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A DESIGN PROCEDURE FOR STEEL STRUCTURE BASED ON MATERIAL NONLINEAR ANALYSIS

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1. Introduction

The development of structural theory and of computing facilities have led to a great reduction in the cost of computation. This therefore would seem a good time to change structural steel design codes to incorporate theoretical developments in structural analysis, such as nonlinear analysis.

2. Proposed Method

In this study, an equivalent initial imperfection of a nonlinear material property is proposed to represent the material and geometrical imperfections that influence the ultimate strength of structures. In the proposed method, the ultimate strength of structures is defined as the violation of a given yielding criterion.

The equivalent initial imperfection in the form of a normalized reduced modulus versus axial force relationship is to be used for practical design. This relationship is obtained from the compressive column strength curve that inherently represents the material and geometrical nonlinearities. This concept derives from Engesser's original Tangent Modulus theory; general application of the theory is facilitated by the use of nonlinear analysis.

Considering the strength curve as the attainment of critical loads with varying reduced modulus of elasticities, the critical buckling load can be expressed as

$$\mathbf{P} = \frac{\pi^2 \mathbf{E_t I}}{(\mathbf{KL})^2} \tag{1}$$

where, $\mathbf{I}$ = *the moment of inertia*; $\mathbf{L}$ = *length of a compressive member*; $\mathbf{K}$ = *the effective length factor* and $\mathbf{E_t}$ = *variable of reduced modulus*. The general expression of slenderness ratio λ is given as

$$\lambda = \frac{\mathbf{KL}}{\pi}\sqrt{\frac{\mathbf{P_y}}{\mathbf{E_o I}}} \tag{2}$$

where $\mathbf{P_y}$ = *Yield Force* and $\mathbf{E_o}$ = *Initial Young's modulus of elasticity*. Making use of $\mathbf{P_y}$ from ***Eqs.(2)*** as a denominator of $\mathbf{P}$ from ***Eqs.(1)*** leads to

$$\frac{\mathbf{P}}{\mathbf{P_y}} = \frac{\mathbf{E_t}}{\mathbf{E_o}\lambda^2} \tag{3}$$

The normalized relationship can be expressed as

$$\bar{\mathbf{E}} = \bar{\mathbf{P}}\,\lambda^2 \tag{4}$$

in which, $\bar{\mathbf{E}} = \mathbf{E_t} / \mathbf{E_o}$ and $\bar{\mathbf{P}} = \mathbf{P} / \mathbf{P_y}$.

Time considerations mean that, for practical design, fine mesh segmentation of cross section is not feasible. By using ***Eqs.(4)***, a constant $\mathbf{E_t}$ which corresponds to $\mathbf{P}$ is imposed at each element member of a structure regardless of the length of the member. Then, it can be observed that for a given column strength curve equation, which is expressed as a relationship between λ and $\mathbf{P}$, a substitution of λ into ***Eqs.(4)*** will eliminate the role of λ in the equation. As a result, the proposed method is easy to adopt in solving more complex structures regardless of λ, whose value depends upon the length of each member.

3. Strengths of Simply Supported Column

Due to the necessity of using a strength curve in the proposed method, simply supported columns are evaluated by nonlinear finite displacement analysis to give the numerically exact strength curve. A representative cross section of *W12x14* is chosen. The stress-strain relationship is assumed to be elastic-perfectly plastic. The maximum magnitude of *0.001L* is selected as the initial crookedness following the eigenmode of the column. The presence of a compressive residual stress of *25%* of yield strength with welding pattern is incorporated. The results of evaluations are presented in ***Fig 1***.

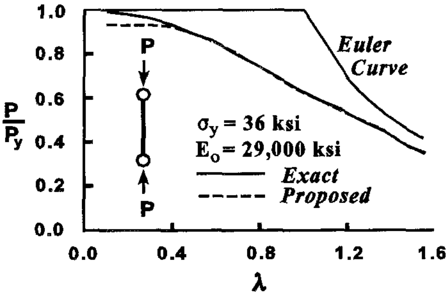

Fig 1 Column Strength Curve

4. Criteria of Yielding as a Prediction of Ultimate Strengths

As the criterion of yielding, a general interaction equation is the most important factor considered in this proposal. By adopting a single yielding criterion [1] :

$$1.15p^2 + 3.67p^2m^2 + m^2 = 1.0 \tag{5}$$

where $p = P/P_y$, $m = M/M_p$ and M_p = *full plastic moment capacity*, the results of evaluation of simply supported columns are shown in ***Fig 1***. The maximum error found is about *6%*.

5. Structures for Applicability Check

To show the applicability of the proposed method in a member with a combination of axial and bending forces, four columns of *W12x14* with different λ are selected for verification. The results, presented in ***Fig 2a*** and ***Fig 2b***, show that the predictions of the ultimate strength are satisfactory to within *12%* of maximum error.

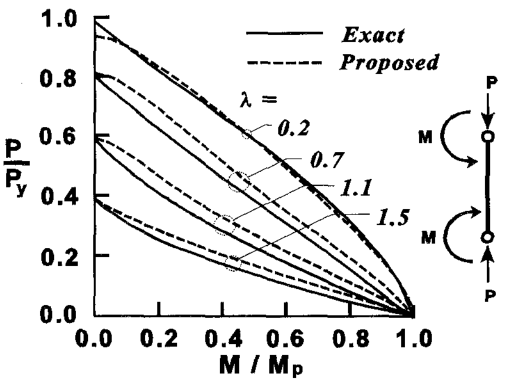

Fig 2a Interaction Curves, β = 1.0

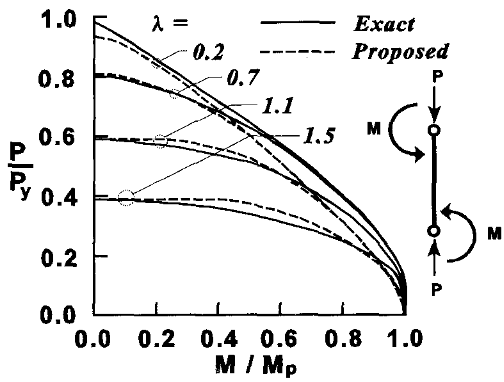

Fig 2b Interaction Curves, β = −1.0

6. Conclusion

A method to evaluate the ultimate strength of structures is proposed. The prediction of ultimate strengths by the proposed method agrees within the margin of error acceptable in practical design. One of the features of this proposed method is that the concept of effective length, which is not well defined in the current design practice, is not used. Another feature is that it can predict the ultimate strength of structures closely without introducing any kind of complicated formulae for structural components.

7. Reference

[1] Orbison, J.G., McGuire, W., and Abel, J.F.: "Yield surface applications in nonlinear steel frame analysis", in *Computer Methods in Applied Mechanics and Engineering*, North-Holland, No.33, 1982, pp557-573