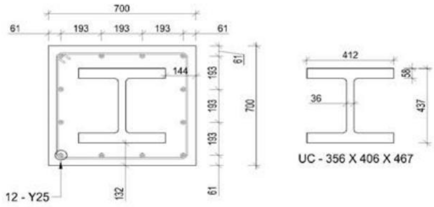


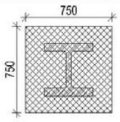
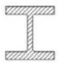
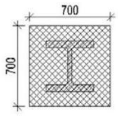
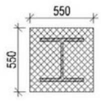
TABLE - 1	SCHEDULE OF COMPOSITE COLUMNS		
COLUMN ID	COLUMN SIZES		REINFORCEMENT DETAILS
	CONCRETE	STEEL PROPERTIES	
C1	 750 × 750	 UC 356 X 406 X 551	12 NOS - 25mmØ
C2	 700 × 700	 UC 356 X 406 X 467	12 NOS - 25mmØ
C3	 550 × 550	 UC 356 X 368 X 202	12 NOS - 12mmØ

Fig 1

II. Design According to Eurocode-4

Eurocode -4 is the most recently developed and internationally acclaimed guidelines adopted for design of composite columns. The design theory proposed by the code is based on the rigid plastic method of analysis which assumes fully yielded steel and fully crushed concrete.

General conditions as per Eurocode - 4 :-

1.Cl.6.7 of Eurocode – 4 applies to columns and compression members with steel grades S234 to

S460 and normal weight concrete of strength classes C20/25 to C50/60

2.Cl.6.7.1 Structural steel contribution ratio

$$0.2 \leq \delta \leq 0.9$$

Where $\delta = (A_a . f_{yd}) / (N_{pl.Rd})$

A_a =C/S area of structural steel

f_{yd} = design yield strength of steel

$N_{pl.Rd}$ = plastic resistance to compression

3.Cl.6.7.3.2 $\mathbf{N_{pl.Rd} = A_a f_{yd} + 0.85 A_c f_{cd} + A_s f_{sd}}$

Where,

A_c = area of concrete
f_{cd} = design cylindrical strength of concrete A_s = Area of reinforced steel

f_{sd} = design yield strength of reinforced steel

Eurocode – 4 discusses two methods of design of composite column **A .**

General method of design:
The effect of local buckling of the steel section on the resistance shall be considered in design. The effects of local buckling may be neglected for a steel section fully encased if the concrete cover to the flange of a fully encased steel section should

a. Not be less than 40 mm.

b. Nor less than one-sixth of the breadth b of flange .

B . Simplified method
Scope of simplified method
1. Double symmetry cross sections.
2. Uniform cross-sections over the member length with rolled, cold – formed or welded steel sections.
3. Steel contribution ratio $\delta = \frac{A_a f_{yd}}{N_{pl,Rd}}$

$0.2 \leq \delta \leq 0.9$:

[if $\delta \leq 0.2$ - the column should be treated as reinforced concrete]

[if $\delta \geq 0.9$ - the column should be treated as structural steel]
4. The non dimensional slenderness $\lambda \leq 2$ $\bar{\lambda} = \sqrt{\frac{N_{pl,Rk}}{N_{cr}}}$
5. Longitudinal reinforcement ratio

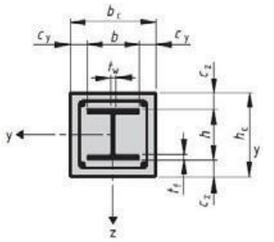
0.3% p 6%p = As / A$_c$

6. The ratio of depth to the width of the composite cross section should be within the limit of

0.2 to 0.5.
7. for a fully encased steel section.

Max $C_z = 0.3h$

Max $C_y = 0.4b$



Plastic resistance to compression
Pp = $A_a f_y /\gamma a + \alpha c.A_c(f_{ck}) /\gamma c + A_s.f_{sk} /\gamma s$ A_a = area of structural steel A_c = area of concrete. A_s = area of reinforcement
f_y , f_{sk} = yield stress of steel section & reinforcement
$(f_{ck})cy$ = characteristic cylindrical strength of concrete = $0.8* (f_{ck})cu$ αc (strength coefficient) = 0.85 for encased concrete section

Effective elastic flexural stiffness for short term loading $(EI)_{eff.} = E_aI_a + E_aI_c + K_eE_{cm}I_s$

Where K_e is the correction factor = 0.6 {EC-4 6.7.3.3 (3)}

I_a , I_c, I_s are second moment of area of structural steel , uncracked concrete section & reinforcement.

