Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (39) No. (1) January, 2017

# STUDY OF DIFFERENT POINTS OF VIEW OF CODES ON THE DESIGN CAPACITY OF ENCASED COMPOSITE COLUMNS

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## ملخص البحث

غالباً ما يتم استخدام اكواد مختلفة لتصميم الأعمدة المركبة، والقيم المستنتجة تختلف من كود إلى آخر. يعتمد كل كود من الاكواد على عوامل ومعاملات مختلفة، بينما نجد ان قدرة القطاع الحقيقة لا تختلف عند استخدام المبادئ الأولى للتحليل.
تحديد قوى الضغط المحورية القصوي للقطاعات المركبة يعتمد علي المقاومات القصوي للعناصر المكونة للقطاع المركب مع عمل التخفيضات الناتجة عن معامل النحافة الكلي والجزئي.
ويقدم هذا البحث مقارنة بين القيم التصميمية المختلفة المستنتجة من الاكواد المختلفة للأعمدة المركبة.

## Abstract

Sometimes, when different codes are used to design composite columns, the gained values vary from one code to another; each code depends on different factors and coefficients, regardless of the fact that the capacity of a section is the same when first principles are used to analyze it.
For axial forces, the available compressive strength of a composite member is based on a summation of the strengths of all of the components of the column with reductions applied for member slenderness and local buckling effects, where applicable.
This research presents a comparison between the calculated designs capacities of composite columns from different codes.

## Keywords

Concrete-encased composite column, rectangular section, Allowable Stress Design, Load and Resistance Factor Design, comparison between different codes.

## Introduction

Composite structures are a promising system in Egypt which can meet the needs of the construction industry which aspires for further development and prosperity.
The design codes adapted in this research are AISC (LRFD and ASD) [9], EUROCODE 4 [6] design of composite steel and concrete structures, Egyptian code of practice for steel construction (Load and Resistance Factor Design) (LRFD) [4], and Egyptian code of practice for steel construction and bridges (Allowable Stress Design) (ASD) [3].
The types of columns taken into consideration are encased and filled composite columns, and the concept of comparison id based on code factors and equations.

A general comparison of code recommendations in terms of design basis, slenderness considerations and material properties is presented. This is followed by a quantitative assessment of capacity calculation for a specific cross-section under axial loading.
It is concluded that large conflicts exist between codes, even those using basically the same design methodology, and occasionally the same experimental data base. This confirms the need for harmonization, in order to achieve a higher degree of uniformity of code design steps and more rational safety margins.
The composite concrete and steel structural system combines the rigidity and formability of reinforced concrete with the strength of structural steel to make an economic structure. For concrete encased composite structural members, an additional advantage is that the concrete used for encasing the structural steel not only increases its stiffness, but also saves it from fire damage and local buckling failure.
In the United States, specific regulations for the design of concrete-encased composite columns are included in two different sets of structural design specifications. One is the building code for structural concrete of the American Concrete Institute (ACI) [2], and the other is the specification of Load and Resistance Factor Design (LRFD) published by American Institute of Steel Construction (AISC) [9].
While, in Egypt specific regulations for the design of concrete-encased composite columns are included in two different sets of structural design specifications. One is the Egyptian code of practice for steel construction (Load and Resistance Factor Design) (LRFD) [4], and the other is the Egyptian code of practice for steel construction and bridges (Allowable Stress Design) (ASD) [3].

