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Strength of Solid and Built-Up Timber Compression Members

La résistance des colonnes massives et composées en bois

Tragfähigkeit von massiven und zusammengesetzten Holzstützen

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SUMMARY
Mathematical models for the behavior of solid and built-up timber compression members are developed. These models are verified by an extensive experimental program. The results of this investigation are discussed in relation to current design practice and codes on timber columns. A rational approach to the analysis and design of timber compression members is outlined.

RESUME
Des modèles mathématiques concernant le comportement des colonnes massives et composées en bois sont développés. Ces modèles sont vérifiés par un programme expérimental détaillé. Les résultats de cette investigation sont discutés et comparés avec les méthodes actuelles de dimensionnement, ainsi que les normes s'y rapportant. Une méthode rationelle par l'analyse et le dimensionnement de ces colonnes est esquissée.

ZUSAMMENFASSUNG
Mathematische Modelle zur Beschreibung des Tragverhaltens massiver und zusammengesetzter Stützen aus Holz werden entwickelt. Diese Modelle wurden durch ein ausführliches Versuchsprogramm überprüft. Die Ergebnisse werden mit der heutigen Konstruktionspraxis und den geltenden Vorschriften verglichen. Zum Schluss werden praktische Möglichkeiten zur Berechnung und zur Bemessung von Holzstützen aufgezeigt.

1. INTRODUCTION

Compression members commonly referred to as "columns", if they are slender enough, fail by buckling either before or after the elastic limit has been reached depending on the proportions of the column. The behavior and design of timber columns have been the subject of research for many years. Some of the research literature on the subject is listed in the references. Despite the continued research effort, the basic column problem is still not fully understood and the current design methods for solid timber columns are based on empirical formulas [2, 10]. Furthermore, there is very little guidance given for the design of built-up columns in the codes and specifications on timber design [2, 10].

In recent years, the author has been engaged in a number of projects related to solid and built-up timber columns, carried out at Nova Scotia Technical College [4 to 9, 14]. This paper outlines the highlights of these investigations. Detailed information on various aspects of the research can be obtained from the pertinent references listed at the end of the paper. The main objectives of this research have been to study the behavior of and develop a rational approach for the analysis and design of solid and built-up columns. The results are also discussed in relation to the current specifications and code stipulations on timber columns. A unified, design procedure is developed for columns in the elastic and inelastic ranges of stress. The types of timber columns included in the investigations are: solid, layered, spaced, braced and box columns.

The problem of a column is treated as a problem in stability. The theoretical development assumes a pure, axially loaded column, that is, a column which is centrally loaded by a compressive force whose resultant at each end coincides with its longitudinal axis. Although the concept of a pure column is an idealization in actual situation, it is a fundamental case in the study of behavior of columns in broad sense and is generally considered as the basis for the design of centrally loaded columns. Bending moments resulting from an unintentional end eccentricity, due to factors such as non-homogenity of the material, imperfection in fabrication, initial curvature, etc., will reduce the strength of a column that is intended to be centrally loaded. However these effects should be accounted for by an appropriate factor of safety in design formulas. If the bending moment is caused by an intential end eccentricity, rotation of adjacent members, or lateral loads, the problem then falls into the classification of beam-columns which is beyond the scope of this paper.

2. RATIONAL PROCEDURE FOR ANALYSIS AND DESIGN

The tangent-modulus concept is extended for predicting the strength of solid as well as built-up timber columns [4, 6]. The column formula can be written as:

$$F_{cr} = \frac{\pi^2 E_t}{\lambda^2} B \tag{1}$$

where: E_t = tangent modulus = slope of the stress-strain curve at a particular stress level; F_{cr} = column buckling stress; λ = slenderness ratio of the column; B = a factor which accounts for the column configuration and effect on non-rigidity of connections in built-up columns. For solid columns, B = 1. The expressions for B values for different types of built-up columns--layered, spaced, braced and box--are given in [6, 8, 9, 14].

