Optimization of Steel Reinforcement in a Reinforced Concrete Column using Eurocode2 and BS8110-97

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Abstract

In this paper, the results of optimal design of steel reinforcement in a rectangular reinforced concrete column using Eurocode2 are discussed. Axial, uniaxial and biaxial loaded columnswere selected and designed using both Eurocode2 and BS 8110 code with the aid of a programmed Excel Spreadsheet. The result of the analysis was used to design the column reinforcement based on both codes. The percentage differences between the areas of reinforcement required by the two codes were calculated with the BS 8110 code results serving as the control values. It was found that the average percentage difference due to BS 8110 exceeded that of Eurocode2 in most cases considered.

Keywords: *Optimal design, steel reinforcement, Eurocode2, BS 8110, axial, biaxial, moment*

I. INTRODUCTION

The structural design of most buildingsand reinforced concrete members such as beams, slabs, columns and foundation is based on design codes of practice. The structural design codes guide the design civil and structural engineer in the general appraisal of the structural scheme, detailed analysis and design. Codes of practice are basically design guidelinescompiled by experienced engineers and a team of professionals, and they provide a framework for addressing issues of safety and serviceability in structural design (Samir, 2014; SiaKeeSieng, 2010). In Africa, national codes of practice have been primarily derived from the British standard (BS8110, 1997). In the last three decades however, a new set of codes to replace the British and other European national standards has been developed. Eurocodesaim at providing common design criteria and methods to fulfil the specified requirements of safety, serviceability and economy (European Union, 2004; Jawad, 2006; Labani and Priyabrata 2014; Liew, 2009; Moss, and Webster, 2004; Nwofor et al, 2015).In some parts of the world, Eurocode2is being used for design of reinforced concrete structures it is yet gained full popularity in Nigeria.The British standard codes of practice had been in use for the design of reinforced concrete structuresbefore the Eurocode2 came into being(Oyenuga, 2011).

One of the aims of structural design is that the structure must be economical in terms of its construction cost and maintenance cost (Mosley et al, 2007). Nigeria is currently facing a period of economic recession and every citizen of Nigeria is struggling to afforda structure of his/her own with his/her hard earned money. Affording a structure will require the use of steel reinforcement at one point or the other in the building process. The prices of building and construction materials such as steel reinforcement increase on daily basis. The conventional design codes used high value of safety factor that resultsto uneconomical design of structures. There is therefore, an immediate need to explore into the potentials of Eurocode2 that uses lower factor of safety values without compromising safety. This study aims at investigating the significant differences between the BS 8110 and the Eurocode2 using programmed Microsoft Excel spreadsheets. A reinforced concrete beam, an axially loaded column, uniaxially loaded column and abiaxial loaded column are used as case studies. The spread sheet is user friendly.

II. MATERIALS AND METHODS

The design stresses for concrete and steel section are given by:

$Concrete\ design\ stress, f_{cd}$

$$= \frac{\alpha f_{cu}}{\gamma_{mc}} \qquad (1)$$

$Reinforcement\ design\ stress, f_{yd}$

$$= \frac{f_y}{\gamma_{ms}} \qquad (2)$$

Table 1: Material Properties Based on BS 8110 and Eurocode 2

Parameter	BS 8110	Eurocode 2
α	0.67	0.85
γ_{mc}	1.5	1.5
γ_{ms}	1.15	1.15
f_{cd}	$0.45f_{cu}$	$0.57f_{cu}$
f_{yd}	$0.87f_y$	$0.87f_y$

Since both the concrete and the column reinforcement contribute in the load carrying capacity of the column, the ultimate load, N which can be supported by the column is the algebraic sum of the force resisted by the concrete (F_c) and the reinforcement (F_s).

$$N = F_c + F_s \qquad (3)$$

Where: $F_c = stress, f_{cd} \times area\ of\ concrete, A_c$

$F_s = \text{stress}, \text{f}_{\text{yd}} \times \text{area of steel reinforcement}, \text{A}_\text{s}$

$$\text{N} = \text{stress}_{(\text{conc.})} \times \text{area}_{(\text{conc.})} + \text{stress}_{(\text{st.})} \times \text{area}_{(\text{st.})} \qquad (4)$$