## Review of design methods

AISC-LRFD and ASD approach

The AISC specification has included design provisions for composite beams with shear connectors since 1961, the design requirements for composite columns were not recommended until the publication of the first edition of the AISC-LRFD specification in 1986.
The concept of extending the steel column design methodology to the composite columns using modified properties was first introduced by Furlong [8]. Modified yield stress $F_{my}$, modulus of elasticity $E_m$ and radius of gyration $r_m$ were incorporated into steel column design equations for the design of composite columns. This procedure was presented by the Task Group 20 of the Structural Stability Research Council (SSRC) in 1979 [14].
The following sections briefly introduce the concerned strength provisions for encased composite columns as recommended in Chapter I of the AISC-LRFD specification (2010) [9].
Axial compressive strength:-
The capacity of an encased column is determined from the same equations as that for bare steel columns except that the modified properties $F_{my}$, $E_m$ and $r_m$ are substituted into the formulae. The nominal axial compressive strength of an encased composite column is

$$P_n = A_s F_{cr} \tag{1}$$

where
$A_s$ is the area of the steel shape and

$F_{cr}$ is the critical stress of the column given by the following equations:

$F_{cr} = (0.658\lambda_c^2)F_{my}$ for $\lambda_c \leq 1.5$ (2)

and

$F_{cr} = (0.877/\lambda_c^2)F_{my}$ for $\lambda_c > 1.5$ (3)

where $\lambda_c = (KL/\pi r_m)(F_{my}/E_m$ ; $F_{my}$ = modified yield stress; $r_m$ = modified radius of gyration; $E_m$ = modified modulus of elasticity.

The modified properties $F_{my}$ , $E_m$ and $r_m$ account for the contribution of concrete and rebars to the composite section. The modified values $F_{my}$ and $E_m$ can be determined from the following equations:

$F_{my} = F_y + c_1 F_{yr}(A_r/A_s) + c_2 f_c'(A_c/A_s)$ (4)

and

$E_m = E_s + c_3 E_c (A_c/A_s)$ (5)

Where $c_1$, $c_2$, $c_3$ = numerical coefficients, for encased composite columns $c_1$=0.7, $c_2$=0.6 and $c_3$=0.2.

Second-order effect:-

For columns designed on the basis of elastic analysis, the factored moment $M_u$ shall be determined by a second-order analysis or by the moment magnification method. The moment magnifier $B_1$ is expressed as

$B_1 = (0.6+0.4(M_{u1}/M_{u2}))/(1-(P_u \lambda_c c^2 / A_s F_{my})) \geq 1$ (6)

<u>Eurocode4 approach</u>

The Eurocode is one of the most global codes which deal with composite structures and Eurocode 4 specializes in composite steel and concrete structures. Several countries in Europe and other continents depend on Eurocode 4 to design steel and concrete structures. The following formulas and steps describe the method of design adopted for composite structures.

For simplification, for members in axial compression, the design value of the normal force $N_{Ed}$ should satisfy :

$N_{Ed} / \chi N_{pl,Rd} \geq 1.0$ (7)

where :

$N_{pl,Rd}$ is the plastic resistance of the composite section according to the following formula (11),

$N_{pl,Rd} = A_a f_{yd} + 0.85 A_c f_{cd} + A_s f_{sd}$ (8)

$\chi$ is the reduction factor for the relevant buckling mode given in the formula (12) in terms of the relevant relative slenderness λ.

$\chi = 1/ (\lambda + (\lambda^2 + \varphi^2)^{0.5})$ (9)

$\varphi = 0.5 (1 + \alpha (\lambda - 0.2) + \lambda^2)$ (10)

The relevant buckling curves for cross-sections of encased composite columns is (b) for imperfection 1/200 about the major axis (Table 6.5 [ref Eurocode])

α is an imperfection factor which depends on the buckling axis. For strong axis buckling, $\alpha = 0.34$ (curve b)

For the determination of the relative slenderness λ and the elastic critical force Ncr ,the characteristic value of the effective flexural stiffness ($EI_{eff}$) of a cross section of a composite column should be calculated from:

$EI_{eff} = E_a I_a + E_s I_s + K_e E_{cm} I_c$ (11)

The relative slenderness λ for the plane of bending being considered is given by :

$\lambda = (N_{pl,Rd} / N_{cr})^{0.5}$ (12)

where :

$N_{pl,Rd}$ is the characteristic value of the plastic resistance to compression given by formula (11).