To elucidate the column buckling problem in the inelastic range, a function proposed by Ylinen [15] is adopted in the present research. The function contains three parameters: F_u = ultimate compressive stress; E = modulus of elasticity; and c = a constant depending on F_u, E and the shape of the curve beyond the limit of proportionality. The shape of the stress-strain curve according to this function can be seen in Fig.1. The function is a very good approximation to the experimental stress-strain curves for wood [4], and is well suited to the analysis of buckling problems as the value of E_t corresponding to it can be expressed in a simple form, Fig. 1. Introducing E_t value derived from this function into Eq. 1 results in the following solution for column buckling stress:

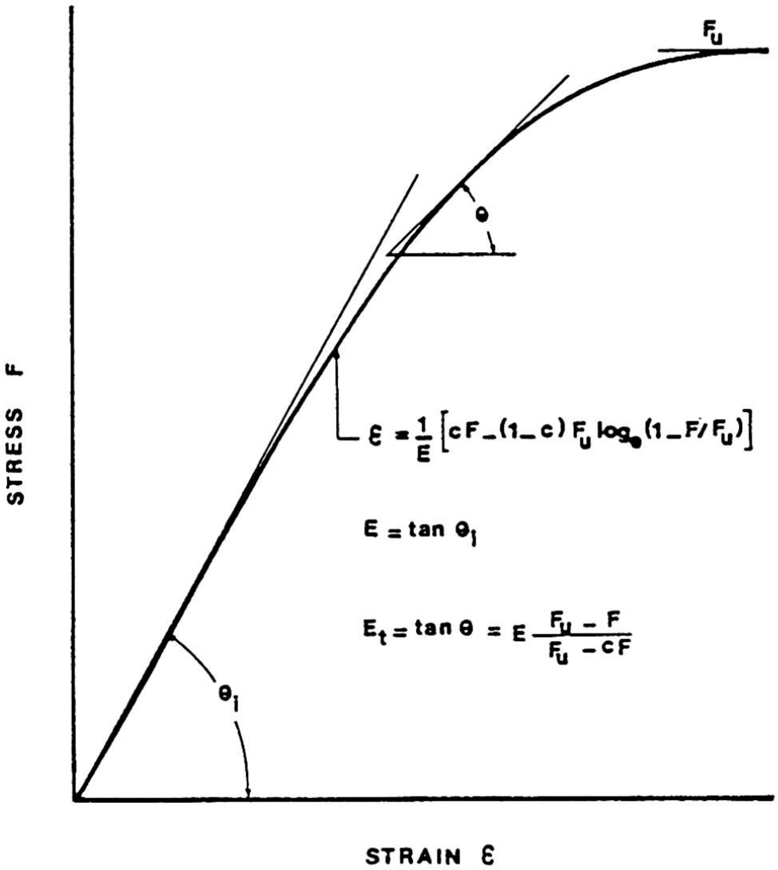

Fig. 1 Stress-Strain Curve

$$F_{cr} = \frac{B\pi^2 E + F_u\lambda^2}{2c\lambda^2} - \frac{\sqrt{(B\pi^2 E + F_u\lambda^2)^2 - 4Bc\lambda^2\pi^2 E F_u}}{2c\lambda^2} \qquad (2)$$