For a rectangular column,

$$N = (f_{cd} \times bh) - (f_{cd} \times A_s) + (f_{yd} \qquad (5)$$

$$N = f_{cd}.bh + (f_{yd} - f_{cd})A_s \qquad (6)$$

The area of steel reinforcement is given by:

$$A_s = \frac{N - f_{cd}.bh}{(f_{yd} - f_{cd})} \qquad (7)$$

Substituting the parameter in Table 1into Equation (7),yields the area of reinforcement according to BS8810 is given as:

$$A_s = \frac{N - 0.45f_{cu}.bh}{(0.87f_y - 0.45f_{cu})} \qquad (8a)$$

Equation (8)applies to a column that is subjected to a pure axial load which can never be achieved in practice due to construction inaccuracies. BS 8110 reduces the design stresses by about 10 per cent to cater for loading eccentricity.

The area of steel reinforcement required for a short-braced axially loaded column is now given by:

$$A_s = \frac{N - 0.4f_{cu}.bh}{(0.75f_y - 0.4f_{cu})} \qquad (8b)$$

Again, substituting the parameters from Table1 into Equation (8a) gives the area of the steel reinforcement using Eurocode2 as:

$$A_s = \frac{N - 0.57f_{cu}.bh}{(0.87f_y - 0.57f_{cu})} \qquad (9)$$

Microsoft Excel 2016 Templates

The BS 8110/Eurocode2 axial sheet is used for the design of axial loaded and it consists of cells with input data like compressive strength of concrete placed in cell C9, tensile strength of reinforcing steel placed in cell C10, partial factor of safety for steel and concrete materials are placed in cell F9 and F10 respectively.Column section dimension is placed in

The major categories suggested in Eurocode2 are just the uniaxial and biaxial loaded column, but for the purpose of comparison with the BS 8110. The same process in design of axially loaded column in BS 8110 is adopted for Eurocode2. Hence, reducing the design stresses by about 10 per cent, gives the following expression:

$$A_s = \frac{N - 0.5f_{cu}.bh}{(0.75f_y - 0.5f_{cu})} \qquad (9b)$$

For a rectangular column subjected to uniaxial and biaxial loads, the design moment must be balanced by the moment of resistance of the forces developed within the cross-section. Therefore, taking moment about the mid section yields:

$$M = F_{cc}\left(\frac{h}{2} - \frac{s}{2}\right) + F_{sc}\left(\frac{h}{2} - d'\right) + F_s\left(\frac{h}{2} - d\right) \qquad (10)$$

Expressing Equation (10) in terms of concrete and reinforcement stress, changes Equation (10) to:

$$M = f_{cd}bs\left(\frac{h}{2} - \frac{s}{2}\right) + f_{sc}A'_s\left(\frac{h}{2} - d'\right) + f_sA_s\left(d - \frac{h}{2}\right) \qquad (11)$$

When reinforcements are arranged symmetrically, $A'_s = A_s = A_{sc}/2$ and $d' = h - d$, and Equations(10) and (11) can be re-written as:

$$\frac{N}{bhf_{cd}} = \frac{s}{h} + \frac{f_{sc}}{f_{cd}}\frac{A_s}{bh} + \frac{f_s}{f_{cd}}\frac{A_s}{bh} \qquad (12)$$

$$\frac{M}{bh^2f_{cd}} = \frac{s}{h}\left(0.5 - \frac{s}{2h}\right) + \frac{f_{sc}}{f_{cd}}\frac{A_s}{bh}\left(\frac{d}{h} - 0.5\right) + \frac{f_s}{f_{cd}}\frac{A_s}{bh}\left(\frac{d}{h} - 0.5\right) \qquad (13)$$

From Equations (12 – 13) above, the steel strain, f_s and stress, f_{sc} vary with depth of the neutral axis (x). Both N/bhf_{cd} and M/bh^2f_{cd} can be calculated for specified ratios of A_s/bh and x/h so that column design charts for symmetrical arrangement of reinforcement can be developed from the value obtained.