Non-dimensional slenderness □

$N_{pl,Rk}$ = axial resistance (unfactored)

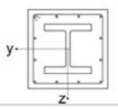
N_{cr} = elastic critical load = $\pi^2 * EIe/l^2$

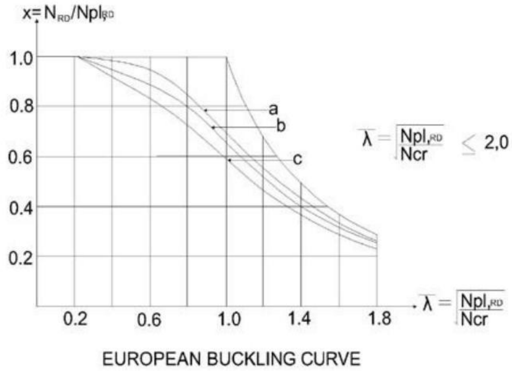
$$\bar{\lambda} = \sqrt{\frac{N_{pl,Rk}}{N_{cr}}}$$

Design value of resistance for axial compression

Npl.R = □ Npl.Rd.

= reduction factor for relevant buckling mode

CROSS SECTION	AXIS OF BUCKLING	BUCKLING CURVE
	y-y	b
	z-z	c

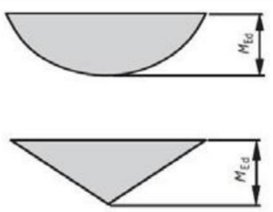
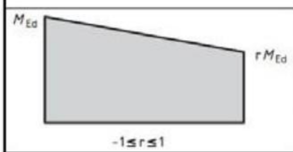


Check for second order effects
Isolated non-sway columns need not be checked for second-

order effects if ***$N_{Ed}/N_{cr} < 0.1$***

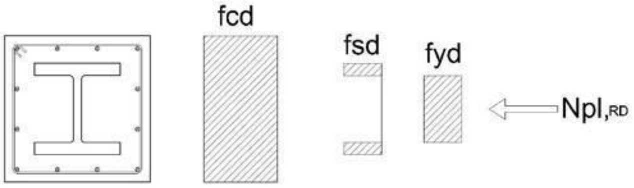
Second-order effect may be allowed by multiplying the greatest first – order bending moment by factor k. Final moment Mrd= k*M1

$$k = \frac{\beta}{1 - N_{Ed}/N_{cr,eff}}, \quad \geq 1,0$$

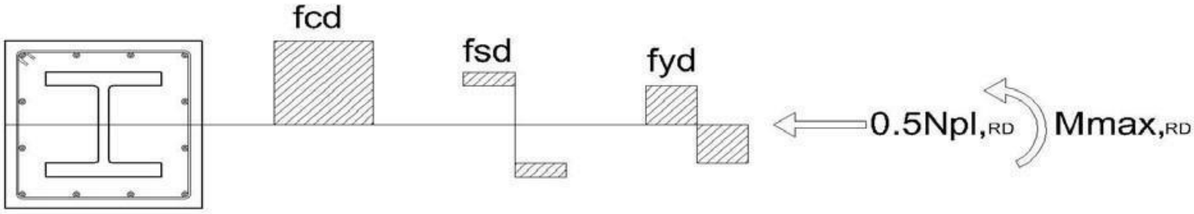
Moment distribution	Moment factors β	Comment
	First-order bending moments from member imperfection or lateral load: $\beta = 1,0$	M_{Ed} is the maximum bending moment within the column length ignoring second-order effects
	End moments: $\beta = 0,66 + 0,44r$ but $\beta \geq 0,44$	M_{Ed} and $r\,M_{Ed}$ are the end moments from first-order or second-order global analysis

Moment capacity of the section
Interaction curve generation

A. Axial load is taken by concrete, steel & reinforcement.



B. Tension part of the concrete in not taken into consideration. Mpl .max = fyd Zpa + 0.5fcd Zpc + fyd Wps



C. Stress in web area (hn * tw) changes by 2fyd (tension to compression) Stress in the area hn (bc –tw) of concrete area changes from zero to fcd . Load carrying capacity of section changes by (Ac*fcd)/2.