$N_{cr}$ is the elastic critical normal force for the relevant buckling mode, calculated with the effective flexural stiffness ( $EI_{eff}$) determined in accordance the following formula (16)

$N_{cr} = \pi^2 E_{eff} /(KL)^2$ (13)

Egyptian ASD approach

The allowable compressive axial stress, Fc, for symmetric axially loaded composite columns are computed on the steel section area utilizing a modified radius of gyration, yield stress and Young's modulus, $\mathbf{r_m}$, $\mathbf{F_{ym}}$, and $\mathbf{E_m}$ respectively, to account for the composite behavior.

For inelastic buckling, $\lambda \leq 100$

$F_c = ( 0.58 - \alpha F_{ym} \lambda^2 ) F_{ym}$ (14)

For elastic buckling, $\lambda \geq 100$

$F_c = 3.57 E_m / \lambda^2$ (15)

Where:

$F_{ym} = F_y + c_1 F_{yr} (A_r/A_s) + c_2 f_{cu} (A_c/A_s)$. (16)

$E_m = E_s + c_3 E_c (A_c/A_s)$. (17)

$\alpha = (0.58 \times 10^4 F_{ym} - 3.57 E_m) / (10^4 F_{ym})^2$. (18)

$f_{cu}$ = 28-day cube strength of concrete.

$\lambda$ = Slenderness ratio = $k\ell/r_m$.

$K\ell$ = Buckling length, bigger of in-plane and out-of-plane buckling lengths.

$r_m$ = Radius of gyration of the steel shape, pipe or tubing except that for steel shapes encased in concrete it shall not be less than 0.3 times the overall width of the composite column in the plane of bending.

$F_{ym}$ = Modified yield stress, t/cm$^2$.

$F_y$ = Yield stress of steel section, t/cm$^2$.

$F_{yr}$ = Yield stress of longitudinal reinforcing bars, t/cm$^2$.

$E_m$ = Modified Young's modulus, t/cm$^2$, $\geq E_s$.

$E_s$ = Young's modulus of steel, t/cm$^2$.

$E_c$ = Young's modulus of concrete, t/cm$^2$ (see Table 10.1[ref])

$A_s$ = Area of steel section, pipe or tubing, cm$^2$.

$A_r$ = Area of longitudinal reinforcing bars, cm$^2$.

$A_c$ = Area of concrete, cm2, excluding $A_s$ and $A_r$.

$c_1$, $c_2$, and $c_3$ = numerical coefficients taken as follows:

For concrete encased sections,

$c_1 = 0.7$, $c_2 = 0.48$, and $c_3 = 0.20$.

Egyptian LRFD approach

The design strength, Øc Pn, for symmetric axially loaded composite columns are computed on the steel section area utilizing a modified radius of gyration, yield stress and young's modulus, rm, Fym and Em respectively, to account for composite behavior.

$P_u = \O_c P_n$ (19)

$= \O_c A_s F_{cr}$ (20)

For inelastic buckling, $\lambda_m \leq 1.1$ $F_{cr}=(1- 0.348 \lambda_m^2) F_{ym}$ (21)

For elastic buckling, , $\lambda_m \geq 1.1$ $F_{cr} = 0.648 F_{ym}/ \lambda^2$ (22)

Where:

$F_{ym} = F_y + c_1 F_{yr} (A_r/A_s) + c_2 F_{cu} (A_c/A_s)$ (23)

$E_m = E_s + c_3 E_c (A_c/A_s)$ (24)

$\lambda_m$ = Slenderness ratio = $L_b(F_{ym}/E_m)^{1/2} / \pi r_m$ (25)

Where:

$L_b$ = buckling length, bigger of in-plane and out-of-plane buckling lengths

$r_m$ = radius of gyration of the steel shape, pipe or tubing except that for steel shapes encased in concrete it shall not be less than 0.3 times the overall width of the composite column in the plane of bending

