# COMPARISON OF SOME DESIGN PROVISIONS OF BS 8110 AND EC2 CODES FOR THE DESIGN OF REINFORCED CONCRETE COLUMNS

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## INTRODUCTION

In Sri Lanka, BS 8110 is the code of design for concrete structures. BS 8110 produced by the British Standard Institution (BSI), offers guidance for reinforced concrete design within the United Kingdom and to most of the Commonwealth countries (Bond et al, 2006, Hagsten & Hestbech, 2002). In the year 2004, the European committee for standardization (CEN), published a final version of EN 1992-1 (called Eurocode 2 or EC2) for the design of concrete structures. One of the main objectives of the Eurocodes is to improve the competitiveness of the European construction industry. Eurocode 2 is expected to be used in parallel with the current code for a few years and ultimately replace the old code for concrete building design in the relevant countries (Mose and Brooker, 2007). BSI and other standards organizations in Europe have realized that local requirements also need to be considered. Each member country of the union has produced its own National Annex in which local requirements are specified (Bungey et al, 2007).

One of the expected goals of usage of EC 2 was to effectively replace the current British Standards as the primary basis for designing of concrete buildings and civil engineering structures in the UK by year 2011 (Draycott & Bullman, 2009). In this paper, an attempt is made to summarize the differences between BS8110 and EC 2 for the design of columns.

## COLUMN DESIGN

### Comparison between different codes

It is obvious that there are differences between these two codes in design philosophy. The significant differences between EC2 and BS 8110 are identified and explained as below.

### Stress block

In EC 2, similar to BS8110, the rectangular stress block used for the design of beams can also be used for columns.

### Effective length

Effective length has a direct influence in the load carrying capacity of the slender columns. Table 1a summarizes the differences between two codes in effective lengths used.

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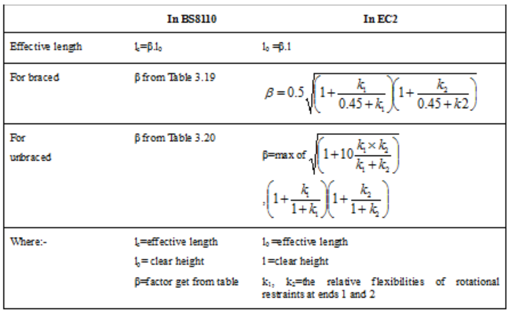
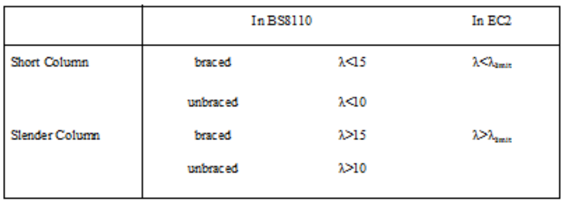
**Table 1a: Determination of effective length**



|  | In BS8110 | In EC2 |
|---|---|---|
| Effective length | $l_e = \beta . l_o$ | $l_0 = \beta . l$ |
| For braced | β from Table 3.19 | $\beta = 0.5\sqrt{\left(1+\frac{k_1}{0.45+k_1}\right)\left(1+\frac{k_2}{0.45+k2}\right)}$ |
| For unbraced | β from Table 3.20 | β=max of $\sqrt{\left(1+10\frac{k_1 \times k_2}{k_1+k_2}\right)}$ ; $\left(1+\frac{k_1}{1+k_1}\right)\left(1+\frac{k_2}{1+k_2}\right)$ |
| Where:- | $l_e$=effective length<br>$l_o$= clear height<br>β=factor get from table | $l_0$ =effective length<br>$l$ =clear height<br>$k_1$, $k_2$=the relative flexibilities of rotational restraints at ends 1 and 2 |

**Table 1b: Classification of columns**



|  | In BS8110 |  | In EC2 |
|---|---|---|---|
| Short Column | braced | $\lambda<15$ | $\lambda<\lambda_{limit}$ |
|  | unbraced | $\lambda<10$ |  |
| Slender Column | braced | $\lambda>15$ | $\lambda>\lambda_{limit}$ |
|  | unbraced | $\lambda>10$ |  |

Slenderness ratio is an important parameter in column design, which decides whether the column capacity is predominantly influenced by buckling. In BS 8110 slenderness ratio is calculated based on $l_{ex}/h$ or $l_{ey}/b$. where $l_{ex}$, $l_{ey}$ are effective lengths of column and $h$, $b$ are dimensions of the column. However, in EC2 it is based on $l_0/r$ and slenderness limit. Where $l_0$,$r$ are effective length and radius of gyration respectively (Table 1b).

