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Strength of Jack-Beams with slender webs and mono-symmetric sections

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Abstract Jack-Beams (J-Beams) are used to support discontinued columns that do not extend to lower floors, satisfying space requirements in large stores and workshops. Often large concentrated loads are acting on the laterally unsupported J-Beam top. Built-up I-sections are often used in designing J-Beams. Lateral-torsional buckling (LTB) is crucial in designing J-Beams as it is one of the main requirements in controlling the ultimate bending strength of steel J-Beams carrying loads on top flange. This study investigates the ultimate bending strength of commonly used J-Beams with different sections and classes including slender webs. A numerical model is developed to accurately estimate the ultimate load of J-Beams. The strengths of the selected J-Beams are calculated for different models of unsupported lengths and different section types according to detailed finite element model (FEM) for this type of system. The goal is to investigate the performance of the J-Beams for the selected section types and beam lengths. Single concentrated loads at the top flange of the J-Beams are applied at the FE models. Imperfections of different values are implemented to examine their sensitivity and to find out their effect on the LTB of J-Beams at failure, and hence, their effect on the ultimate strength of J-Beams. The study also introduces simplified procedure and gives recommendations for designing J-Beams using the numerical results of the selected sections.

Introduction

The ultimate bending strength of J-Beams is affected by the Lateral-torsional buckling phenomenon. This phenomenon controls the strength of J-Beams that are not adequately restraint to lateral deflection and twisting out of the loading plane.

For elastic LTB under pure constant bending, the unsupported length is considered to be the J-Beam length (i.e. the J-Beam is laterally restrained at its ends).

The critical buckling moment in the case of pure bending described above is given by [1]:

$$M_{ocr} = \frac{\pi}{L}\sqrt{EI_y GJ}\sqrt{1+\frac{\pi^2 EC_W}{GJL^2}}, \tag{1}$$

where L is the length of the J-Beam span which is considered unsupported laterally.

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The elastic lateral buckling of J-Beams under vertical loads depends mainly on two parameters: the lateral rigidity of flanges EI_y and the torsional rigidity GJ. For long J-Beams the effect of the lateral and warping rigidity C_w decreases and the torsional rigidity dominates. Where E and I are the elastic and shear moduli.

For short compact sections the lateral rigidity provides the main resistance of J-Beams. It is noticed that short J-Beams with slender elements are subjected to local failures under heavy vertical loads. The resistance is further reduced by the yield spread either locally or globally due to excessive stresses.

For other cases of different moment gradients along the J-Beam unsupported length, the use of the moment gradient factor C_b was adopted to Eq. (1) to take the effect of different moment distribution along the J-Beam's unsupported length [1]:

$$M_{ocr} = \frac{C_b \pi}{L} \sqrt{EI_y GJ} \sqrt{1 + \frac{\pi^2 E C_W}{GJL^2}}, \tag{2}$$

The first formula for C_b to find its way into structural design codes is the result of work presented by Salvadori (1955). There is one omission in either of the two formulas just presented Eqs. (1) and (2): They do not account for the position of the load on the y-axis of the cross-section [1].

AISC-LRFD [2] proposes a linear transition equation from the end of the elastic region to the plastic moment and scales it with *a constant moment gradient factor*, C_b, for all ranges of inelastic Beam's slenderness as follows:

$$M_n = C_b \left[M_p - \left(M_p - M_r \right) \left(\frac{L_b - L_p}{L_r - L_p} \right) \right] \leqslant M_p, \tag{3}$$

There are different values for C_b in AISC-LRFD depending on the load conditions of the openings. Apart from the load cases mentioned in AISC-LRFD [2], there are some other cases that the transverse loads act away from the shear center axis. For example, top flange loading on a crane runway girder and bottom flange loading acting on a monorail can be considered in practice [3,4].

J-Beam supporting rafters at the center of the upper flange, as shown in Fig. 1, are subjected to lateral instability.

Loads on J-Beam top flange center are overturning and thus remarkably reduce the ultimate capacity. In the following, these cases are investigated on carefully selected J-Beam sections with various lengths. The cross sections contain slender webs to reduce material costs. Furthermore, webs are assumed plain with no stiffeners arranged in order to reduce material and labor expenses (Fig. 2).

In this paper, all the studied sections are investigated for single loading at the center of the top compression flange. This loading case is destabilizing with respect to LTB phenomenon.

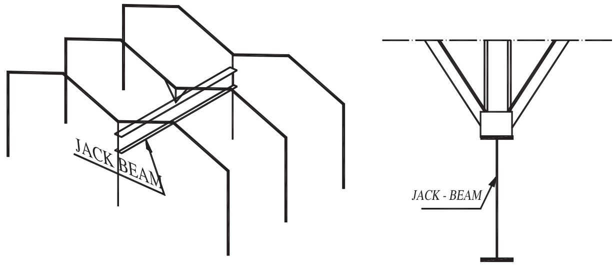

Fig. 1 J-Beam replacing column.

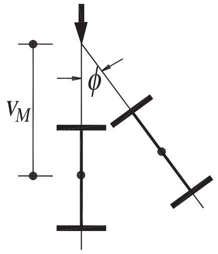

Fig. 2 Section torsion.

The selected sections are mono-symmetric of different classes including slender web elements. The J-Beams are simulated using FEA model, including geometrical imperfections in the out-of-plane of J-Beam bending.

The purpose of this paper is to investigate the inelastic LTB behavior for J-Beams loaded on top and having built up sections with slender webs. The effect of lateral imperfections is considered. The upper flanges are laterally free. A concentrated load acts on center of the top compression flange. The overturning moment of this type of loading is considered throughout the analysis.

For this purpose a finite element model based on the software package ANSYS [5] is developed for the nonlinear inelastic LTB analysis of built up mono-symmetric J-Beams with different lengths and web slenderness. Then the results are used to investigate the accuracy of the LTB equations given in the AISC-LRFD provisions, and to propose a simplified design procedure.

Literature review

A comprehensive literature review was given by Mohebkhan [3] covering the advances of LTB related research work.

The differential equation of the elastic, top loaded J-Beam with single forces is given as follows Eq. (4):

$$E\,C_M\,\phi'''' - G\,J\,\phi'' - \left[\frac{M^2}{E\,I_y} - M''\,v_M \right] \phi = 0, \tag{4}$$

As for double symmetric J-Beams the center of gravity coincides with the shear center at web mid height. The warping constant is $C_M = I_y\,.h^2/4$, where h is the height of the J-Beam. GJ is the torsional rigidity, where $J = \sum(bt^3/3)$. It is noticed that the third coefficient includes M'' representing the single load acting vertically on the J-Beam and making the mathematical closed solution very complex. The differential equation is solved numerically and the solution is simplified and is given in Eq. (4) as follows

$$M_{CR} = \frac{k}{L} \sqrt{EI_y\,GJ}, \tag{5}$$

In this equation k is given graphically and includes correction factor representing single loading on the J-Beam acting on top, at the center of gravity or at the bottom [6]. Eq. (5) is used later in this paper to verify the numerical accuracy of the finite element model.

Extensive laboratory tests and numerical investigations have been conducted to study the LTB behavior of steel J-Beams by Nethercot et al., Galambos et al. [1], and Trahair [7]. The findings of the above mentioned studies have led to the