$F_{ym}$ = modified yield stress, t/cm$^2$, $\geq F_y$

$F_y$ = yield stress of steel, t/cm$^2$

$\varnothing_c$ = strength reduction factor for compression members, 0.80

$F_{yr}$ = yield stress of longitudinal steel reinforcement, t/cm$^2$

$E_m$ = modified Young's modulus, t/cm$^2$, $\geq E_s$

$E_s$ = Young's Modulus of Steel, 2100 t/cm$^2$

$E_c$ = Young's Modulus of concrete, t/cm$^2$

$A_s$ = area of steel section, pipe or tubing, cm$^2$

$A_r$ = area of longitudinal steel reinforcement, cm$^2$

$A_c$ = area of concrete, cm2, excluding $A_s$ and $A_r$

$c_1$, $c_2$, and $c_3$ = numerical coefficients taken as follows:

- For concrete encased sections,

$c_1 = 0.7$, $c_2 = 0.48$, and $c_3 = 0.20$

## Methodology and parametric study

A parametric study is conducted to compare between the above mentioned codes. Several composite sections are studied using different codes. The concrete dimensions of composite columns are varied as given in Table (1), the characteristic strength of concrete is 0.25 t/cm$^2$. The structural steel section represents 5% of the concrete cross section, the yield stress and the ultimate strength of structure steel are respectively 2.4 t/cm$^2$ and 3.6 t/cm$^2$. While, the rebar steel section represents 1% of the concrete cross section, the yield stress and the ultimate strength of rebar steel are respectively 2.4 t/cm$^2$ and 3.6 t/cm$^2$. The structural steel ratio is chosen to be higher than the minimum codes requirement which is 4%. The rebar steel cross-sectional area is chosen to cover the minimum requirements.

The concrete dimensions are offset from the outer dimensions of the structural steel section by 10 cm to fulfil the concrete cover and minimum distances between the structural steel section and the rebar. The buckling length begins at zero and is increased till it exceeds 34 m. The maximum capacities of the sections are calculated according to the previously mentioned design codes. The ultimate and allowable axial loads are determined by using AISC, Egyptian LRFD, Egyptian ASD, and Eurocode4.

Table (1): cross section dimension of composite columns

| Section number | Concrete dimensions (cm) | Structural steel section (IPE) | Rebar cross- sectional area ($cm^2$) |
|---|---|---|---|
| 1 | 20X25 | I180 | 5 |
| 2 | 25X25 | I220 | 6.25 |
| 3 | 25X35 | I270 | 8.75 |
| 4 | 25X40 | I300 | 10 |
| 5 | 25X50 | I330 | 12.5 |
| 6 | 25X60 | I360 | 15 |
| 7 | 30X65 | I450 | 16.25 |
| 8 | 30X75 | I500 | 22.5 |
| 9 | 30X90 | I550 | 27 |
| 10 | 30X100 | I600 | 30 |

## Results and comparison

Figures (1) - (6) present the summary of results as follows. Figure (1) represents the relationship between allowable stress section capacity and the buckling length of composite column according to AISC requirements for allowable stress design. Figure (2) shows the ultimate strength versus the buckling length of composite column according to AISC requirement for load resistance factor design. Figure (3) displays the relationship between the ultimate strength and the buckling length of composite column according to Eurocode4 requirement for load resistance factor design. Figure (4) shows the allowable stress section capacity versus the buckling length of composite column according to ASD the requirements (allowable stress design) of the Egyptian code. Figure (5) presents the relationship between ultimate strength and the buckling length of composite column according to the requirements of LRFD of the Egyptian code. Figure (6) shows a comparison between different capacities of the same composite section (section number 4) according to different codes requirements.

From the mentioned figures it can be seen that increasing the composite column cross section area (concrete and structure steel) tend to increase the composite column capacity.

From Figs. (1) - (5) it can be noted that the difference between sections capacities can be neglected at the beginning of the curves. While the largest difference in values of section capacities occurs a buckling length of 15.00 meters. Finally the difference between section capacities retracts with the increase in buckling length.

