CHAPTER 3

REVIEW OF CODAL RECOMMENDATIONS

3.1 GENERAL

For the computation of maximum strength of composite columns, the strength of the cross-section, which is usually expressed in terms of the squash load is a basic requirement. Extensive research has been carried out worldwide over the past several years on concrete-filled steel columns. Based on this research, codal provisions have been formulated. A comparative study on the various factors and limitations pertaining to concrete-filled steel tubes as specified by Eurocode 4-2004, BS 5400-2005, AIJ-1997 and AISC-LRFD-2010 has been compiled and presented in this chapter.

3.2 CONCRETE-FILLED SECTIONS

The codes do not consider the type of the in-fill explicitly. The characteristic compressive strength and Modulus of Elasticity of the in-fill material are used in the calculations.

3.2.1 Local Buckling

For thin-walled members under compression, the concept of local buckling arises. For fully encased steel sections, no verification for local buckling is necessary as the concrete surrounding the steel section effectively prevents local buckling. Local buckling may be critical in concrete-filled tubular sections with large width to thickness ratios. Other factors that influence local buckling are material strength, the type of stress system to which the section is subjected, the support conditions provided and the steel
fabrication process adopted. To prevent premature local buckling, codes specify certain limitations for the width to thickness ratio of individual elements. The critical buckling stress of a plate element subjected to uniform compression is given by

\[ \sigma_{cr} = \frac{K \pi^2 E}{12(1-\nu^2) \left( \frac{w}{t} \right)^2} \]  \hspace{1cm} (3.1)

where,

- \( \sigma_{cr} \) - Local buckling stress
- \( K \) - Plate buckling co-efficient
- \( w \) - Flat width of the element
- \( t \) - Thickness of the element
- \( E \) - Modulus of Elasticity
- \( \nu \) - Poisson’s ratio

The expressions for local buckling coefficient suggested by various codes for stiffened compression elements are discussed below.

3.2.1.1 Eurocode 4 (2004)

As per clause 4.8.2.5, the effects of local buckling of steel members in composite columns may be neglected for steel sections fully encased and for other types of composite columns, provided that for circular hollow steel sections,

\[ \frac{D}{t} \leq 90 \varepsilon^2 \]  \hspace{1cm} (3.2)

\[ \varepsilon = (235/ f_y)^{1/2} \]  \hspace{1cm} (3.3)
where,

\[D - \text{External diameter of the circular hollow steel section}\]
\[f_y - \text{Yield strength of steel in N/mm}^2\]

### 3.2.1.2 BS 5400: 5 (2005)

As per clause 6.2.2.1, in order to avoid the influence of local buckling on the column strength, the ratio of the outside diameter to the wall thickness of a circular section should not exceed

\[\frac{D}{t} \leq 46\left(\frac{355}{\sigma_y}\right)\]  \hspace{1cm} (3.4)

where,

\[\sigma_y - \text{Nominal yield stress of the material of the circular section in N/mm}^2\].

### 3.2.1.3 AISC – LRFD (2010)

According to clause 4 of Chapter I, the outer diameter to thickness ratio in order to prevent local buckling is given separately for compact and non-compact sections.

For compact sections, \[D/t \leq 0.15 \frac{E_s}{f_y}\] \hspace{1cm} (3.5)

For non-compact sections, \[D/t \leq 0.19 \frac{E_s}{f_y}\] \hspace{1cm} (3.6)

### 3.2.1.4 AIJ (1997)

The limiting values of the diameter-to-thickness ratio for a circular tube is given as

\[\frac{D}{t_s} \leq 1.5 \left(\frac{23500}{F}\right)\] \hspace{1cm} (3.7)
where,

\[ D - \text{ Diameter of the circular tube} \]
\[ t_s - \text{ Wall thickness of steel tube} \]
\[ F - \text{ Standard strength to determine allowable stresses of steel and is taken as smaller of yield stress and 0.7 times tensile strength (MPa)} \]

### 3.2.2 Limits on Slenderness

The limitations specified by various codes on the slenderness value of composite columns are given below

#### 3.2.2.1 Eurocode 4 (2004)

As per clause 4.8.3.7 of Eurocode 4, the non-dimensional slenderness for the plane of bending considered is given by

\[ \lambda = \sqrt{\frac{N_{plR}}{N_{cr}}} \]  \hspace{1cm} (3.8)

where,

\[ N_{plR} - \text{ Plastic resistance to compression} \]
\[ N_{cr} - \text{ Elastic critical load} \]

For concrete-filled tubes of circular cross-section, account may be taken of the increase in strength of concrete caused by confinement provided the relative slenderness does not exceed 0.5.
3.2.2.2 BS 5400 : 5 (2005)

As per clause 11.1.5, the ratio of the effective length to the least lateral dimension of the composite column, should not exceed 55 for concrete-filled circular hollow sections.

3.2.2.3 AISC – LRFD (2010)

The column slenderness $\lambda_c$ is given by the formula

$$\lambda_c = \frac{1}{r_m} \left( \frac{\sigma_y + 0.85f_y A_c}{E_s + 0.4E_c A_s} \right)^{1/2}$$

(3.9)

where,

- $A_s$ - Area of the steel section
- $A_c$ - Area of concrete
- $f_y$ - Yield strength of steel
- $E_s$ - Elastic modulus of steel
- $E_c$ - Elastic modulus of concrete
- $r_m$ - Radius of gyration of the steel shell (or) 0.3 times the overall thickness of the composite cross-section in the plane of buckling
- $l_e$ - Effective length
3.2.2.4 AIJ (1997)

The effective slenderness ratio is given by

\[ \lambda = \pi \left( \frac{E_s}{0.6f_y} \right)^{1/2} \]  \hspace{1cm} (3.10)