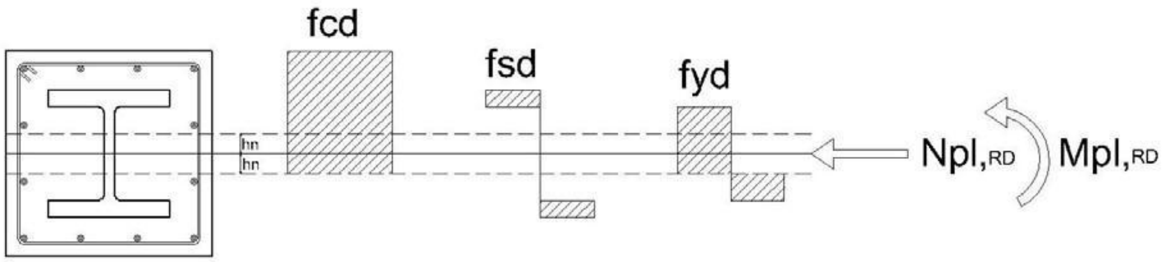
Mpl.Rd = fyd.Wpa + 0.5fcdWpc + fydWps – Wpanfyd - 0.5Wpcnfcd

$X = N_{sd} / N_{plRd}$

X_d = Design axial force / Plastic resistance of section

X_c = Plastic axial resistance of concrete / Plastic resistance of section
Final moment resistance of structure

$MRd = 0.9\ M_{pl}.Rd$



Complete check
Column with Axial load & Bi-Axial bending

NRd ≤ χx

*Npl.x.Rd

NRd ≤ χy*Npl.y.Rd

MRdx ≤ 0.9 μx Mpl.x.Rd

MRdy ≤ 0.9 μy Mpl.y.Rd

Interaction check

$$\frac{Mx\ Muy}{\mu x M\ pl.x.Rd} \leq \frac{1}{\mu y M\ pl.y.Rd}$$

III. Design According To Aisc

AISC-LRFD: code proposes design mechanism for composite structures. According to the LRFD design mechanism it believes that composite materials in a composite structure should act together to resist bending or in other words as one i.e. monolithically.

Limitations

For encased composite members, the following limitations shall be met:

1) The cross sectional area of steel core should be comprises of at least 1% of the total composite cross section.

2) Concrete encasement of the steel core shall be reinforced with continuous longitudinal bars and lateral pies or spirals. .

   Maximum spacing of lateral ties should not be greater than 0.5 times the least column dimension.

3) The minimum reinforcement ratio for continuous longitudinal reinforcing, ρsr, shall be

   0.004, where ρsr is given by : ρsr = Asr/Ag where

   Ag = gross area of composite member in (mm²)

Asr = area of continuos reinforcing bars in (mm²)

Nominal Compressive Strength

The resistance and safety factors used in calculation of design and allowable design compressive strength , $\varphi c\ P_n$ are:

φ**c** = 0.75 (LFRD)

The slenderness ratio is preferably should not exceed 200 (AISC E2).

The nominal compressive strength of members of doubly symmetric axially loaded encased composite sections, P_n, is the value obtained in accordance with the limit state of flexural buckling. The torsional and flexural-torsional buckling limit states do not need to be considered.

When $P_{no}/P_e \leq 2.25$

$Pn = Pno\ 0.658\ Pno/Pe$

When $P_{no}/P_e > 2.25$

$P_n = 0.877\ P_e$

$P_{no} = F_y A_s + F_{ysr} A_{sr} + 0.85 f_c' A_c$

P_e = elastical critical buckling load

$= \pi^2 (EI_{eff.})/(KL)^2$

A_c = area of concrete in m^2

A_s = area of the steel section, in m^2

E_c = modulus of elasticity of concrete as input by the user , ksi

$EI_{eff.}$ = effective stiffness of the composite section, kip-in^2

$= E_sI_s + 0.5E_sI_{sr} + C_1E_cI_c$

C_1= coefficient for calculation of effective rigidity of an encased composite compression member

$= 0.1 + 2* A_s /(A_s +A_c)$

E_s = modulus of elasticity of steel

= 29,000 ksi

F_y = specified minimum yield stress of steel section, ksi

F_{ysr} = specified minimum yield stress of reinforcing bars, ksi

I_c = most of inertia of the concrete section about the elastic neutral axis of the composite section, in^4

I_s = moment of inertia of steel shape about the elastic neutral axis of the composite section, in^4 I_{sr} = moment of inertia of reinforcing bars about the elastic neutral axis of the composite section, in^4

K = effective length factor = K_2

L = laterally unbraced length of the member, in.

f'_c = specified compressive strength of concrete, ksi **Nominal flexural strength**

This section applies to members subjected to simple bending about one principal axis. The members are assumed to be loaded in a plane parallel to a principal axis that passes through the shear centre, or restrained against twisting.