## Slenderness ratio

In EC 2 there is a detailed procedure to determine slenderness limit ($\lambda_{lim}$) for column classification. Determination of slenderness limit is given below.

$$\lambda_{lim}=20.A.B.C/\sqrt{n} \qquad \{Eq.\ 1\}$$

Where:

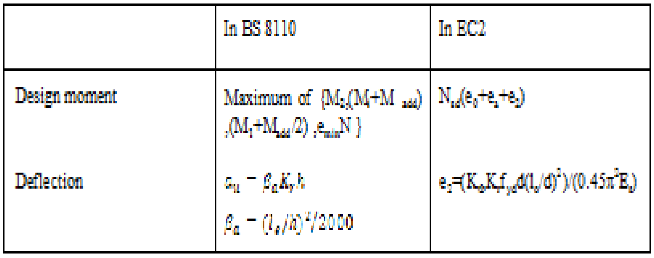
$A=1/(1+0.2\Phi_{ef})$ $\Phi_{ef}$ is the effective creep ratio (if $\Phi_{ef}$ is unknown, A=0.7 may be used)
$B=\sqrt{(1+2\omega)}$ $\omega = A_s f_{yd}/(A_c f_{cd})$ (if ω is not known, B=1.1 may be used)
$C= 1.7 - r_m$ $r_m=M_{01}/M_{02}$ $M_{01}, M_{02}$ are first order end moments,$|M_{01}| \leq |M_{02}|$
(if $r_m$ is unknown, C=0.7 may be used)
$n = N_{ed}/(A_c f_{cd})$ $N_{ed}$ = *applied design load and* $f_{cd}$ = *Concrete strength*

It should also be noted that the slenderness limit ($\lambda_{lim}$) in EC 2, is dependent on the applied design axial load among other parameters such as concrete creep, load sharing capacity between concrete & reinforcement and end moment ratio. By making $\lambda_{lim}$ inversely proportional to the square root of the ratio of applied axial compressive stress to strength, EC 2 has accounted for the negative effect of axial stress intensity on stability.

## Determination of the design moment and deflection in a slender column.

In slender column design, the design moment and second order eccentricity calculation methodologies in BS 8110 and EC2 are different. Those differences are shown in Table 2.

**Table 2: Determination of design moment**



|  | In BS 8110 | In EC2 |
|---|---|---|
| Design moment | Maximum of $\{M_2,(M_i+M_{add}),(M_1+M_{add}/2), e_{min}N\}$ | $N_{ed}(e_0+e_a+e_2)$ |
| Deflection | $a_u = \beta_a K h$<br>$\beta_a = (l_e/h)^2/2000$ | $e_2=(K_\varphi K_r f_{yd} d (l_0/d)^2)/(0.45\pi^2 E_s)$ |

Where:-

$M_i$ -Initial design ultimate moment
$M_{add}$ -Additional design ultimate moment
$e_0$ - Equivalent first order eccentricity
$e_a$ - Accidental eccentricity

$e_2$ - Second-order eccentricity
$K_r$ - Reduction factor
$K_\Phi$ - Creep ratio factor

*Determination of accidental eccentricity ($e_a$)* $e_a = v(l_o/2)$
Where:- $v = 1/200$
$l_o$ – Effective length

*Determination of the reduction factor ($K_r$)* $K_r = (N_{uz}-N)/(N_{uz}-N_{bal})$
Where:- $N_{uz}$ - Axial load capacity of the column
N - Ultimate axial load
$N_{bal}$ - Axial load at balanced condition

The calculation of $N_{bal}$ is also different in both codes as;
$N_{bal} = 0.25f_{cu}bd$ (BS 8110)
$N_{bal} = 0.29f_{ck}A_c$ (EC 2)

### Vertical reinforcement for columns

The maximum and minimum amounts of vertical reinforcement permitted by each code are decided by the geometrical property of the cross section. The maximum and minimum amounts of vertical reinforcement are given below in Tables 3a & 3b.

**Table 3a: Maximum amount of vertical reinforcement**

| BS 8110 | EC 2 |
|---|---|
| 6% of $A_c$ (10% at laps) | 4% of $A_c$ (8% at laps) |

**Table 3b: Minimum amount of vertical reinforcement**

| BS 8110 | EC 2 |
|---|---|
| $A_{s,min} = 0.004A_c$ | $A_{s,min} = 0.1N_{Ed}/f_{yd} > 0.002A_c$ |

### EVALUATION OF THE DIFFERENCES

According to Euler theory there are four distinguished end conditions. However, the clear boundaries of the differences are difficult to distinguish in the real world. Therefore, both codes have correctly addressed this issue by providing intermediate values. If the coefficient of the effective length for theoretical pinned condition is considered as the upper boundary, the coefficient of the effective length for the theoretical fixed condition will be the lower boundary.