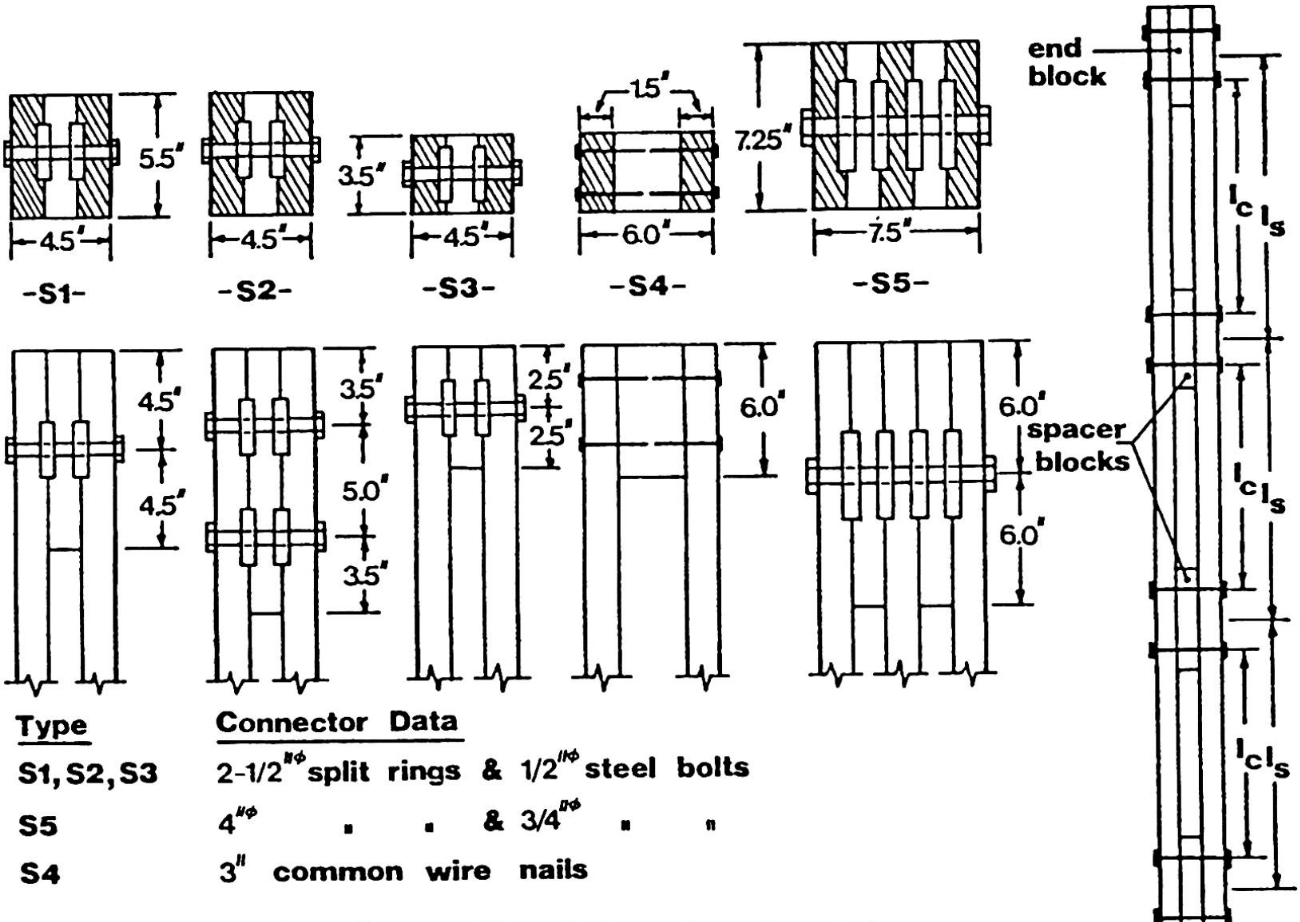

Fig. 2 Details of Spaced Timber Columns

Theoretical predictions by Eq. 2 were compared with the experimental data obtained from many series of tests on solid and built-up timber columns. Some 1200 columns of eastern spruce were tested in total. As an illustration, Fig. 2 is given here to show types of spaced columns that were investigated. Good agreement was observed between the theoretical and experimental results for all series of tests.

The use of Eq. 2 makes the column buckling problem rational and limits empiricism to an absolute minimum. However, this equation is inconvenient to use directly in design. If a specific value is assigned to 'c', curves can be plotted between the two dimensionless quantities F_{cr}/F_u and λ for various values of factor F_u/EB. The curves between these two quantities for eastern spruce lumber can be seen in Fig.3. The value of parameter c for eastern spruce is taken equal to 0.90 as was found by compression tests. The ratio F_{cr}/F_u is referred to as the 'buckling coefficient' and is denoted by β. In Fig.3, β is plotted against λ for F_u/EB values ranging from 1.00×10^{-3} to 18.00×10^{-3}. The experimental values of the ratio F_u/EB encountered in the present research were well within the range. As a comprehensive aid for design, graphs like Fig. 3 can be plotted for a wide range of F_u/EB values. With the aid of such graphs, the critical column stress, F_{cr}, in a given column can be calculated quite easily. To determine the allowable column stress, F_u and E should be replaced, in all calculations, by the allowable compressive parallel to grain stress and design value for modulus of elasticity of column material.