C13 and C14 also number of bars on each face is placed in C14 and C15. Each formula in each cell is programmed in accordance to the prescribed code used.

Microsoft Excel 2016 was programmed to carry out the computation and analysis ofthe input data. The materials data collected from the codes (BS8110 and Eurocode2) were entered in the first sheet as well as the geometrical properties of the reinforced concrete column. The data were put in the first sheet (Fig 1) and classification of the column if short or slender was carried out.Also, in Figure 1, the design of axially loaded column was carried out. In Fig 2, the calculations for the M-N interaction chart were carried out.

III. BS 8110/EC2 UNIAXIAL AND BIAXIAL SHEET

The BS 8110/Eurocode2spreadsheet sheet was used to design a rectangular column under uniaxial and biaxial load cases. The Area of reinforcement was varied to fall within the envelope enclosed by the red marker line. The closer the dot (white maker) is to the red marker the more economical the area of reinforcement for the design section. The input data cell is the same as that of the first sheet, but differs in the axial force, N and design moment, M.

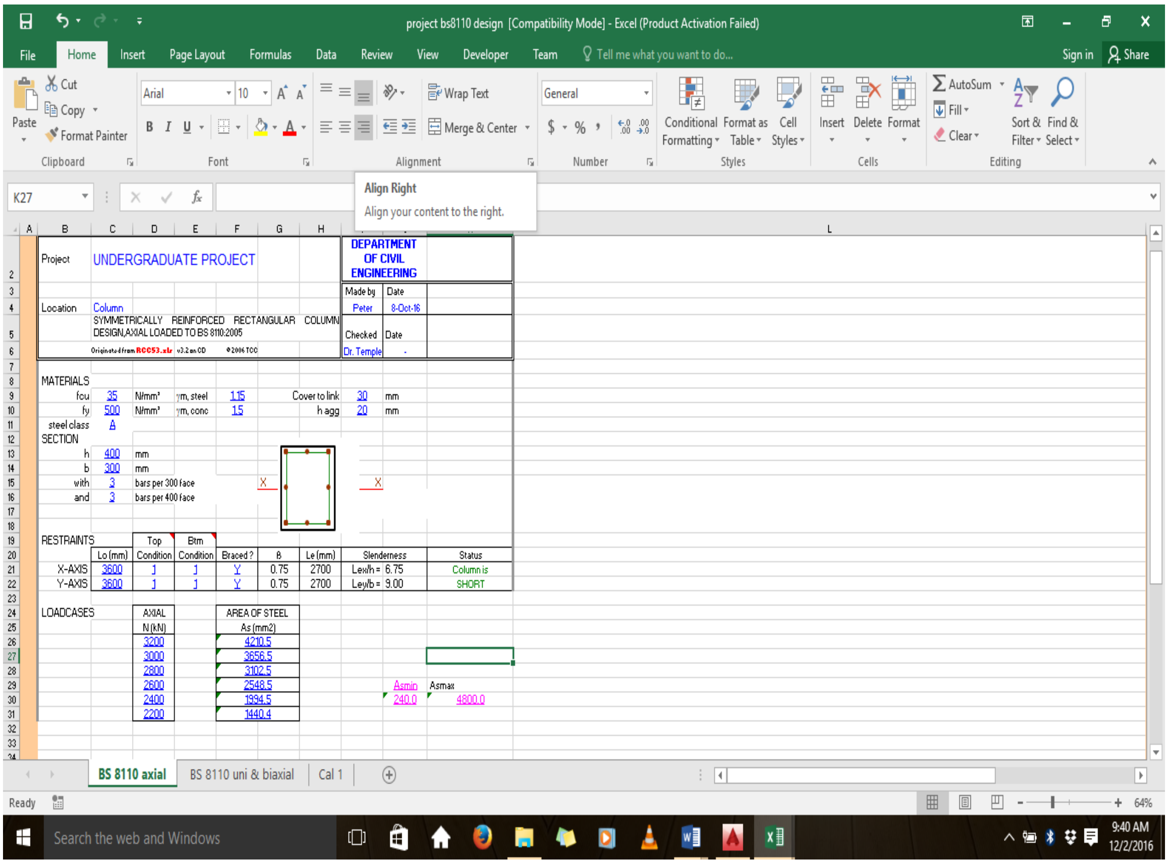

Fig 1: A typical BS 8110/ Eurocode2Axial Sheet (Excel 2016)

