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A parametric study on the longitudinal stiffeners of web panels

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ABSTRACT

Optimum location and dimensions of longitudinal stiffeners in web plates under in-plane bending are investigated. This parametric study is performed by numerical simulation utilizing finite element method. Several plates having various aspect ratios are analyzed and an equation for minimum required second moment of area of stiffeners is presented and compared to that recommended by AASHTO. Also, it is shown that the optimum location of stiffener mainly depends on its relative flexural rigidity.

1. Introduction

In plate girders subjected to moving loads, the web plates between transverse stiffeners are prone to buckle locally due to direct compressive stresses, arising from in-plane bending moments. This mode of buckling is independent of shear buckling, but may interact with it.

In most fabricated girders, webs are slender and tend to buckle locally prior to flexural–torsional, distortional buckling, or yielding. In most cases, elastic buckling does not represent a true strength limit state, since the webs exhibit significant post-buckling reserves of strength. In spite of this reserve, intermittent buckling under live loads, commonly known as plate breathing, gives way to fatigue cracks in regions where tension fields and folds are anchored on to flanges and transverse stiffeners; which in turn degrades the strength of plates and causes premature failure. Fatigue cracks are usually due to the secondary bending stresses induced by out-of-plane deflections of web [1–4]. This experience forces engineers to use longitudinal stiffeners in order to prevent web buckling. Longitudinal stiffeners are primarily added to obtain a higher local buckling capacity under in-plane bending. A properly designed and efficient stiffener should remain intact and enforce a nodal line at stiffener-plate junction. On the other hand, transverse stiffeners are meant to perform a similar task under shear loading [5].

The local buckling and post-local buckling performance of web plates in bending can be improved by the provision of a longitudinal stiffener parallel to the direction of the longitudinal stresses [6]. Azhari and Bradford [7] used complex finite strip method to show that the introduction of longitudinal stiffeners would increase critical stresses of I-section beams. In Eurocode 3 [8] the interaction of shear and bending is discussed, but longitudinal stiffeners are not considered. Ultimate strength of longitudinally stiffened I-girder was investigated by Graciano [9]. Their girders were subjected to patch loading or combined patch loading and bending.

Extensive work has been carried out to determine expressions for critical buckling loads of flat unstiffened plates under shear, compression, bending and a combination of different loadings. Existing solutions are based on constant stress levels throughout the plate, and no theoretical solution or design rule exists for more complex situations. Therefore, finite element analysis is often used to solve more complicated cases.

Featherston and Ruiz [10] worked on the buckling of flat plates under bending and shear. They outlined a program of work that had been undertaken to compare collapse loads predicted by theoretical, experimental and finite element analysis for the case of a flat rectangular plate under combined shear and bending. Kang and Leissa [11] formulated an exact solution for the buckling of flat unstiffened rectangular plates having linearly varying in-plane loading on two opposite simply supported edges.

In this paper, overall and local buckling modes of longitudinally stiffened plates of the type depicted in Fig. 1, under in-plane bending are considered. The main aim of this study is to find the optimum geometrical characteristics (i.e. location and dimensions) of longitudinal stiffeners. In order to find the optimum position of the stiffener, the “bisection iteration” method was utilized. With respect to most design rules,

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Nomenclature

a	length of web panel
a_n	deflection coefficient of plate
A_s	cross sectional area of stiffener
b	stiffener distance from compression edge
b_s	width of stiffener
d	depth of web panel
D	flexural rigidity of the plate
E	Young's modulus of elasticity
I_s	stiffener moment of inertia about mid plane of plate
k_b	bending buckling coefficient
m	number of half-waves in the longitudinal x-direction
n	number of half-waves in the transverse y-direction
t_s	thickness of stiffener
t_w	thickness of web plate
T	total work done by external forces
U	total strain energy
w	deflection of plate
ν	Poisson's ratio
σ_b	bending stress
σ_0	maximum normal stress at the edge
φ	plate aspect ratio

longitudinal stiffeners are placed on one side of the plates. This is to gain maximum inertia from the material, reduce welding and prevent intersecting transverse stiffeners. A typical stiffened web plate model is illustrated in Fig. 1. The web depth is denoted by d; a represents the distance between the two transverse stiffeners, and b denotes the location of longitudinal stiffener from the compression flange. Numerous models are analyzed and a relation for predicting minimum required stiffener rigidity is proposed.