The design flexural strength, φ_bM_n is determined using the resistance and safety factors:

$\varphi_b = 0.90$ (LFRD)

Encased I-Rectangular sections

The plastic moment capacity in the major direction,

$M_{p,major} = M_D – Z_{sn}F_y-1/2Z_{cn}(0.85f_c')$

Zcn = h1hn2 – Zs- Zsn

Where,

$M_D = Z_sF_y + Z_rF_{yr} + 1/2Z_c(0.85f_c')$

Z_s = full x axis plastic section modulus of a stell I-shape

Z_r = full x axis plastic modulus of reinforcement

A_{sr} = area of continuous longitudinal reinforcing bars

Z_r = $(A_s – A_{srs})(h_2/2-c)$

Zc = h1h22 /4-Zs-Zr

The position of h_n and Z_{sn} depends on the position of plastic neutral axis.

The plastic moment capacity in minor direction, M_p , is calculated as follows :

Mp,minor = MD - ZsnFy – 1/2Zcn(0.85f'c)

Zcn = h1h2n - Zsn

Where,

$M_D = Z_S F_y + Z_r F_{sr} + 1/2 Z_c(0.85f'_c)$

Z_r = section modulus of reinforcement

A_{sr} = area of continuous longitudinal reinforcing bars

$Z_r = A_{sr}(h_2/2-c)$

$Z_c = h_1 h_2^2/4 – Z_c – Z_r$

The position of h_n and Z_{sn} depends on the position of plastic neutral axis.

Design of members for combined forces

Members subjected to flexure and axial compression

For $P_r/P_c \geq 0.2$

Pr/Pc+8/9(Mr33/Mc33+Mr22/Mc22)≤1.0 For

$P_r/P_c < 0.2$

Pr/2Pc + (Mr33/Mc33 + Mr22/Mc22)≤ 1.0

Where P_r and P_c are the required and available axial strengths; M_r and M_c are the required and available flexural strengths; and 3 and 2 represent the strong and weak axes, respectively.

For design in accordance with LFRD provisions:

P_t = required axial compressive strength using LFRD load combinations

P_c = design axial compressive strength = $\varphi_c P_n$

M_r = required flexural strength using LFRD combinations

M_c = design flexural strength = $\varphi_b M_n$ φ_c = resistance

factor for compression =0.75 φ_b = resistance factor
for flexure =0.90

IV. Interactive Composite Column Design

The interactive composite column design command is an easy mode that allows to review the design results for any composite column design and interactively revise the design assumptions and immediately review the revised results. Etabs is analysis and design software that access the user to select design code as long as structure have first been model and analyze data such as material property and member forces are directly recovered from the model data base and are user defined or default design settings. As with the design applications the user should carefully review all of the user option and default setting before the design process that it is correct and according to code. The software is a better option to make user the direct analysis because it can capture the second order P-delta analysis and P- delta effect.

Stress check

Composite column design/check consists of calculating flexural, axial and shear forces or stress at several locations along the length of the member and then comparing those calculated values with acceptable limits. That comparison produces the demand/capacity ratio, which typically should not exceed a value of one if code requirement are to be satisfied. The programs follows the same review procedures whether it is checking a user specified shape or a shape selected by the program from a predefined list. The program also check the requirements for the beam column capacity ratio, checks the capacity of the panel zone, and calculates the doubler plate and continuity plate thickness, if needed. The program does not do the connection design. However, it calculates the design the basis forces for connection design.