In using BS 8110 the minimum value of□that can be derived is 0.75. This value is an intermediate value in comparison to Euler values (pinned 1 and fixed 0.5). However, by using EC 2 the minimum value of 0.5 can be derived. EC2 suggests that the fixed condition can be really achieved in the field. It can be explicitly shown that this situation can be achieved in the field. One of the possible ways is setting $k_1$ and $k_2$ to zero. This situation is possible by having a negligible column stiffness compared to the beam stiffness as the $k_1$ and $k_2$are calculated by taking the ratio of column stiffness to the beam stiffness. By increasing the beam width and depth drastically compared to column, the fixed condition can be achieved. In BS 8110 the minimum value is 0.75 which is 50% higher than the EC2 value.

In order to get the pinned end condition $\beta$ should be equal to 1.

$$\beta = 0.5\sqrt{\left(1+\frac{k_1}{0.45+k_1}\right)\left(1+\frac{k_2}{0.45+k2}\right)} = 1$$

i.e $$\sqrt{\left(1+\frac{k_1}{0.45+k_1}\right)\left(1+\frac{k_2}{0.45+k_2}\right)} = 2$$ {Eq. 2}

Considering the symmetrical arrangement (both in the upper floor and lower floor) as the starting point,

Eq. 2 yields, $\left(1+\frac{k}{0.45+k}\right) = 2$ {Eq. 3}

Equation 3 is mathematically true only *when* $k \rightarrow \infty$. This implies that Column stiffness is significantly higher (order of millions higher) than the beam stiffness which is practically very rare. Therefore, EC 2 does not converge to a pinned condition. However, BS 8110 gives pinned condition, when condition 3 is met as in Table 9.2.

Determination of slenderness ratio is more detailed in EC 2 compared to BS 8110. Observing the behavior of limiting slenderness ratio, it can be noticed that the slenderness ratio of EC 2 can be increased by maximizing the Eq. 1. In order to maximize the equation $A$, $B$ and $C$ should have their maximum values together with the minimum value for $n$. It is straightforward to maximize $A$, $B$ and $C$ and their values are 1, 1and 1.7 respectively. However, minimizing $n$ is not straightforward as it involves the design load. The trivial solution is minimizing the design load which is equal to zero. However, this solution has practically no importance. Therefore, the trivial solution is neglected as the solution does not provide any valuable output. When the parameter $n$ becomes less than 1.0, limiting slenderness will be always greater than 20. This value is approximately 30% higher than the BS 8110 limiting slenderness value. However, $n$ will be less than one in most of the real situations as the load is shared by concrete and steel in a column. Therefore, it is reasonable to argue that the limiting slenderness is greater than 20 if $A$, $B$ and $C$ have their maximum values.

## Comparison of Normal load (N)- Moment (M) interaction chart in column design

Interaction charts are used to determine the reinforcement areas in column design when axial load and bending moment are simultaneously acting. The chart is drawn for a particular grade of concrete and a particular characteristic strength of reinforcement. Figure 1 illustrates the difference between charts from BS 8110 and EC 2.

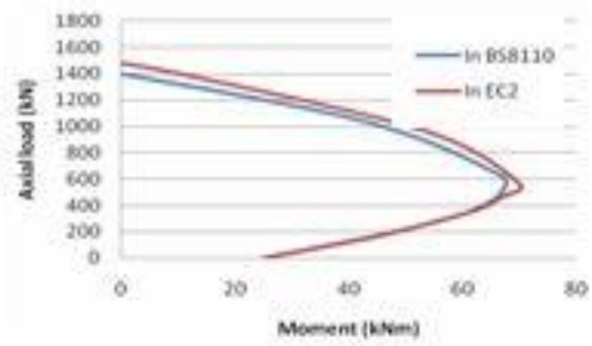


Figure 1 – Column Interaction Diagrams

For comparison of the balanced condition with two codes, following parameters are used. Column size - 300 x 300 mm, Concrete grade- C25, and Nominal cover - 20 mm, Main bar - 4T12, Transverse link - 6 mm. The balancing point, where the steel strain and concrete strain is same, occurs at the normal load of 600 kN and 65 kNm according to BS 8110, with 550 kN and 70 kNm according EC 2.

## CONCLUSIONS

For determining the effective length, BS8110 provides tables and expressions as well as values of β with assessment of the end conditions that are appropriate. But the EC 2 procedure appears more complicated, as an assessment needs to be made of the relative flexibilities of the rotational restraints at each end of the column. According to EC 2, though different end fixities could be obtained, pinned condition will not be attainable.

For determining slenderness status of a column, BS8110 gives simple guidance through fixed limits. However, in EC 2, a more complex approach dependant on several parameters is presented which does not have much practical value and is prone to interpretation and calculation errors.

According to the M-N diagram at the balance point marginal decrease of normal load (less than 8%) was observed in EC 2 and 15% increase of the moment was observed indicating that would over-estimate flexural capacity.

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