2. Theoretical background

2.1. Buckling of unstiffened plates

In a simply supported plate, subjected to bending moment in its own plane, as in thin webs of plate girders, it is supposed that the buckled form consists of m half-waves in the x-direction. Therefore, the deflection of the plate (w) can be represented by the series given in [12,13]

$$w = \sin\frac{m\pi x}{a}\sum_{n=1}^{\infty} a_n \sin\frac{n\pi y}{d} \tag{1}$$

where n is the number of half-waves across the web depth and, a_n is the deflection coefficient. The corresponding strain energy, which does not involve any knowledge of the load distribution is

$$U = \frac{\pi^4 Dad}{8}\sum_{n=1}^{\infty} a_n^2\left(\frac{m^2}{a^2}+\frac{n^2}{d^2}\right)^2 \tag{2}$$

D represents the flexural rigidity of plate. Then, if σ_0 is the maximum normal stress at the plate edges, the total work done by the linearly varying bending stresses (σ_b) would be

$$T = \frac{1}{2}\sigma_0 t_w \int_0^d \int_0^a \left(1-\frac{2y}{d}\right)\left(\frac{\partial w}{\partial x}\right)^2 \mathrm{d}x\,\mathrm{d}y \tag{3}$$

where t_w is the thickness of web plate and $\sigma_b = \sigma_0(1-2y/d)$. Equating $U = T$ yields to an expression for evaluating critical edge stress $(\sigma_0)_{cr}$. The results given by Timoshenko [12], Allen and Bulson [13] show that the buckling coefficient k_b (in Eq. (4)) is about 23.9; which is six times greater than the case of plates under pure compression:

$$(\sigma_0)_{cr} = k_b\frac{\pi^2 E}{12(1-\upsilon^2)}\left(\frac{t_w}{d}\right)^2 \tag{4}$$

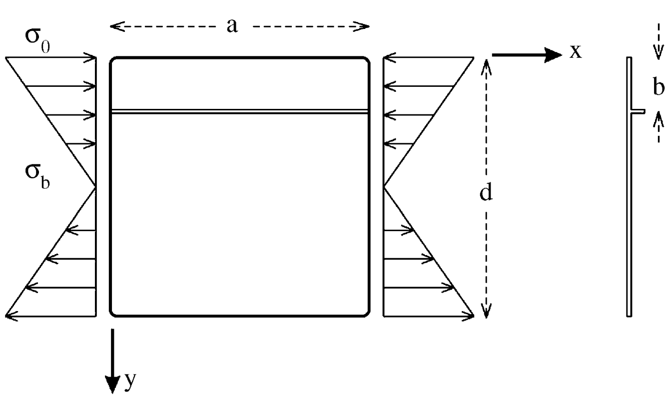

Fig. 1. Longitudinally stiffened plate under in-plane bending.

2.2. Stability of longitudinally stiffened web plates

The longitudinal stiffener should be placed in a judicious position so that it can influence the buckling mode and stresses to a considerable extent. For simply supported plates, Rockey [14] deduced that, in plate girders, the optimum position for the longitudinal stiffener was at a distance of one-fifth of the depth of the plate from the compression edge. He added that the relative value of the second moment of area of stiffener (I_s) to produce a nodal line, it must satisfy the relationship given in

$$\frac{EI_s}{dD} = 43.4 + 381\left(\frac{A_s}{t_w d}\right) + 1080\left(\frac{A_s}{t_w d}\right)^2 \tag{5}$$

where A_s is the cross-sectional area of stiffener. If the above requirements are met, he added, the elastic buckling stress coefficient would be equal to 129, noting that this equation is only applicable to stiffeners having negligible torsional rigidity. However, it should be noted that I_s is given in terms of A_s and thus, the designer must find the optimum stiffener dimension by trial and error.

The shear strength of girder webs can be conservatively estimated by neglecting the contribution of longitudinal stiffeners because the recommended location of the longitudinal stiffener is 0.2d from the compression flange; and is not much helpful in increasing the shear strength as they are for bending. Theoretical and experimental studies have indicated that the optimum location of one longitudinal stiffener is 0.5d for shear [15]. d is the depth of the web plate, as shown in Fig. 1.

Dubas [16] had presented a general solution for the plate buckling with longitudinal stiffener under bending, with all edges simply supported. The longitudinal stiffener was located at one-fifth of the web depth from the compression flange. But Rockey and Leggett [6] presumed fixed boundary condition.