The Effects of Design Methods on Compressive Members in Steel Frame Work

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Abstract -- The stability of frames rely remarkably on the effective length factors which depend on the end condition of column. Many design codes or approaches have provided values of these factors to be easily adopted by design engineers. However, the discrepancies from the various approaches have raised concern over the need for careful analysis of frames in order to evaluate the factors that will give a better and improved stability to the frame. From the study, the effects of the discrepancies in the effective length factors are not felt in short columns because such members fail by crushing but the effects are seriously felt on slender members or columns whose instability needed further examination. In order to study the instability of a slender column in a steel frame-work, three approaches of evaluating the effective length factors were considered and used in the design of an industrial non-sway (portal) frame namely; Wood's method or approach, Euler's method and BS 5950 method. BS 5950 and Euler's effective length factors were provided while as Wood's factors were computed or determined. From the study frame, Wood's approach produced the least effective length factor of 0.68L followed by Euler's with 0.707L and then BS 5950 with 0.85L. Thus, among the three approaches considered Wood's approach gave the highest buckling load of 778.5kN, followed by Euler's with 744.14kN and BS 5950 is the least with 579.4kN. Wood's approach is more conservative because it involves the stiffness contribution of the neighboring members or other framing members to the investigated column. Therefore, wood's concept or approach should be adopted not only for multi-story frames but also for portal frames.

Indexed Terms: Compressive Members, Design Methods, Effective Length, Steel Frame, Multi Storey.

I. INTRODUCTION

The concept of effective length method for compression members such as columns has been widely adopted by many design codes of practice and used by practicing engineers to analyses the stability of frames. According to [1] the effective length method uses a distribution factor, k, or effective length factor to access the end restraint of columns in discussing the stability of a compression member under an applied load.[2]noted that the strength of a column and the manner in which it fails are greatly dependent on its effective length and the increase in the effective length of a compression member decreases its buckling stress. Certainly, a short column usually crushes under the application of load, while a slender column fails by buckling under the application of load. The buckling of such compression members has led to the use of effective length method to analyse its stability for both isolated columns and frames. For compression members in rigid jointed frames the effective length is directly related to the restraint provided by all the surrounding members [3] and it is most recommended for high or multi-storey frames. According to [4] the effective length method allows the buckling capacity of a member in a structural system to be calculated by considering an equivalent Euler's buckling between the inflection points, i.e. the points of zero moment on the member. While [5] mathematically considered it as reducing the evaluation of critical stress for columns to that of equivalent pinned –ended braced column. The code approach such as , BS 5950, Euro code 3 and others used in the design of compression members have provided effective length values utilize from monographs, charts or formulae based on the assumption that members in a frame are independent of each other and the effective lengths are assumed as function of stiffness of end restraints.

However, in a frame or multi-frame, the interaction of all the members occurs because of the frame buckling as a whole rather than column buckling, [1]. Most codes of practice used by practicing engineers may not fully or specifically consider the whole distribution and summation stiffness of all adjoining members connected to a joint as they could affect the stability of a frame (such as portal frame). While some may only analyze frame using the effective length of compression members detached from the whole frame.

Moreover, where the contributions from adjacent or adjoining columns or members were not considered, discrepancies in the stability of the frame (braced frame) may arise.

II. AIM AND OBJECTIVES

The aim of this project is : To investigate the effective lengths variation of compression members in steel frame-work.

The objectives are:

1. To determine, compare and criticize the effective length of compression members in steel frame work using Wood's method or recommendation, Euler's theoretical approach/method and BS 5950 provision.
2. To examine the strength of the resulting structure designed using the various approach
3. To evaluate the discrepancies arising from the various methods and to advice on their structural implication in evaluating the critical buckling load and critical permissible stress.

III. SCOPE OF STUDY

The study considered the effective design approach using the effective length provided by BS 5950, Euler's and that computed from Wood's approach. A standard portal frame of a single bay single storey industrial braced frame (building) of 8m x 8m x 10m height with an office (4m x 4m) was used as a case study. The loads considered are dead and imposed load only. Only prismatic sections (members with constant cross-section and constant flexural stiffness, EI, across its span) were considered. All joints in the frame are assumed rigid, such that moment can be transferred from one member to another. Rotations at opposite ends of the restraining beams are equal in magnitude thus producing single curvature.