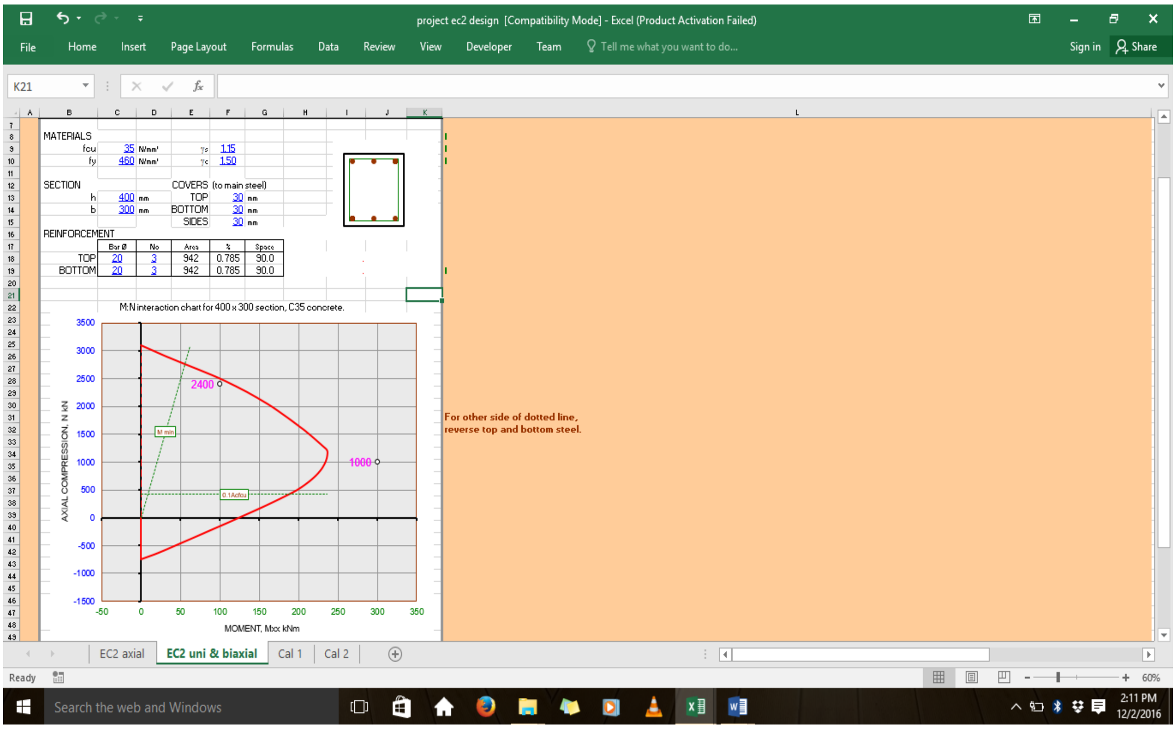

Fig 2: ATypicalBS 8110/Eurocode2Uniaxial and Biaxial ColumnSheet (Excel 2016)

IV. RESULTS AND DISCUSSION

The results of the design of the columns of the building according to BS 8110-97 and Eurocode2 for different columns axial loadcasesusing Microsoft excel programsarepresented in Fig 3.

The percentage difference between of the area of steel reinforcement required was calculated for each design load considered withthe values obtained from BS 8110-97 serving as control points. The negativevalues of percentage differencesobserved in Fig 3shows that the area ofsteelreinforcementrequired by BS 8110-97 is greater than that required byEurocode2.

