Effective Length Factors of Steel Frame Columns Arranged Diagonally in the Main Beam Plane

Lin Sun

College of Architecture and Civil Engineering, Xi'an University of Science and Technology, Xi'an, Shaanxi, 710054, China

Corresponding author's e-mail: 1977858375@qq.com

Abstract. This article calculates the effective length coefficient of frame columns by orthogonal decomposition of the linear stiffness of beams. Meanwhile, a simplified model was established using SAP2000 finite element software, and effective length factors in the x and y directions were calculated using the Euler formula. By comparing effective length factors calculated by manual calculation, Euler inverse calculation, and SAP2000 methods, it is found that the three calculation results for the frame structure with lateral displacement are consistent. However, the effective length factor calculated by Euler's formula in reverse ignores the coupling effect between constraints, resulting in a greater result than the other two calculation methods, and the manually calculated effective length factor is the smallest. This method can be used as a reference for determining the calculated length coefficient of the frame columns in the main beam plane oblique steel frame structure.

Keywords: effective length factors; eigen value buckling analysis; critical loads; Euler formula; buckling factor

1 INTRODUCTION

The effective length coefficient is the ratio of the actual length to the critical buckling length, which is a parameter used to measure the stability and load-bearing capacity of a structural element under compression. For the frame column of a common irregular frame structure, such as the cross-bias of main beams, it is impossible to determine which direction the column is constrained by. Therefore, it is impossible to directly use the effective length factor calculated by regular frame structure in the specification for stability design. Tong G [1] determines the effective length to consider interlayer and columnar interactions through simple algebraic operations. Sliman [2] studied the problem of determining the exact value of the effective length factor of columns under asymmetric loads in an asymmetric frame. With the continuous development of finite element software, Szalai [3] and Fan Zhong [4-5] have carried out deeper research on the effective length factor of columns. This paper establishes a simplified model for the calculation of the effective length coefficient of steel frame columns with oblique plane intersection of the main beam, based on an actual project. The calculation process of

B. Yuan et al. (eds.), *Proceedings of the 2024 8th International Conference on Civil Architecture and Structural Engineering (ICCASE 2024)*, Atlantis Highlights in Engineering 33,
https://doi.org/10.2991/978-94-6463-449-5_69

the effective length coefficient under different methods is explained and compared. This method can provide a reference for determining the effective length coefficient of frame columns when the main beam plane is at an oblique intersection.

2 PROJECT OVERVIEW

The design of this structure is based on the outdoor corridor of 626 Baiyin Tang Road, Gansu Province. The structural system of this project is steel frame-support structure. The structural effect drawing and three-dimensional model are shown in Fig. 1. below. In order to facilitate the study, the structural arrangement of the project is simplified in this paper. The plan of the simplified structure is shown in Fig. 2. The structural arrangement is fan shaped, the structural system is steel frame structure, the number of layers is 4, the height of the layer is 3.6 meters, and the total height of the structure is 14.4 meters.

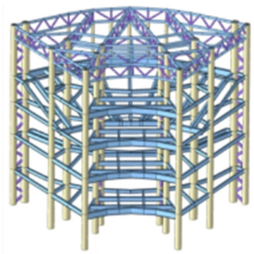


Fig. 1. 3D model

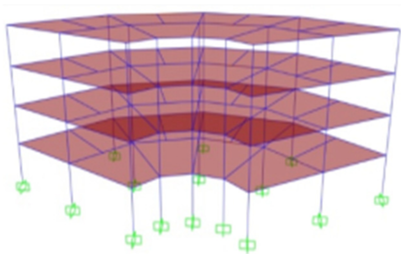


Fig. 2. Simplified structure

The steel model of the simplified structure is Q355, the floor and roof are 120mm reinforced concrete floor slabs, the concrete grade is C30. The design earthquake group is the first group, the fortification intensity is 8 degrees, the design basic seismic acceleration is 0.20g, the site category is class II, the seismic grade of the steel frame is level 3, the characteristic period is 0.35, and the period reduction factor is 0.9. The basic wind pressure is $0.35kN/m^2$, the ground roughness is class B.

3 THE EFFECTIVE LENGTH FACTOR ANALYSIS BASED ON THE STANDARD

3.1 The Effective Length Factor Solution Formula

The beam is usually arranged along the centroid direction of the column section, and is orthogonal to each other, which plays a restraining role in the instability of the direction of the column centroid spindle, and the calculation formula (Formula 1, Formula 2) in the standard is applicable to the beam orthogonal situation

The effective length factor of the frame column with side movement μ:

$$\mu = \sqrt{\frac{7.5K_1K_2 + 4(K_1 + K_2) + 1.6}{7.5K_1K_2 + (K_1 + K_2)}} \tag{1}$$

The effective length factor of the frame column with no side movement μ:

$$\mu = \sqrt{\frac{(1 + 0.41K_1)(1 + 0.41K_2)}{(1 + 0.82K_1)(1 + 0.82K_2)}} \tag{2}$$

In the formula, K_1 and K_2 are the ratio of the sum of beam line stiffness and column line stiffness of the upper and lower nodes of the column.