IV. LIMITATION OF STUDY

This study does not consider wind or dynamic loading because it is not a high building. It is limited to non-sway steel frame whose initial imperfections are overlooked.

V. Literature Review

Compressive Members

The term compression member is generally used to describe structural elements or components subjected to axial compressing load. According to the research conducted by [6] on the strength comparison between Indian standard code 800-2007, whose compression members is controlled by stress reduction factor and effective slenderness ratio, and Indian standard 800-1984, whose members depend on the slenderness which is inversely proportional to the permissible stress in axial compression. They concluded that the strength behaviour of steel compression members to carry load depends on the weight per unit length of the member. However, [7] noted from their experimental research that compression members design with high strength steel reduce the section size of members, which are associated with material consumption and member weight, and improve the stability of compression member if design with.[4] outlined the common types of compression member in steel frameworks; the column, known as stanchion or strut, being the best known. Top chord of truss, bracing members, compression flanges of built up beams and rolled beams are all examples of compression members. He [4] stated that columns or stanchions are usually straight vertical members whose lengths are considered greater than their cross-sectional dimensions and are compressed by axial forces acting at both ends. [8] noted that the behaviour of compression members under increasing load can be noticed clearly by calculating the bending stresses and lateral deflection that occur as the axial load is gradually applied. For optimum performance, compression members such as stanchions need to have a high radius of gyration r, in the direction where buckling can occur [9]. According to [9] circular hollow sections should therefore be most suitable as they maximize this parameter in all directions. Hot-rolled sections are in fact the most common cross-section used for compression members, most of them having large flanges are designed to be suitable for compression load. They listed some sectional members shown in Figure 1. In Addition [10] noted that the type of connection is important in the design of simple compression members because it defines the effective length to be taken into account in the evaluation of buckling. Circular sections do not represent the optimum solution if the effective length is not the same in the two principal directions. Members are frequently subjected to bending moment in addition to axial load; in these condition I-Sections can be preferable to H-sections.

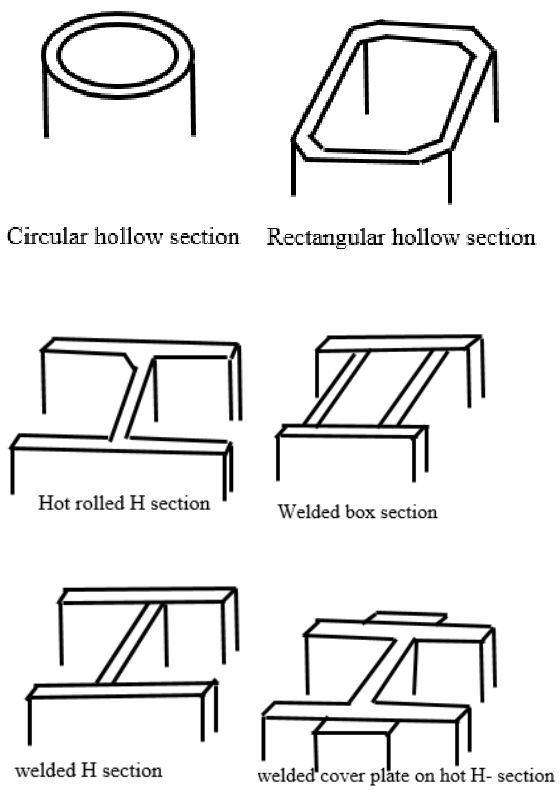

Figure 1 Cross section of compression members.

Classification of steel compression members

1. Classification based on slenderness ratio.

[4], defines slenderness ratio of columns as the ratio of the effective length Le, to the least radius of gyration (rmin) of the column section. He classified columns as follows,

i. Short column – which have the slenderness ratio, $\frac{le}{r_{min}} < 60$
ii. Intermediate column – which have slenderness ratio in the range of $60 < \frac{le}{r_{min}} < 100$
iii. Long column – having slenderness ratio in the range of $\frac{le}{r_{min}} > 100$

Here r_{min} is the least radius of gyration calculated on the basis of the minor principle moment of inertial Imin ,such that $I_{min} = A\, r_{min}^2$ or $r_{min} = \sqrt{\frac{I_{min}}{A}}$ …………… (1)

A is the cross sectional area.