The results of areas of steel required for varied axial loads at constant moment values are presented in Figs 4 to 7 respectively.From Figs 4 to 7, it can be seen that the percentage difference between the areas of steel required by the two codes was calculated with the results obtained from BS code serving as control points. It can be seen that the percentage difference for axial loads of 2000KN, 2200KN, 2400KN, 2600KN are -64%, -47%, -37% and -31% respectively. The average of the percentage differences is -45%.

The results of areas of steel required for varied moments at constant axial loadvalues are presented in Figs 8 to 11 respectively.From Figs 8 to 11, it can be observed that:

i. The percentage differences for axial loads 2000KN, 2200KN, 2400KN and 2600KN at a constant moment of 50KNm are -64%, -49%, -41% and -28% respectively, with an average percentage difference value of -46%.
ii. The percentage differences for axial loads2000KN, 2200KN, 2400KN and 2600KN at a constant moment of 100KNm are -43%, -32%, -31% and -25% respectively, with an average percentage difference value of -33%.
iii. The percentage differences for axial loads of 2000KN, 2200KN, 2400KN and 2600KN at a constant moment of 150KNm are -27%, -27%, -25% and -21% respectively, with an average percentage difference value of -25%.
iv. The percentage differences for axial loads 2000KN, 2200KN, 2400KN and 2600KN at a constant moment of 200KNm are -19%, -19%, -20% and -17% respectively, with an average percentage difference value of -19%.
v. The percentage differences for moments 50KNm, 100KNm, 150KNmand 200KNm at constant axial loads of 2000KN are -64%, -43%, -28% and -19%respectively, with an average percentage difference value of -39%.
vi. The percentage difference for moments 50KNm, 100KNm, 150KNm and 200KNm at a constant axial load of 2200KN is -49%, -32%, -27% and -19% respectively, with an average percentage difference value of -32%.
vii. The percentage differences for moments 50KNm, 100KNm, 150KNm and 200KNm

at a constant axial load of 2400KN are -41%, -31%, -25% and -20% respectively, with an average percentage difference value of -29%.

viii. The percentage differences for moments 50KNm, 100KNm, 150KNm and 200KNm at a constant axial load of 2600KN are -28%, -25%, -21% and -17% respectively, with an average percentage difference value of -23%.

The results show that BS 8110 codes require more area of reinforcement for both the axial and uniaxial load cases considered. The percentage difference decreases with increase in axial load and moment. The results generally show that the BS8110 requires more area of reinforcement compared to Eurocode2.

This variation in trend can be attributed to the partial safety factor to design strength for concrete. The BS8110 code applies lesser partial safety factors to design strength of 0.67 at the ultimate limit state for concrete. In contrast to Eurocode2, a higher partial safety to design strength of 0.85 at ultimate limit state for concrete is used.

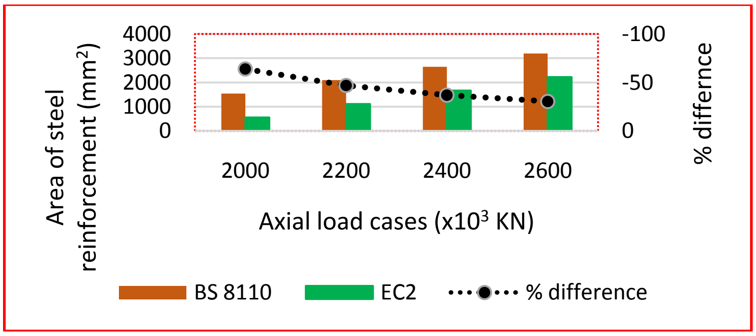

Fig 3: Relationship Betweenarea of Steel Requiredand Varied Axial Loads

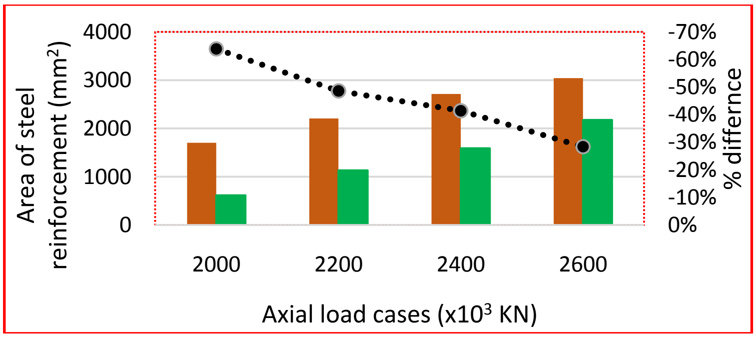

Fig 4: Relationship Between Areas of Steel Required And Varied Axial Load at Constant Moment of 50knm

