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Economical design procedures for built-up box sections subject to compression and bi-axial bending

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ABSTRACT

The paper offers to practitioners economical procedures that can be utilized to optimize the design of built up box sections subject to compression and biaxial bending. Little emphasis appeared in the published literature that addressed this general loading condition. The analysis methodology and structural idealization are first overviewed. Diagrams are presented showing buckling behavior of the section by accounting rotational and lateral restraints. The post-buckling response is also illustrated for various applied stress ratios. A design space concept is then introduced showing interaction of serviceability and strength limit states. These procedures are cost effective and appropriate for industrial implementation to optimize the structural design.

1. Introduction

Box sections are extensively used in commercial buildings, bridges, marine structures and many of the heavy industrial facilities. They provide efficient structural performance in resisting axial compression, flexural and torsional stresses. In building construction, built up thin walled box sections are fabricated in some cases by welding two cold-formed C-sections to increase; 1) the flexural stiffness of the member , so long spans can be used; and 2) the torsional stiffness by generating symmetric cross sections. Box sections are also fabricated by assembling plate elements. In this case, different flange or web thickness can be used to reduce the weight of the structure. Built-up box section may be subject to either concentric or eccentric loading. Eccentric loading may also result through load transfers by attached members. Experiments and numerical studies have shown that local buckling of box section is a common failure criterion in thin walled box members.

Research into thin walled steel box sections has been a subject of interest for many years. Several numerical and experimental studies were conducted in the past to study the behavior of box section. Majority of the investigations and design guidelines are limited to box sections subjected to either the uniform compression or pure bending. Spence and Morley [1] performed tests on box girders under different combinations of symmetrical and anti-symmetrical loads. Rasmussen and Baker [2] studied experimentally the ultimate load-carrying capacity and failure mechanisms of thin walled box section beams subject to eccentric loads. Heins and Lee [3] reported field tests for a two-span curved steel single-box girder bridge. Reyes and Guzmán [4] performed experimental investigation to study the behavior of box sections composed of two welded C-section members under uniform compression. Usami and Fukumoto [5] presented experimental results of local and overall buckling of welded box sections fabricated from high strength steel. Tests were also carried to study the influence of residual stress in hollow steel sections in references [5,6].

Ductility of the flanges was studied numerically by Zheng et al. [7] using short steel box columns. Aoki and Susantha [8] also conducted cyclic loading tests to examine the ductility of box sections by considering axial load fluctuations. Serrette [9] investigated the flexural performance built-up box sections under eccentric loading. The built-up box sections were made with two face-to-face C-shapes, with a track section cover connected to the top and bottom flanges. They presented test results showing the effect of edge loading. Jeon et al. [10] developed analytical model to study static and dynamic behavior of composite box beams. Cortinez and Piovan [11] investigated the stability of composite thin-walled beams with open or closed cross-sections. Hsu and Tsao [12] studied the flexural–torsional behavior of thin-walled hollow box columns subjected to a cyclic eccentric load. Bedair [13,14]

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investigated the interactive buckling of stiffened box sections under uniform compression with applications to bridge and industrial facilities. The influence of the flange/web proportions on the behavior of section was highlighted. Industrial examples were presented showing the variation of the flange buckling stress for various stiffening configurations. It was shown that the behavior of the flange is largely affected by the restraints imposed by the webs. Other investigations by Bedair [15–22] highlighted the behavior of W and channel steel sections under various loading combinations. Discrete models were presented to idealize realistically the restraints of the attached structural components. Design guidelines were proposed that can be utilized by practicing engineers and steel fabricators to maximize the performance of W and channel steel sections.

The interaction of plate assemblies was addressed by several researchers. Stamatelos et al. [23] presented a methodology to study local buckling and post-buckling behavior of plate assemblies. Transverse and rotational springs with varying stiffness were used to model the plate-stiffener interaction. Zhang et al. [24] used a triangular composite stiffened plate/shell element to analyze stiffened plates using Mindlin shear deformation theory. The rotations of ribs and the plate are determined using displacement compatibility conditions. Li and Xiaohui [25] presented finite element model to study the bending behavior of stiffened laminated plates. The compatibility of displacements and stresses between the plate and the stiffeners conditions were used to establish the governing equations. Nath [26] presented analytical solutions for elastic fields of a stiffened composite plate subjected to axial tension and pure bending. A potential function is expressed in terms of the displacement components that satisfy the equilibrium condition. Fourier series approximation is then used satisfying the boundary conditions. Jiang, Bao and Robert [27] presented several modeling strategies for bending and buckling of orthotropic and rectangular plates using finite element method. Numerical comparison is made using first and second order three dimensional elements with varieties of mesh intensities. It must be noted that three dimensional solid elements require excessive computer time and consequently may not be practical for analysis of plate assemblies.