Classification based on mode of failure

[11], termed stanchions as short and long depending on their proneness to buckling. According to them;

Short columns develop a compressive stress when force is applied at both ends of the column which result in the shortening of the column in the direction of the applied forces. Under incremental loading, the shortening continues until the column "squashes or crushes". Thus, failure occurs once the stress exceeds the elastic (yield point) limit of the material.

In long columns, the axial shortening of column is observed only at the initial stages of incremental loading. But as the applied force is increased, the strut becomes "unstable" and develops a deformation in the direction normal to the loading axis. The column is in a "buckled" state.

Steel Frame Structures

According to [12] Steel frame is a building technique with a skeleton frame of vertical steel column and horizontal I – beams, constructed in a rectangular grid to support the floor, roof and walls of a building which are all attached to the frame.[13], classified frames into two basic types; braced or non-sway frame of which moment distribution applies readily, and Non-braced or sway frame of which moment distribution applies with additional steps needed to analyse sway effect. The [14], stated that frame is braced when lateral stability is provided by diagonal bracing, shear wall or equivalent means.[15], categorised steel braced frames as non – sway frames when lateral displacements are sufficiently small, and translational stiffness of a column's end resistance are taken as infinity. According to [16], structures are classified as non-sway frames if the lateral stiffness of the braced frames are equal to five times small than the frame stiffness of the weak brace frame. They referred the lateral stiffness of a brace system as a shear wall, a reinforced concrete core. The [17], classified frame as non – sway if its response to in-plane horizontal loads is sufficiently stiff for it to be acceptably accurate to neglect any additional internal forces or moments arising from horizontal displacement of its nodes. It also classified a multi-storey streel frame as braced when the bracing system reduces the horizontal displacement by at least 80%.

Effective length of Stanchions

According [18] and [19] the effective length of a column in frame structure depends on the relative rigidity or rotational resistance of members connected at the ends or joint the column.[1] pointed out that the buckling of a column and its load carrying capacity is greatly influence by its end support condition. He noted the following as the most common idealised end condition.

- i Both ends pinned
- ii Both ends fixed
- iii One end fixed, and the other end pinned
- iv One end fixed and the other end free.

The table below shows the effective length of column with various end conditions for various approach

Table 1: Effective Length for various column condition

End conditions	Euler's Theoretical Le	BS 5950 Le	Euro code 3 Le	India Standered:800 Le
Pinned – pinned	1.0 L	1.0 L	1.0L	1.0L
Fixed – fixed	0.5 L	0.70 L	0.7L	0.65L
Fixed – pinned	0.707 L	0.85 L	0.85L	0.8L
Fixed- free	2.0L	2.0L	2.0L	2.0L

Frame Stability

The problem of instability of a frame was tackled first by Goldberg [20] by investigating the lateral bucking load of braced frames. He obtained the elastic critical load equations for a typical intermediate column in a multi-storey frame by considering the effect of the girder stiffness at the top and bottom of the column, and the average stiffness of the storey. [21], proposed a " weighted mean'' approach to determine frame buckling from individual element analyses. They applied this method to frames in which column stiffness changes significantly between storeys. This method involves post processing of effective lengths from isolated column analysis to arrive at improved, weighted means values. The errors are normally within a few percent of exact solution. [22] stated that member failure due to instability phenomena can cause the whole frame structure to collapse. In their research, [22] investigated the influence of initial curvature shape and magnitude to the stability of slender column. Their findings show the initial curvature in a column reduced the total load bearing capacity and the reduction depends on the magnitude of the curvature. They further noted that the deformation rate of the member increases as the initial curvature on the column increases. Also their results show that the load bearing capacity increases if the column's bracing stiffness increases. [23] provided insight into the need to consider both individual element and overall system behaviour for accurate bucking analysis in order to evaluate the stability of frame through which the effective length of column in a frame can be obtained. [24] carried out a laboratory research on the effects of critical load on a prototype frames. They adopted two types of frames whose supports were fixed and pinned respectively. The stiffness k, of the frames he used according to Euler's values were 0.5, 0.75, 1.0, and 1.5 for each of the frames. Their findings show that the critical load reduces as the stiffness values increases for all models. Also their results show fixed supported frames offered greater resistance to critical load to that of pinned supported frames. [25], investigated the stability of frame subjected to non-conservative force such as wind load. They concluded that the buckling load of a frame or column increase as the non-conservative force increases. Moreover, [26], described elastic stability of column as a transition from a straight configuration to a laterally bending or deforming state. He described the load at which the transition occurs as the critical load and the bending or the deforming state of frame members renders the frame unstable.