As shown in Fig. (6), the section capacity varies significantly according to different design codes. At the beginning of the curve for short buckling lengths, the difference between capacities is huge and clear. This difference decreases with the increase in buckling length till it reaches a small value at the end of the curve. The EUROCODE gives the maximum section capacity and the Egyptian code (ASD) gives the minimum section capacity. The EUROCODE curve is far from the other four curves, where the other four curves give convergent values. It is noted that there are abnormal bends in the two curves of Egyptian codes (ASD and LRFD), which is not logical. These abnormal bends indicate that the code equations should be modified to improve the smoothness of these curves as in other codes.

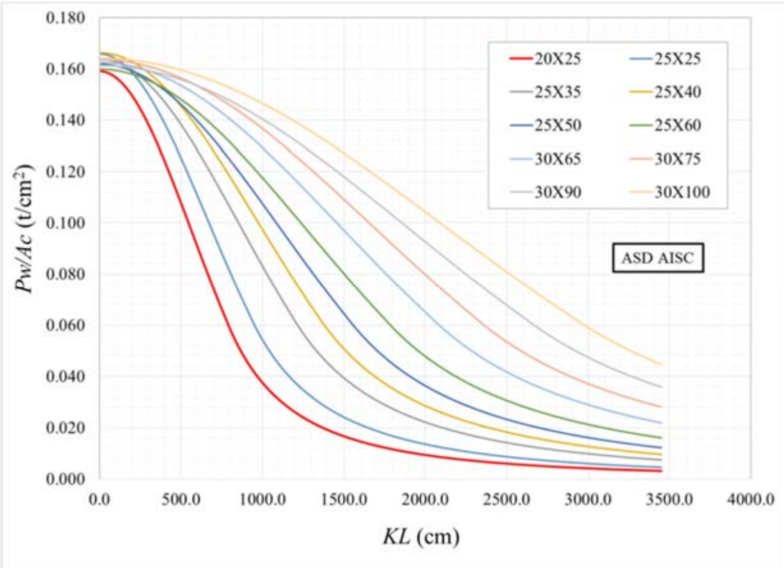


Fig. (1) The allowable stress versus the buckling length of different composite columns according to AISC requirement for allowable stress design.

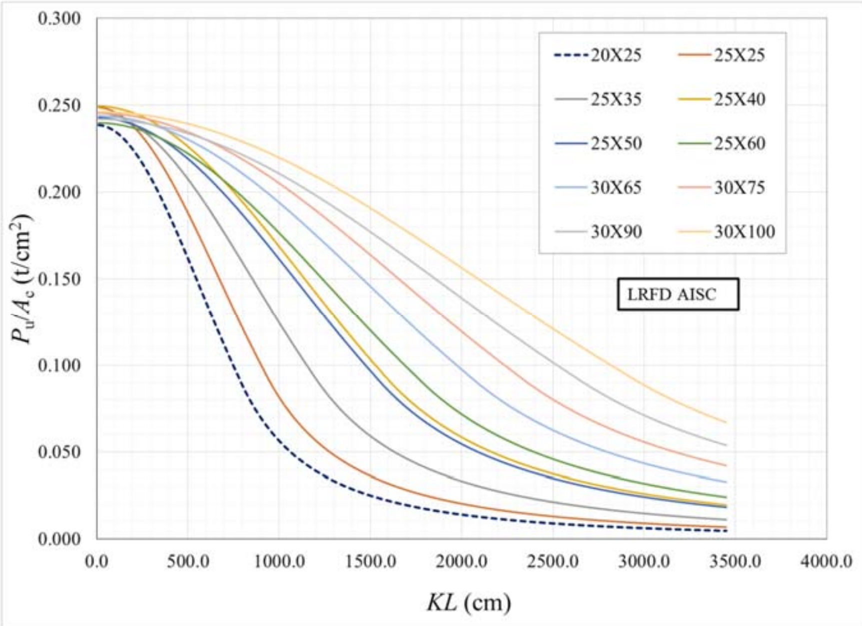


Fig. (2) The ultimate strength versus the buckling length of different composite columns according to AISC requirements for load resistance factor design.