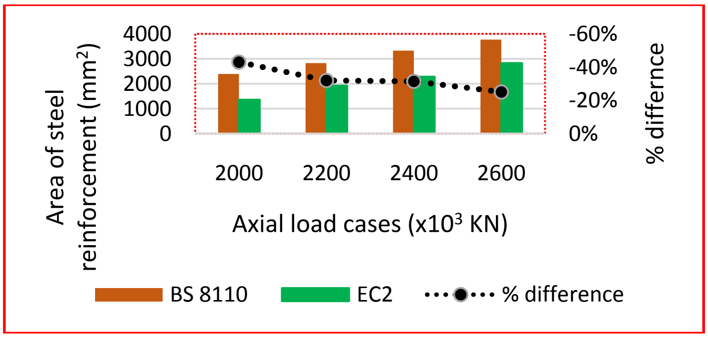

Fig 5: Relationship Between Areas of Steel Required and Varied Axial Load at Constant Moment Of 100knm

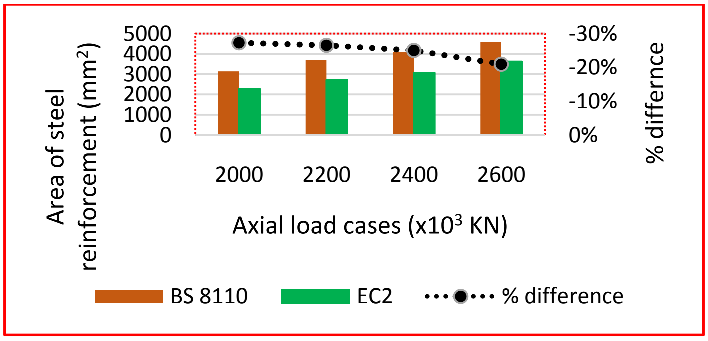

Fig6: Relationship Between Areas of Steel Required and Varied Axial Load at Constant Moment of 150knm

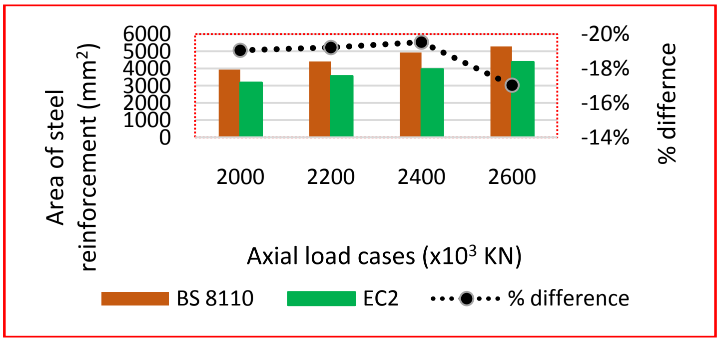

Fig 7: Relationship Between Areas of Steel Required and Varied Axial Load at Constant Moment Of 200knm

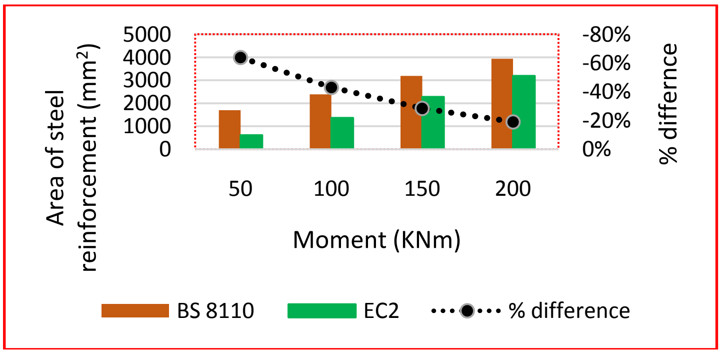

Fig 8: Relationship Between Areas of Steel Required and Varied Moment at Constant Axial Load Of 2000KN