Research Methodology: Design Problem

To illustrate the variations in the effective length recommendations or approaches of compression members in a steel-frame, an Industrial Steel Frame (building) is designed using BS5950 effective length provided for portal frame, Euler's effective length and Wood's effective length computed.

The plan and elevation of the industrial building are shown in Figures 3.1 and 3.2.

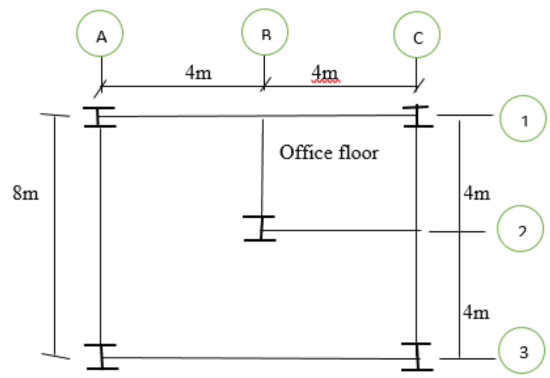

Fig. 2: Floor Plan

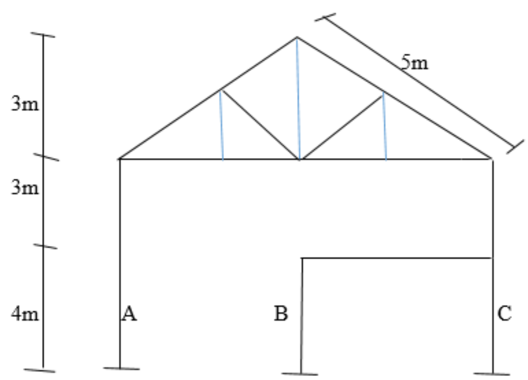

Fig. 3: Frame Elevation

Design Step

The single bay industrial braced frame was designed with or according to BS 5950. The design steps carried out in this study was categorized under two sections namely; Section capacity strength check and Member buckling resistance check.

1. Section capacity strength check.

- Load analysis: The load considered in the design of the frame were dead load and imposed load only. Roof load were obtained from BS 6399-1 while the office floor loads are obtained from Reinforced concrete design handbook (R.C.D.H.) table 63.

  The design axial load or factored load (n) is obtain from;
  $n = 1.4 \; Gk + 1.6Qk$ (2)

  where Gk is dead load and Qk is imposed load.

The fixed end moment formular(F.E.M.) used is $wl^2/12$ (3)

- Section selection and classification

  The steel grade adoted is S275 with desigh strength Py = 275 N/mm2 and thickness 16mm. For all sections. Sections were selcected from Universal beam (UB) and universal column (UC) for beam and columns respectively.

  For the girder, the selection of the girder is obtain from the calculation of plastic modulus S, of which the applied moment (m) < moment capacity (mc).

  Thus, $Mc = PyS$ (4)

  And $S > m / Py$.

- Deflection check for girder is obtain from BS 5950 table 8.
  For columns, the column designed are biaxial. The column sections are optionally selected depending on the loading.