Material properties

a)Structural steel

Characteristic Yield strength	f_y	= 350 N/mm^2
Modulus of elasticity	E_a	=200000.00 N/mm^2

b) Reinforcing Steel

Characteristic Yield Strength	f_{sk}	=500.00 N/mm^2
Modulus of elasticity	E_s	=200000.00 N/mm^2

c) Concrete

Characteristic Comp. Strength (Cube) $(f_{ck})_{cu}$	= 50.00 N/mm^2
Characteristics Comp. Strength (Cylinder) $(f_{ck})_{cy}$	=40.00 N/mm^2

Secant modulus of Elasticity for short term loading,

$E_{cm} = 5700(\text{sqrt}(f_{ck})_{cu})$

$E_{cm} = 40305.09$ N/mm$_2$
=5700*SQRT(40)

d) Partial Safety Factors

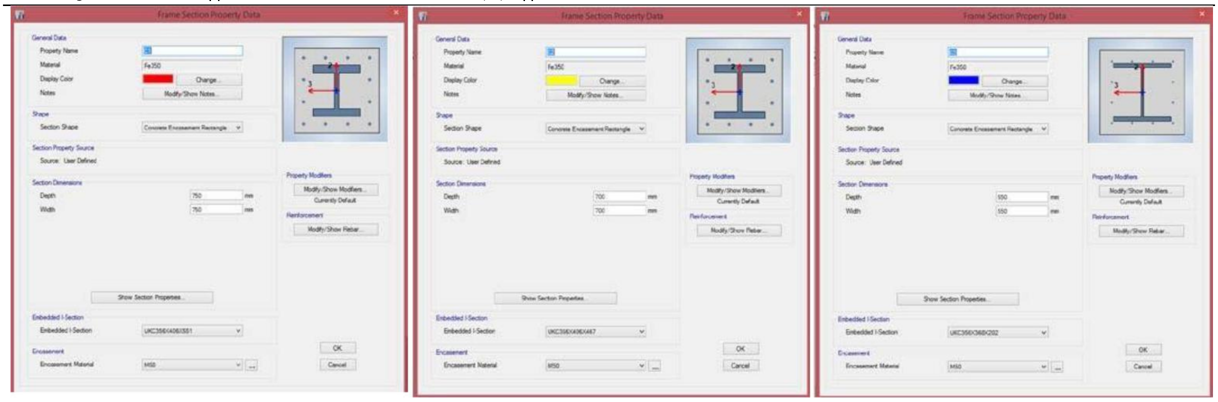
Structural steel	$Y_a = 1.10$
Reinforcing steel	$Y_s = 1.15$
Concrete	$Y_c = 1.50$

Load input

Design axial force (Factored)	N_{ed}	= 28691.00 KN Max. Moment about
Major axis (factored)	M_x	= 101.80 KN-m
Max. Moment about Minor axis (factored)	M_y	=251.00 KN-m
Effective length of column	L_e	= 4.68m