3.2.3 Effective Elastic Stiffness

Various codes propose different equations for the calculation of effective elastic stiffness of a composite cross-section. The various codal specifications are as follows

3.2.3.1 Eurocode 4 (2004)

According to clause 4.8.3.5, the effective elastic flexural stiffness of the cross-section of composite column, \((EI)_c\), is given by

\[ (EI)_c = E_a I_a + 0.8 E_{cd} I_c + E_s I_s \]  \hspace{1cm} (3.11)

where,

- \(I_a, I_c\) and \(I_s\) - Second moments of area for the structural steel, concrete and reinforcement, respectively.
- \(E_a\) and \(E_s\) - Elastic moduli of structural steel and the reinforcement
- \(0.8E_{cd}I_c\) - Effective stiffness of the concrete
- \(E_{cd} = \frac{E_{cm}}{\gamma_c} ; \; E_{cm}\) - Secant modulus of concrete; \(\gamma_c\) - Safety factor for concrete

3.2.3.2 BS 5400: 5 (2005)

According to clause 4.4.2.1, the flexural stiffness constants for sections of discrete members or elements is given as

\[ (EI)_c = E_{cd} I_c + E_s I_s \]  \hspace{1cm} (3.12)
3.2.3.3  AISC – LRFD (2010)

The modified elastic modulus is found by the combination of cross-section characteristics such as area and moment of inertia

\[(EI)_c = E_s I_s + 0.85E_c I_c \quad (3.13)\]

3.2.3.4  AIJ (1997)

Effective flexural stiffness is obtained by the combination of cross-section flexural stiffness of the steel tube and the concrete core.

\[(EI)_c = E_s I_s + 0.12E_c I_c \quad (3.14)\]

3.2.4  Concrete Contribution Factor

BS 5400:5 (2005) considers the contribution of the in-filled concrete to the strength of the composite column explicitly.

3.2.4.1  BS 5400:5 (2005)

As per clause 11.1.4, the concrete contribution factor is defined as the ratio of the contribution of strength of concrete to the strength of the composite column.

Concrete contribution factor \((\alpha) = 0.45 \frac{A_c f_{cu}}{N_u} \quad (3.15)\)

where,

- \(A_c\) - Cross-sectional area of concrete
- \(f_{cu}\) - Cube compressive strength of concrete
- \(N_u\) - Squash load

### 3.2.5 Steel Contribution Ratio

Eurocode 4 (2004) considers the contribution of steel to the strength of the composite column explicitly.

#### 3.2.5.1 Eurocode 4 (2004)

According to clause 4.8.3.4, steel contribution ratio is defined as the contribution of strength of steel to the strength of the composite column.

\[
\delta = \left( \frac{A_a f_y}{\gamma_a} \right) / N_{pl.R} \tag{3.16}
\]

where,

- \(A_a\) - Cross-sectional area of steel section
- \(\gamma_a\) - Partial safety factor for steel

AISC-LRFD (2010), BS 5400 – 5 (2005) and AIJ (1997) provisions do not consider the steel contribution ratio on strength and ductility of the members analysed explicitly.

### 3.2.6 Design model for Axial Compression

The design capacity of concrete-filled steel columns as given by various codes are presented below.

#### 3.2.6.1 Eurocode 4: 2004

The plastic resistance of the in-filled columns are calculated as the summation of the resistance of individual components.
\[ N_{pl,rd} = A_c f_y / \gamma_{ma} + A_c f_{cc} / \gamma_c \]  

(3.17)

where,

- \( A_c \) - Cross-sectional area of concrete
- \( A_s \) - Cross-sectional area of the steel tube
- \( f_{cc} \) - Characteristic concrete cylinder strength
- \( f_y \) - Yield stress of steel section

Partial Safety factors for steel \( (\gamma_{ma} = 1.10) \) and concrete \( (\gamma_c=1.5) \)

### 3.2.6.2 BS 5400: 5 (2005)

The squash load of concrete in-filled columns is calculated as

\[ N_U = 0.91 A_s f_y + 0.45 A_c f_{cc} \]  

(3.18)

where, \( f_{cc} \) - Enhanced characteristic strength of triaxially confined concrete.

### 3.2.6.3 AISC – LRFD (2010)

The design strength of axially loaded filled composite members is determined as

\[ P = A_s f_y + 0.85 A_c f_{ck} \]  

(3.19)

where, \( f_{ck} \) - Characteristic cube compressive strength of concrete

### 3.2.6.4 AIJ (1997)

When the CFT section is under ultimate compressive force \( N_{cu} \), the concrete in a circular CFT section is subjected to axial stress \( \sigma_c \) and lateral
pressure $\sigma_r$, and the steel tube is subjected to axial stress $\sigma_z$ and ring tension stress $\sigma_t$. Design resistance, $N_{cu}$ is given by

$$N_{cu} = A_c\sigma_c + A_s\sigma_z$$  \hspace{1cm} (3.20)

where,

- $\sigma_c$ - Compressive stress in concrete
- $\sigma_z$ - Tensile stress in steel tube

### 3.3 SUMMARY

For the determination of the cross-sectional strength of CFT columns, EC4 provisions assume plastic stress distribution in the cross-section and full compatibility between the steel and concrete. AISC-LRFD, EC4 and AIJ provisions do not consider the concrete contribution factor on strength and ductility of the members analysed explicitly. EC4 considers confinement effect only for circular sections with relative slenderness less than 0.5. AISC-LRFD, BS 5400 and AIJ provisions do not consider the steel contribution ratio on strength and ductility of the members analysed explicitly. EC4 uses limit state concepts to achieve the aims of serviceability and safety by applying partial safety factor to loads and material properties.