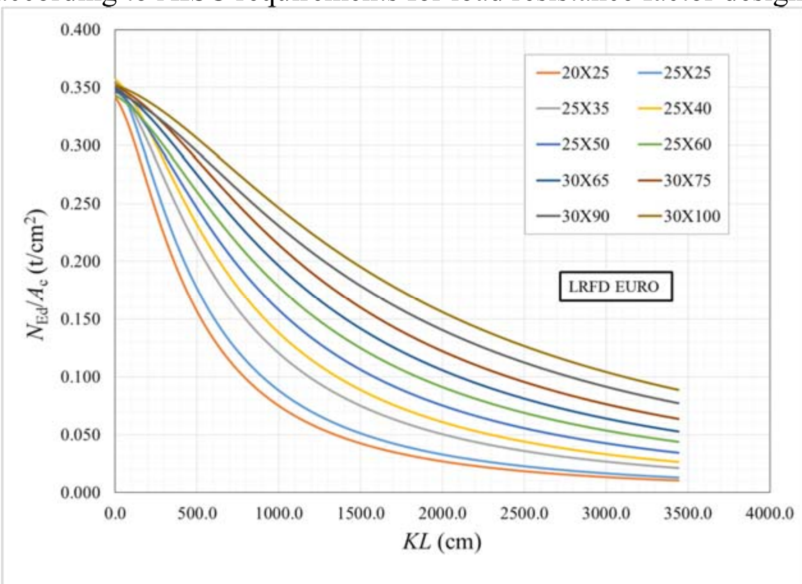


Fig. (3) The ultimate strength versus the buckling length of different composite columns according to Eurocode4 requirements for load resistance factored design.

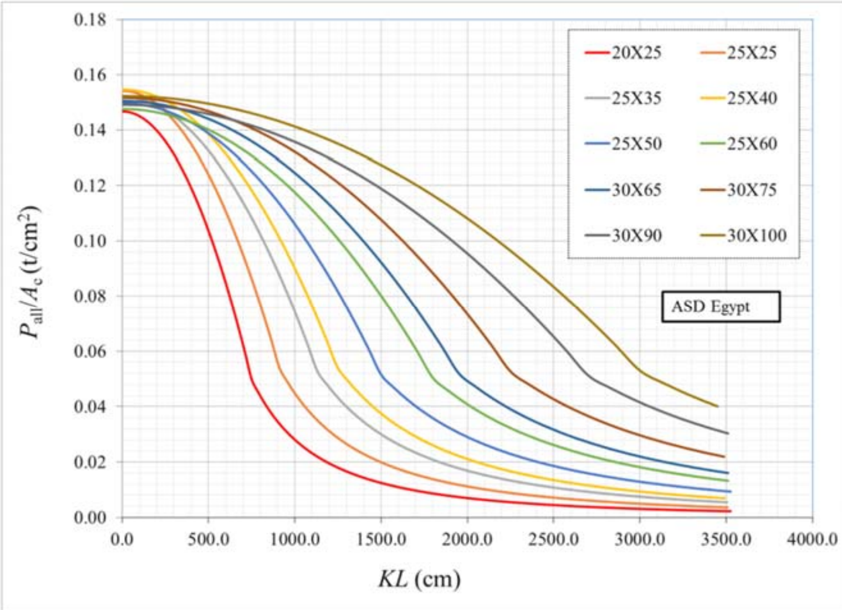


Fig. (4) The allowable stress versus the buckling length of different composite columns according to Egyptian code (ASD) requirements for allowable stress design.