Box sections are sometimes filled with concrete to enhance the member stiffness and load carrying capacity. The concrete fill acts as restraining media to the box section plates. Local buckling of box sections filled with concrete was addressed by a number of researchers. Shanmugam et al. [28] employed effective width procedure to predict the load carrying capacity of thin walled steel tubes with concrete fill subject to biaxial loadings. Uy and Bradford [29] used finite strip method to determine the buckling stress for various boundary conditions. A sinusoidal function is used for the longitudinal displacement and a cubic polynomial for the transverse displacement. Empirical studies were also performed for local buckling strength of steel tubes filled with concrete by Sakai et al. [30] and Wright [31].

Limited literature addressed buckling of box sections under combined compression and biaxial bending. Much of the investigations focused to develop numerical or empirical analysis procedures for box sections under compression or bending. Also, the available local buckling expressions for box sections are applicable to the compression and uniaxial bending loading conditions. Furthermore, North American and European codes of practice [32–36] ignore the rotational and lateral restraints imposed by the attached members.

The objective of the paper is to investigate the serviceability and ultimate states of box sections under combined axial compression and biaxial bending. The box section assemblies are treated as partially restraints against rotation and in-plane translation. The study provides useful guidelines that can be utilized by practicing engineers to maximize the section performance under this general loading.

2. Analysis procedure

Consider typical built-up box section shown in Fig.(1) with unsupported length (L), subject to compressive force (P), and biaxial moments (M_1 and M_2). The web width and thickness are denoted by (b_w, t_w) and the flange width and thickness by (b_F, t_F). The top and bottom flanges are denoted by (F1, F2), and the webs by (W1, W2), as illustrated in Fig. (1). The flanges and the webs are also identified by local co-ordinate systems, with origins (o_{W1}, o_{F1}) that are located at their centerlines. Note that the subscripts {W1, W2, F1, F2} are used to distinguish the local coordinates of each plate component. Therefore, the non-dimensional coordinates of web (W1) are $\xi_{W1} = (x_{W1}/L)$ and $\eta_{W1} = (y_{W1}/b_w)$, and for flange (F1) counterpart are; $\xi_{F1} = (x_{F1}/L)$, $\eta_{F1} = (y_{F1}/b_F)$.

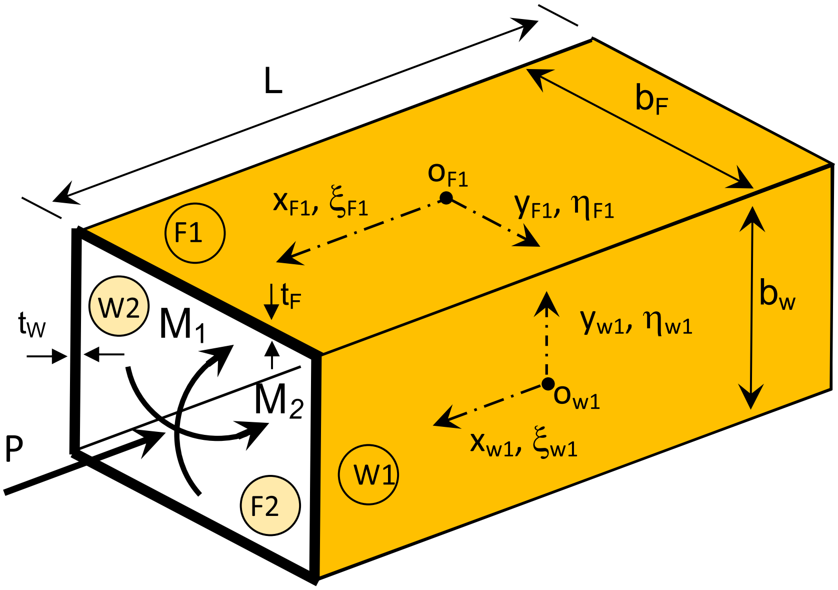

Fig. 1. Typical box section assembly.