  Classification of section was obtained from table 11 and 12 of BS 5950 code. Section can be classified as class 1 plastic, class 2 compact and class 3 semi compact depending on the parameter (£).

$$£ = (275/ Py)0.5 \qquad (5)$$

- Evaluation of moment capacity check (MCx) : BS5950 cl.4.2.5 provided the formulae to obtain the moment capacity. Cross section capacity check.

  cl. 4.8.3.2 of BS 5950 provided the interaction expression for which the selected column must satisfied. Presented in eq. (6)

$$\frac{FC}{AgPy} + \frac{mx}{MCx} + \frac{my}{MCy} \leq 1$$

2. Member Buckling Resistance Check

Estimate the effective length; The effective lengths adopted in the frame design were ; BS 5950 effective length approach provided in table (1) of this work, Euler's effective length approach provided in table (1) of this work, while Wood's effective length approach was computed using the formula

$$ŋx = \frac{\sum Kc,x}{\sum Kcx + \sum Kg,x} \qquad (7)$$

He defined the distribution coefficient (ŋ) and k = I/L, I is section second moment area Kc,x is the rotational stiffness of each column at node x Kg,x is the rotational stiffness of each girder at node x

X is the node at the top and bottom represented as A and B respectively.

Using effective length (Le), below as provided in BS 5950.

$$Le = 0.5 + 0.14 (ŋA + ŋB) + 0.055 (ŋA + ŋB)2 \qquad (8)$$

Estimate the slenderness ratio (λ) ; The slenderness ratio is the of effective length to radius of gyration.

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$$λ= Le /г \qquad (9)$$

Estimate the compressive strength Pc or permissible stress: the compressive strength was obtained from the appropriate part of table 24 depending on the assume buckling curve a,b,c.

Calculate the compressive resistance PC (kN) ; From BS 5950 cl. 4.7.4

$$PC =AgPc \qquad (10)$$

Estimate buckling resistance moment Mb : From cl.4.3.7 of BS 5950,

$$Mb = P_bS_x \qquad (11)$$

Where Pb is bending strength.

Table 20 and cl.4.3.6.9 estimate the bending parameter βw from which Pb is obtain and Mb calculated.

Buckling resistance check: cl. 4.8.3.3.1 provide a simplified interactive expression which the section must satisfied. It is presented below

$$\frac{FC}{PC} + \frac{mLT\ MLT}{Mb} + \frac{myMy}{PyZy} \leq 1 \qquad (12)$$

VI. RESULTS AND DISCUSSION

Results: The details of the designed columns are shown in table 4. The effects of the three methods (approaches) to stability of the frame are presented in table 2 and table 3. While fig.2 shows the pictorial illustration of the permissible stress of the members.

Table 2: Permissible Stress (σcr) of the Columns

Parameters	BS5950 Approach	Wood's Approach	Euler's Approach
Permissible stress σ_{cr} (N/mm^2) Column A	102	137.06	131.01
Permissible stress σ_{cr} (N/mm^2) Column B	213	222.90	240.63
Permissible stress σ_{cr} (N/mm^2) Column C	215.80	232	242.34

Table 3: Critical Buckling load for steel columns

Parameters	BS5950 Approach	Wood's Approach	Euler's Approach
Critical buckling load P_{cr}(kN) Column A	579.4	778.50	744.14
Critical buckling load P_{cr}(kN) Column B	1618.8	1694.04	1828.79
Critical buckling load P_{cr}(kN) Column C	2373.8	2552	2665.72

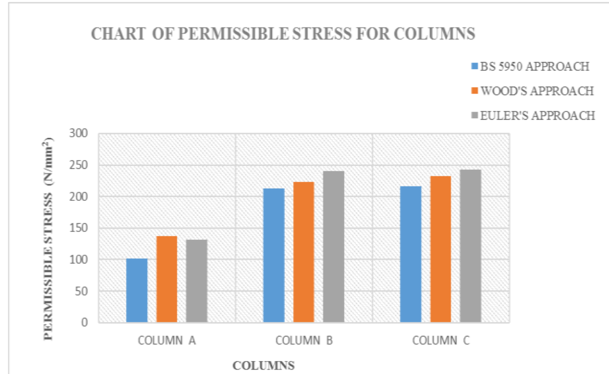

Fig.2: Bar chart for permissible stress for columns

Table 4: Columns detail and the effective length obtain from the various approaches