3.2 Calculation Results

Taking the calculation of the effective length factor of the floor-2 frame column GZ-4-5 as an example, there is a 15 ° angle between GL-2 and the x-axis of the cross-section centroid in Fig. 3. To accurately obtain the calculated length coefficient of the column along the x-direction and y-direction of the centroid axis, the process is as follows:

GL-2 is orthogonally decomposed along the x and y directions in the Fig. 3, and the stiffness of the beam line in the x and y directions is obtained respectively.

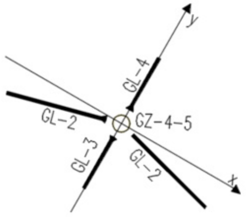


Fig. 3. Orthogonal decomposition of beam line stiffness

Stiffness along the beam line in the x-direction:

$$\sum i_{ix} = \sum \frac{E_i I_{ix}}{l_i} = 2.06 \times 10^5 \times \left[\frac{5.541 \times 10^8}{7502} \times \cos 15^\circ \times 2 \right] = 2.939 \times 10^7$$

Stiffness along the beam line in the y-direction:

$$\sum i_{iy} = \sum \frac{E_i I_{iy}}{l_i} = 2.06 \times 10^5 \times \left[\frac{1.31 \times 10^9}{8400} + \frac{9.119 \times 10^8}{8400} + \frac{5.541 \times 10^8}{7502} \times \cos 75 \times 2 \right] = 6.237 \times 10^7$$

The x-direction K_1 and K_2 are 0.36 and 0.34, and the y-direction K_1 and K_2 are 0.76 and 0.66, respectively.

Using formulas (2) and (3), calculate the effective length factor for components with no lateral displacement in the x and y directions, and the the effective length factor for components with lateral displacemen μ_x =0.888, μ_y=0.816 and μ_x=1.798, μ_y=1.545.

4 THE EFFECTIVE LENGTH FACTOR ANALYSIS BASED ON EIGENVALUE BUCKLING ANALYSIS

When using Euler's formula to the effective length factor of a column, the key is to determine the buckling load factor of the member, and the four commonly used methods are: the first-order global instability method, the method of viewing the modes of each order, the method of applying axial loads, and the method of modifying the local stiffness [6]. In this paper, the effective length factor of the component is determined by applying axial load method Using the Euler formula to be reversed, as follows:

$$\mu = \frac{\pi}{l}\sqrt{\frac{EI}{P_{cr}}} \tag{3}$$

Firstly, the representative value of the load (1.0 dead load + 1.0 live load) is selected as the initial state of the structure, the stiffness of the nonlinear condition under the load combination is inherited in the eigen buckling analysis, and the unit load is applied to the column, and the buckling mode of the column under partial buckling is identified through the eigen buckling analysis, and the critical load of the structure is obtained. Taking 2-GZ-4-5 as an example, the first 3 buckling factors are shown in Table 1, and the first 3 buckling modes are shown in Fig. 4.

Table 1. The first three buckling factors

Component number	Buckling order	Buckling eigenvalue
2-GZ-4-5	1	41994.753
	2	35760.893
	3	338323.411

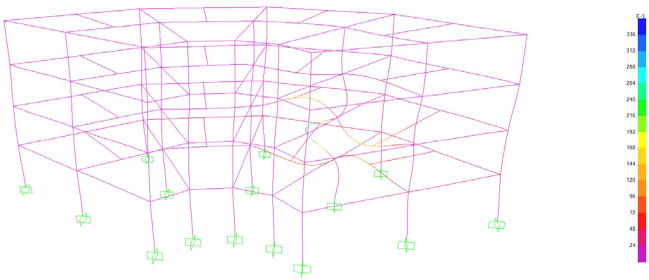
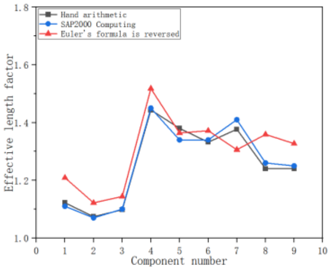


Fig. 4. Buckling mode of 2-GZ-4-5

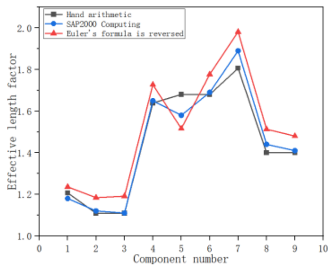
From equation (3), the calculated length factor of all columns is obtained, and the length factor is 1.631 for the 2-GZ-4-5 x direction and 1.768 for the y direction.

5 COMPARISON OF THE EFFECTIVE LENGTH FACTOR

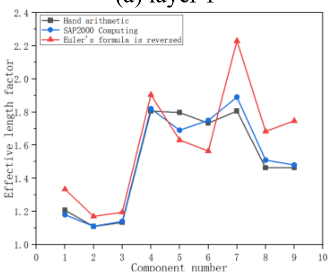
Due to the lateral displacement of the structure, the effective length coefficient results of the components under different methods are shown in Fig. 5. and Fig. 6.



