Second Order Effects on Building Structures – an Approximate Evaluation

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Summary

Slender building structures must be designed by taking into account the second order effects. Whether this effect is significant or not, can be decided by comparing the vertical load to the buckling load of the building. It was suggested by several researchers that second order effects can be neglected, when this ratio is below ten percent. This statement is, for example, part of Eurocode-2 (Design of Concrete Structures), which also contains approximate procedures, how to evaluate the buckling load of buildings, however, for some cases, they may lead to unacceptable, unconservative results. In this paper some of the formulas are corrected, and for a few cases better approximations are suggested. The expressions are based on the solutions of the replacement continua of buildings.

Keywords: second order effect; Eurocode; approximation; summation theorem; high-rise buildings.

1. Introduction

According to Eurocode 2 second order effects can be neglected, if the following relation holds:

$$F_{\mathrm{V,Ed}} \le 0.1 N_{\mathrm{cr}}, \tag{1}$$

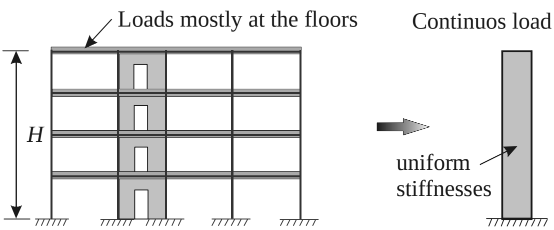

Fig. 1: The structure and the replacement continuum

where $F_{\mathrm{V,Ed}}$ is the total vertical load, while N_{cr} is the global buckling load. To obtain the buckling load for (regular) building structures approximate expressions are suggested, which are based on the buckling load of replacement columns with uniform stiffnesses (Fig. 1). The columns may have bending stiffness (D=EI) and/or shear stiffness ($\hat{S}$).

2. Buckling load of shear walls

When the structure is braced by solid shear walls, according to Eurocode 2, the buckling load can be approximated by assuming a distributed load along the height of the structure, which results in

$$N_{\mathrm{cr,B}} = 7.8D/H^2, \tag{2}$$

https://doi.org/10.2749/222137908796293730

where H is the height of the building and D is the sum of the bending stiffnesses (EI) of the shear walls. This expression is modified due to the following effects: (i) rotation of the foundation, (ii) shear deformations of the walls, and (iii) number of stories. We suppose that the first modification contains a misprint with serious consequences, as it may overpredict the buckling load by up to 400%. The second correction is conservative, however may have an error up to 40%. New approximate formulas are suggested in the paper. When there are several bracing elements, Eurocode 2 suggests that the shear stiffness, $\hat{S}$ is calculated as the sum of their shear stiffnesses; however, this method may be used only under certain conditions to avoid unconservative results. The recommended procedure is given in the paper.

3. Buckling load of frames

The simplest model of a frame structure (Fig. 2) is a replacement column, which has *shear deformation only*. This model was improved in the fifties by Sigalov, Beck and Csonka and a coupled bar model was introduced, which has both shear and bending stiffness. For slender frames, the global bending stiffness is also introduced, which results in a *sandwich beam*.

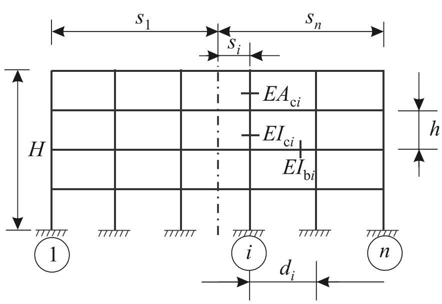

Fig. 2: Frame structure

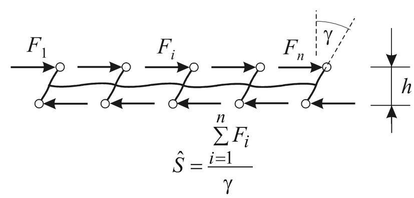

Fig. 3: Shear stiffness of one storey

Eurocede 2 does not give a criterion on the calculation of the buckling load in case of frames, the expressions given in the paper are recommended.

Eurocode 8 (Design of structures for earthquake resistance) presents the following rule: second order effects need not be taken into account, if the following condition is satisfied for all storeys:

$$\theta = \frac{P_{\text{tot}} d_{\text{r}}}{V_{\text{tot}} h} \leq 0.10\,, \tag{3}$$

where P_{tot} is the total load above the storey, d_{r} is the interstorey drift, V_{tot} is the shear force. We may observe that $d_{\text{r}} / h = \gamma$ (Fig.3), and hence Eq.(3) is approximately the total load over the shear stiffness of one storey. If the compressibility of the columns is negligible Eq.(3) is identical to the condition of Eurocode 2, given also by Eq.(1). However, for slender frames Eq.(3) should be modified, and the compressibility of the columns must be taken into account. The suggested modification is given in the paper.

4. Conclusion

In this paper simple expressions are presented for the calculation of the buckling load of building structures. Based on these expressions, modifications are suggested in the expressions of Eurocode to avoid unconservative (or too conservative) results.