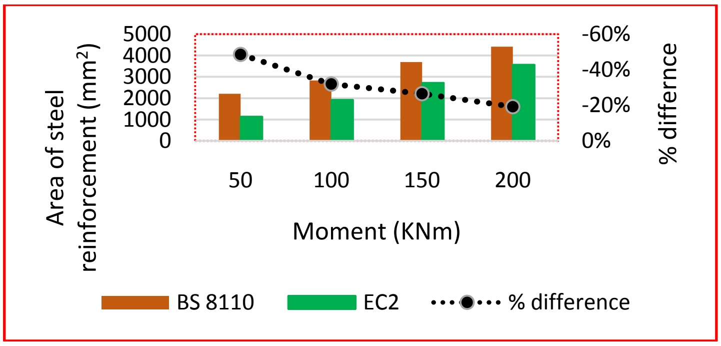

Fig 9: Relationship Between Areas of Steel Required and Varied Moment at Constant Axial Load 2200KN

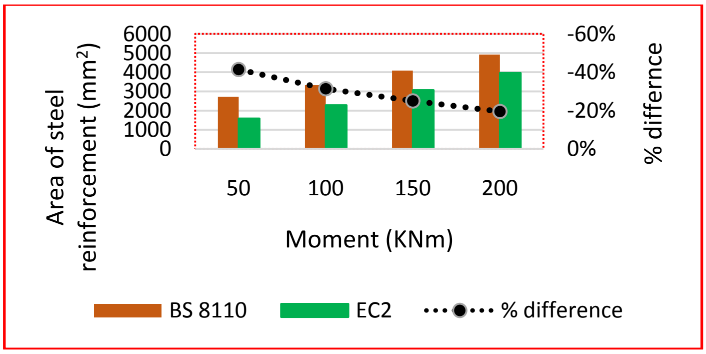

Fig10:Relationship Between Areas of Steel Required and Varied Moment at Constant Axial Load 2400KN

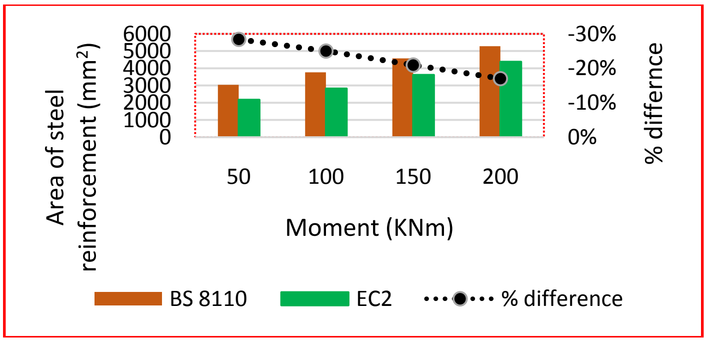

Fig 11: Relationship Betweenareas of Steel Required and Varied Moment at Constant Axial Load Of 2600KN

V. CONCLUSIONS

From this study, the following conclusions are drawn.

i. The BS 8110 exceeds that of Eurocode 2 by an average of about45% for the axial load moment, 46% for the varied axial load and 50KNm moment, 33% for the varied axial load and 100KNm moment, 25% for the varied axial load and 150KNm moment, 19% for the varied axial load and 200KNm moment, 39% for the varied moment and 2000KN load, 32% for the varied moment and 2200KN load, 29% for the varied moment and 2400KN load and 23% for the varied moment and 2600KN load.

ii. BS 8110 code requires more area of reinforcement for short columns which supports relatively lower axial loads, but for higher axial loads the BS 8110 code requires almost similar area of steel reinforcement as Eurocode 2.

iii. Design of the short rectangular columns using the Eurocode 2is more economical compared to BS 8110

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