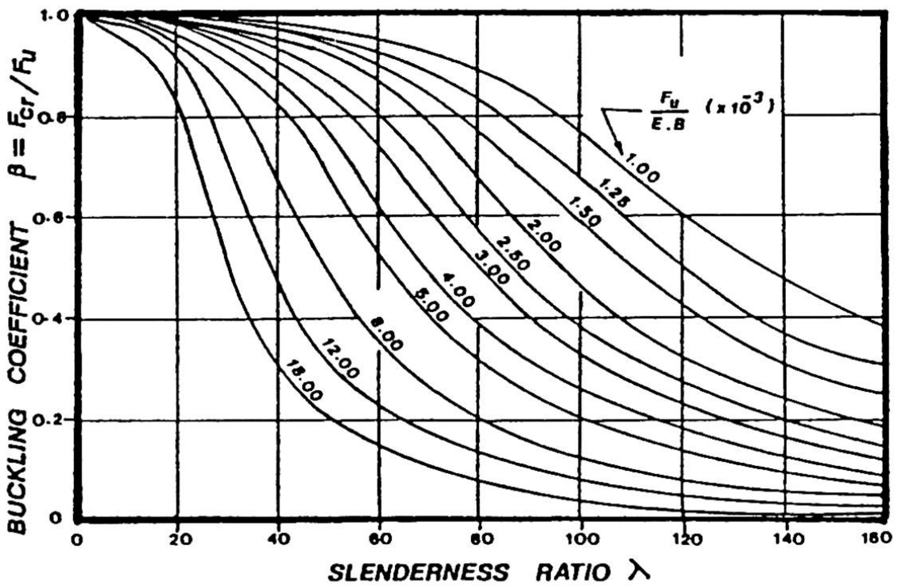

Fig. 3 Buckling Coefficient Versus Slenderness Ratio Curves

3.EFFICIENCY OF BUILT-UP COLUMNS

Comparison is made of the efficiency of various types of built-up timber columns fabricated with different types and sizes of connectors and with different spacings of connectors. Figure 4 shows efficiency curves for different bolt spacings in the type of layered column cross-section sketched on the figure. Efficiency is defined as the ratio of the strength of a laminated column to the strength of equivalent solid column of same overall dimensions as those of the laminated column. Graphs of the type shown in Fig. 4 can be valuable design aid to designers in selecting an efficient combination of lumber sizes and connector spacings.

Though there is hardly a mention of braced and layered columns in current codes and specifications, there is a procedure given for the design of specific type of spaced timber columns built with spilt ring connectors [2, 10]. In light of the experimental results of the investigation on spaced columns, this design procedure seems to be based on a very conservative estimate of spaced column strength.

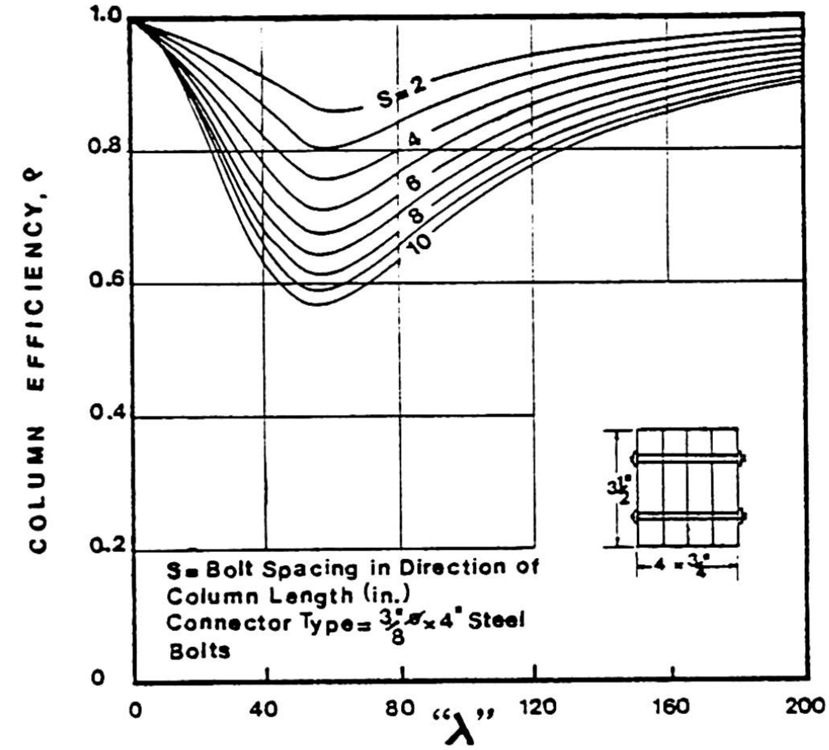

Fig. 4 Efficiency Curves for Layered Columns With Various Bolt Spacings

4. CONCLUSIONS

Based on theoretical and experimental studies, a rational approach to the analysis and design of solid and built-up timber columns is presented. This procedure is valid for all slenderness ratios and is, thus, applicable to columns in the elastic and inelastic ranges of stress. It can be used to determine critical or allowable column stresses. Efficiency of various types of built-up columns is compared and the effect of connector spacing on the column strength is investigated.

Research is continuing to cover timber members subjected to combined axial and bending loads. The effects of end restraints on the strength of timber compression members will be included in the investigation.

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