Column	Grid-line	Length (mm)	Axial load (kN)	Moment capacity (kNm)		Steel Section	Area of section (mm^2)	Slenderness ratio (λ)			BS 5950 Le	Wood's Le	Euler's Le
				Mx	My			BS 5950 approach	Wood's approach	Euler's approach			
A	1-A	7000	72.12	133.93	49.83	203 x 203 x 46 UC	56.8	116.21	92.97	96.66	0.85L	0.68L	0.707L
B	2-B	4000	115.06	182.60	65.64	203 x 203 x 46 UC	76.0	53.95	48.55	38.54	0.7L	0.63L	0.5L
C	1-C	4000	173.75	269.20	98.34	203 x 203 X 86 UC	110.0	52.63	43.61	37.59	0.7L	0.58L	0.5L

Discussion: From the analysis done, the effective length factor k, for column A varies between 0.68 to 0.85 for the three approaches (Wood's, Euler's and BS5950 recommendation), while column B and column C varies between 0.5 to 0.7. Out of the three columns, column A has slenderness ratio > 60 [4] which classified it as a slender column and its effective lengths are 0.68L, 0.85L and 0.707L for Wood's approach, BS5950 approach and Euler's approach respectively as shown in table 4.

The bulking load, presented in table 2 examined under the three approaches shows that the slender column has the least buckling load under BS5950 provision, followed by Euler and then Wood's recommendation. This means that BS 5950 made the least factor of safety, because the method analyzed member (column) isolated from the frame likewise Euler's method, while Wood's approach gave more conservative in that the framing members contributed to stability of the individual columns which is not so with the other methods. Thus, the buckling load for the slender column was evaluated to be 778.50kN, 744.14kN, and 579.4kN for Wood's approach, Euler's approach and BS 5950 respectively. The strength or stress resistance offered by the slender column is found to be greater in Wood's approach compared to other approaches as shown in table 3 and in the bar chart in fig.2 above.

For structural implication, BS 5950 made a conservative design in the sense that even when the critical load is reached the structure can still stand because of the contribution of members framing unto it as per wood's approach.

VII. CONCLUSION

The accuracy in adopting a suitable effective length values to be used in design of members in the frame have become a major concern to the design engineers as this could affect the stability of the frame. Many design codes or approaches have provided values of effective length for easily used by design engineers, but the variations or discrepancies of these values have led in many cases the effects on the frame stability between the assumed or provided effective length values and computed effective length.

To address these issues, three effective length approaches were considered, Euler's approach, BS 5950 code approach and Woods approach, in the design of an industrial portal braced frame. The Euler's approach generally depends on the end conditions of isolated member, BS 5950 approach provided values based on the analysis of the conditions of restraint in the relevant plane, while wood's approach is based on computation of rotation stiffness of all the members that frame on studied column.

From the study, it is shown that the columns of the frame designed using the three effective length approach gave or satisfied the same steel section provided for each of the three columns designed. But the stability of columns differs from each of the three approaches. It is noted that the stability or effect of three approaches considered in the design of compression members of the frame is not felt when short columns are involved because they fail by crushing. However, the effect is seriously felt when slender columns which fail by instability are considered. Out of the three columns considered, two were found to be short (column B and column C) because their slenderness rations were < 60 while column A, which has slenderness ration > 60 [4], falls under slender column whose stability needed further examination. From the study, the computation shows that both buckling load and permissible stress for the particular slender column is highest when the effective length was evaluated using Wood's recommendation and lowest under BS 5950 provision.

In addition, design using BS 5950 approach can also be seen as a conservative design since the structural member can still stand when the critical load is attained.

Recommendation: Wood's recommendation or approach in analyzing non-sway frame has shown more resistance at the joints since it involves rotational stiffness contributed from the neighboring members to resist buckling of the column. Thus, results in reduced effective length of the columns (slender columns) if compare with BS 5950 approach and Euler's approach. Moreover, the stress resistance offer by the steel member and the applied load at which column buckles is relatively high compare to other approaches. Therefore, Wood's approach will give suitable and better stability for simple portal frame just like multi-storey frames, if design with.

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