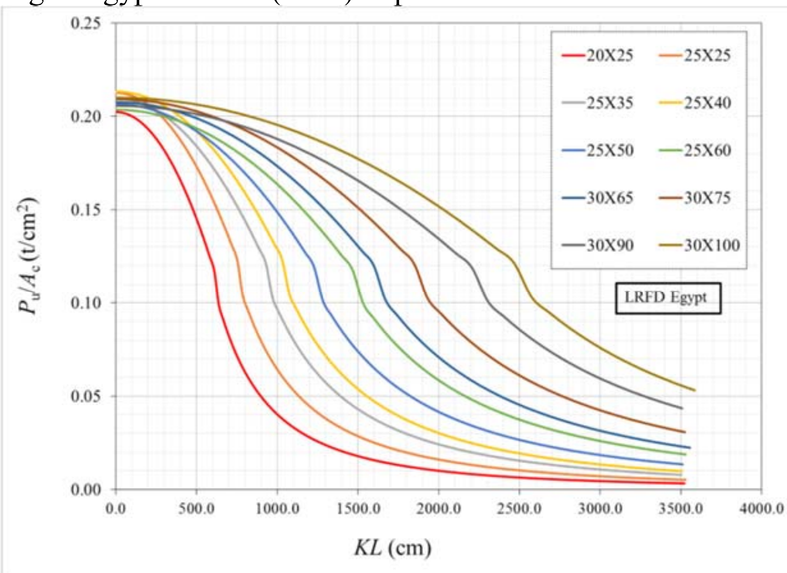


Fig. (5) The ultimate strength versus the buckling length of different composite columns according to Egyptian code (LRFD) requirements for load and resistance factored design.

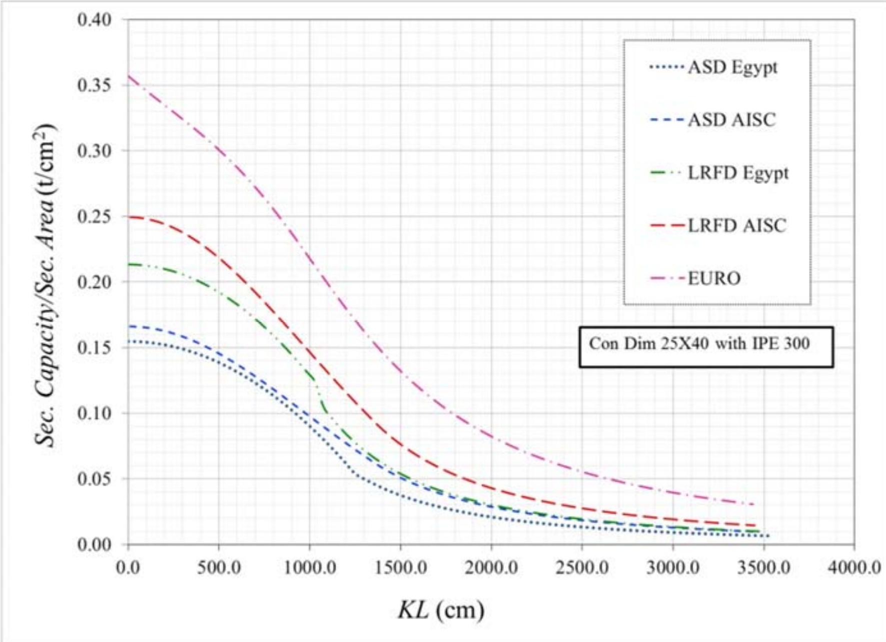


Fig. (6) A comparison between different capacities for the same composite section (4) according to different code requirements.

## Conclusion

From the previous comparisons it can be concluded that the obtained section capacities from the Eurocode4 equations have the highest values, while those obtained from the Egyptian ASD code have the lowest values, while the intermediate values come from AISC LRFD, Egyptian LRFD and AISC ASD codes, respectively.
Moreover, it can be concluded that the section capacities obtained from different codes vary to a greater extent at short buckling length values, and vary to a lesser extent at a buckling length value of 3500 cm or more.
From this study, it can be clearly seen that the Egyptian ASD and LRFD codes have a disturbance in the curve smoothness compared to the curves obtained from other codes, and that this disturbance takes place at the point of intersection between the equations of the elastic buckling phase and the inelastic buckling phase.

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