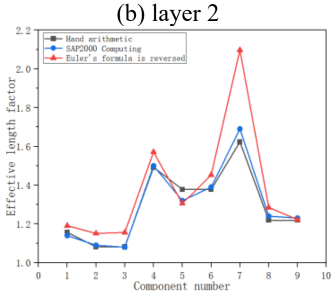
(a) layer 1



(b) layer 2

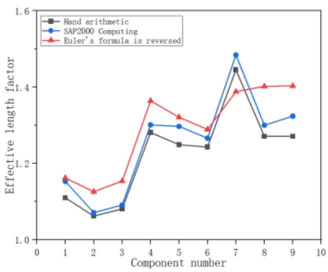


(c) layer 3

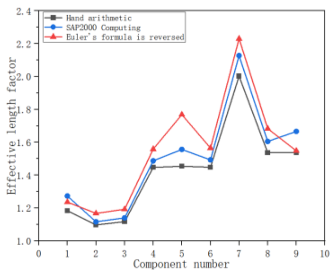


(d) layer 4

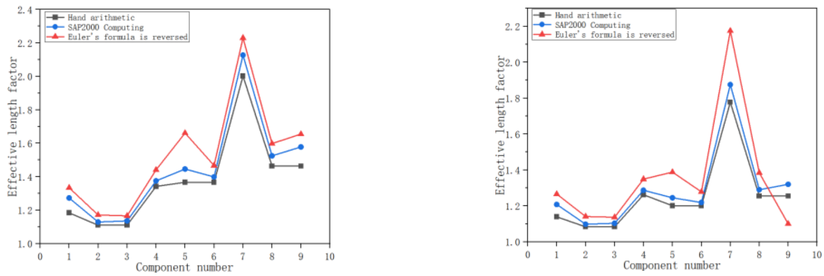
Fig. 5. Comparison of the x-way length coefficients of the side-shifted structure



(a) layer 1



(b) layer 2



(c) layer 3 (d) layer 4

Fig. 6. Comparison of the y-direction length coefficients of the side-shifted structure

It can be seen from Fig. 5. and Fig. 6. The effective length coefficients in the x and y directions of the lateral displacement structure are consistent among the three methods. Overall, among the three methods, the manual calculation method using orthogonal decomposition of the diagonal main beam has the smallest effective length coefficient, and the reverse calculation method using the Euler formula has the largest effective length coefficient. Analyzing the reasons, the method of using Euler's formula to calculate the length coefficient in reverse ignores the coupling effect of stiffness between various constraint conditions, resulting in a relatively large calculated length coefficient of the required components and more dangerous calculation results; The SAP2000 software did not take into account the influence of the oblique intersection of the main beam during the calculation process, which also resulted in a larger structural linearity and more dangerous calculation results when calculated according to orthogonal design.

6 CONCLUSION

This chapter uses three methods to calculate the calculated length coefficients of each column in the simplified structure, and compares effective length factors obtained by the three methods. The following conclusions are drawn:

(1) When the steel frame beams are diagonally intersected, the results of calculating effective length factors of the column by orthogonal decomposition of beam line stiffness in different directions are consistent with the results calculated by SAP2000 and Euler formula.

(2) Among different methods, the Euler formula has the highest calculation result and the orthogonal decomposition manual calculation result is the smallest. This indicates that using the Euler formula to calculate will overestimate the safety of the structure. For frame structures with diagonal beams, the effect of reducing the linear stiffness of the diagonal beams on the effective length of the columns should be considered. References.

REFERENCES

1. Tong G, Wang J. Column effective lengths considering inter-story and inter-column interactions in sway-permitted frames[J]. Journal of Constructional Steel Research, 2005, 62(5): 413-423. DOI: 10. 1016/j. jcsr. 2005. 09. 003
2. Slimani A, Ammari F, Adman R. The effective length factor of columns in unsymmetrical frames asymmetrically loaded[J]. Asian Journal of Civil Engineering, 2018, 19(4).
3. Szalai J, Papp F. New stability design methodology through overall linear buckling analysis[J]. ce/papers, 2019, 3(3-4): 859-864.
4. Chong F, Yue X, Chai H J, et al. Study on the Calculated Length Coefficient of Column of Frame-Shear Wall Double Lateral Force Resistant System[J]. Engineering Mechanics, 2023, 40(S1): 25-38.
5. Chong F, Yue X, Mou Z G, et al. Determination method of length coefficient of frame-core cylinder column [J]. Journal of uilding Structures, 2023, 44(S1): 26-37.
6. F Ma, Song S Y, Zhang R Y, et al. Research on the relevant problems of direct analysis of Steel structures using the Imaginary Load method [J]. Building Science, 2022, 38(11): 27-33.