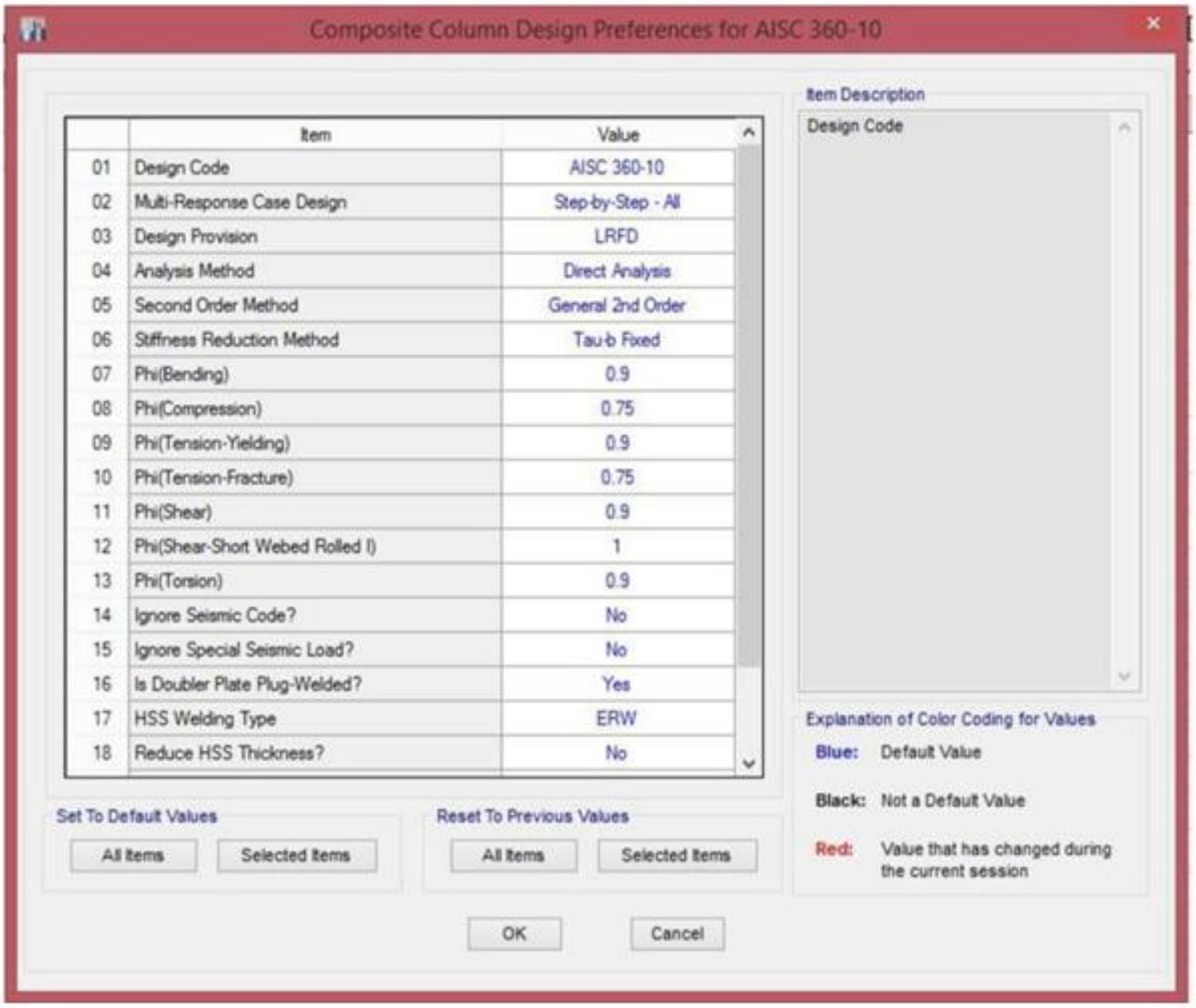
Section

Section C1 , C2 and C3 is defined and assign as per the model , model is single line element of length 4.68m , and assign loads for the analysis and design of the composite column , and the strength calculation of the member .



Design

In Etabs program design of composite column as per the AISC (LRFD) code provision , for encased I section and filled composite column section , define the design preferences according to the design requirement and code of design , Etabs design is very time efficient design software.



V. Comparision of Capacities of Column

SECTION PROPERTIES

COLUMN ID	SIZE OF SECTION	ENCASED STEEL SECTION	REBAR
C1	750X750	UC 356X406X551	12-25mmØ
C2	700X700	UC 356X406X467	12-25mmØ
C3	550X550	UC 356X368X202	12-12mmØ

DESIGN CAPACITY OF THE SECTION

COLUMN ID	**Eurocode-4**		
	AXIAL COMPRESSIVE STRENGTH (kN)	MOMENT RESISTANCE ABOUT MAJOR AXIS (kNm)	MOMENT RESISTANCE ABOUT MINOR AXIS (kNm)
C1	33591.62	5165.38	3598.32
C2	28813.55	4310.51	3032.39
C3	13810.19	1584.81	1127.96

	AISC 360_10 (LRFD)		
	AXIAL COMPRESSIVE STRENGTH (kN)	MOMENT RESISTANCE ABOUT MAJOR AXIS (kNm)	MOMENT RESISTANCE ABOUT MINOR AXIS (kNm)
C1	30934	4931	3364
C2	26696	4068	2753
C3	13455	1538	1028

	Etabs 2015 DESIGN RESULTS		
	AXIAL COMPRESSIVE STRENGTH (kN)	MOMENT RESISTANCE ABOUT MAJOR AXIS (kNm)	MOMENT RESISTANCE ABOUT MINOR AXIS (kNm)
C1	32898	5919	4381
C2	28268	4966	3662
C3	13659	1734	1346

VI. Conclusion

The aim of this study is investigation the aspect which design methodology is more efficient and economical.

1. Axial capacity of the member is more if designed by Eurocode-4.
2. Moment capacity of the member is more if designed by Etabs as per AISC code specification.
3. Slenderness ratio is very important role in design of long composite column.
4. Capacity comparison between Eurocode-4 and AISC-LRFD shows Eurocode-4 is more effective in design.
5. The lateral deformation strength and the nominal squash load are enhanced by the confinement effect on concrete , this enhancement depends upon the size of encased section.

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