Effect of buckling and yielding phenomena on the behavior of steel and aluminium shear panels

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Abstract

The present study investigates the effects of material mechanical properties and slenderness ratios of plates on the nonlinear and cyclic behavior characteristics of metal shear panels (including carbon steel (CS), low yield point steel (LYP160) and aluminium (AL)), using the finite element method. The plates are first qualitatively and quantitatively classified into the five groups of very slender, slender, moderate, stocky and very stocky, regarding their slenderness ratios. Very slender plates have negligible buckling capacity and thus, they buckle at the initial stages of loading. Slender plates buckle in the elastic range of behavior. Moderate plates buckle in the inelastic range of stresses before material yielding occurs in the plates. Stocky plates buckle in the plastic (post-yield) range of stresses. The behavior of very stocky plates is only dominated by yielding phenomenon and they do not buckle during loading. Based on the statistical analysis of results, new relationships for estimation of inelastic and plastic buckling loads are also proposed. The cyclic analysis results show that the energy dissipation capability of very stocky/stocky/moderate plates is solely dependent on the material yield stress and elastic modulus of elasticity, whereas for the slender plates, the effectiveness of material yield stress in the energy dissipation of plates is decreased and the role of the material elastic modulus of elasticity becomes more important. In the case of very slender shear plates, the energy dissipation capability seems to be dependent on the initial and secondary modulus of material only.

KEYWORDS
Metal plate, yielding, buckling, finite element, cyclic analysis

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1. Introduction

Steel and aluminum plates are widely used in the construction of thin-walled structures in various fields of engineering, especially in civil engineering. The use of steel plates in the construction of bridge girders and building box beams and columns, the infill plate of steel shear wall system, the plate at the connection of beam to column, and link-beam webs of eccentrically braced frame systems [1] are very common examples. Aluminum plates are also used in the construction of the beam and column sections and also, stiffened plates as seismic energy dissipation component in seismic areas [2, 3]. Previous Studies have been mainly focused on the behavior of slender plates with certain slenderness ratios. In the case of moderate and thick plates, the study of various aspects of nonlinear and energy dissipation behavior characteristics of plates has received less attention from researchers. In addition, the classification and behavioral characteristics of plates with very small [4] or very large [5] slenderness ratios, despite existing applications, have received less attention from past researchers. Previous studies [1, 6] have also shown that the results of AASHTO for behavior classification of metal plates and those reported by researchers using the finite element can be different. Further, for moderate or stocky plates, there is a difference between the buckling capacity results of different metal plates from formulas proposed by AASHTO and those of finite element analyses [1, 7].

The present study uses finite element method to study the effect of buckling and yielding phenomena on the energy absorption and linear/nonlinear behavior characteristics of steel and aluminum shear plates with different slenderness ratio. First, different metal plates are characterized and classified into the five proposed groups named very slender, slender, moderate, stocky and very stocky, according to the occurrence of buckling and yielding. Based on the obtained results of different plates, new relationships are proposed for classification of metal plates of different slenderness ratios. Also, new relationships are proposed for more accurately estimating the buckling load of different metal plates of moderate and stocky classes. Finally, the effect of material and slenderness ratio of metal plates on the energy dissipation behavior characteristics under cyclic loading is qualitatively and quantitatively investigated.

2. Methodology

In this study, over 110 square metal plates with fixed dimensions (1000×1000 mm) and different slenderness ratios are studied using ABAQUS finite element software. Linear buckling, linear/nonlinear static and quasi-static cyclic analysis methods are used. The studies are performed for three different types of conventional and commonly used metal materials, including two types of steel materials (carbon steel (CS) and low yield point steel (LYP160)) and one type of aluminum material for wide range of slenderness ratios (λ=10~2200), assuming simply boundary conditions.

3. Results and Discussion

In addition to the three classical behavioral classes (stocky, moderate and slender), two classes of very slender and very stocky are proposed and the behavior of plates for these five classes are examined, considering metal plates having a wide range of slenderness ratios.

Very slender plates have low buckling capacity and significant post-buckling capacity. After the occurrence of the first yielding, they gradually lose their stiffness and thus, show a small post-yielding capacity up to ultimate strength. After that, they enter the softening phase of the behavior. Slender plates have a relatively low to medium buckling capacity or a moderate to relatively high buckling capacity in contrast, depending on their slenderness ratio. Shortly after the occurrence of first yielding, they reach their maximum strength. Buckling, first yielding and ultimate strength happen almost simultaneously in moderate plates. In stocky plates at a capacity equivalent to the nominal shear yield capacity, yielding occurs almost at the entire plate surface. Afterwards, the plate carries limited load with hardening behavior until the occurrence of plastic buckling. With the occurrence of plastic buckling, the plate reaches its maximum strength and the out of plane displacements begin to increase. Very stocky plates yield completely at a load equivalent to the nominal shear yielding capacity. Then, plate shows a limited post-yielding capacity with hardening behavior until reaching the ultimate strength. Because of the absence of buckling, unlike other classes, no softening behavior is observed for this class and out of plane displacement is very small.

The results in this study show that in stocky to slender plates, there is some difference between AASHTO and finite element results for the classification of various metal plates. The ranges of slenderness ratios for different behavioral classes, contrary to AASHTO relationship, also change with the plate material. Based on the obtained results, the ranges of slenderness ratios for each of behavioral classes are defined for each plate materials.

The results of buckling critical stress obtained from numerical analyses and existing theoretical relations are compared for different behavioral classes. For moderate and stocky plates, the results of existing theoretical relationships and finite element analyses are different. Thus, based on the obtained numerical results, new relationships are proposed for the moderate and stocky plates that are able to predict the buckling of these classes with relatively better accuracy compared to AASHTO relationships. (Eqs.1 & 2 respectively)

$$\tau_{cr} = 0.592 \frac{\sqrt{EK\sigma_y}}{\lambda} \quad (1)$$

$$\tau_{cr} = 0.827\sigma_y \times \left(\frac{KE_t}{\lambda E} \right)^{0.047} \quad (2)$$

4. Conclusion

Very slender plates have little buckling strength and considerable post-buckling capacity. Most of their post-buckling capacity occurs before yielding and after the yielding, plate shows limited capacity up to the ultimate strength. At the ultimate state, only a limited area at the tensile corner edges experiences yielding. Slender plates, depending their slenderness ratio, have little to considerable capacity in the elastic phase of behavior. At the ultimate state, a limited area along the tensile diagonal yields, while the level of stresses in other regions, is not very high. Moderate plates carry a significant part of the shear load in the elastic range of the behavior and they experience yielding in a relatively wider area along the tensile diagonal at the ultimate state. Stocky plates, depending on the slenderness ratio, provide a significant part of their capacity in the elastic phase of the behavior and at the moment of plastic buckling occurrence, they reach their ultimate strength while the full plate area is yielded uniformly. Very stocky plates, depending on the material type of plate, carry a certain and significant part of the shear load in the elastic range of the behavior.

The cyclic analysis results showed that the energy dissipation capability of very stocky/stocky/moderate plates is solely dependent on the material yield stress and elastic modulus of elasticity, whereas for the slender plates, the effectiveness of material yield stress in the energy dissipation of plates is decreased and the role of the material elastic modulus of elasticity becomes more important. In the case of very slender shear plates, the energy dissipation capability seems to be dependent on the initial and secondary modulus of material only.

5. References

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