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Evaluation of Direct Strength Method for Local Buckling Strength of Cold Formed Steel Stiffened Lipped Channels

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Abstract

Intermediate stiffeners in the web and flanges are used in cold-formed steel (CFS) lipped channels to avoid local buckling. Many researchers demonstrated that the direct strength method (DSM) is not accurate for estimating the strength of stiffened channel compression members. The inadequacy of DSM for stiffened channels may be because either the strength due to independent buckling modes (local, distortional or global) or interaction of buckling modes are not adequately determined. In this study, the DSM-local buckling strength equation is evaluated using the results from FEA for the web height to flange width ratio (*h/b*) of 1 and 2. It is observed that the normalized local buckling strength (*Pul/Py*) is a function of the *h/b* ratio of the cross-section in addition to the non-dimensional slenderness ratio and the strength obtained from DSM is conservative.

Keywords: cold formed steel, direct strength method, lipped channel, intermediate stiffeners, local buckling, finite element analysis.

1 Introduction

The direct strength method (DSM) (AISI [1]; AS/NZS:4600 [2]) simplified the design of cold-formed steel (CFS) members significantly compared to the traditional effective width method. In DSM, the local, distortional and global buckling strengths (*Pul*, *Pud*, and *Pug*, respectively) are computed based on empirical equations which require two inputs; yield load of the cross-section (*Py*) and elastic buckling loads corresponding to local, distortional and global buckling modes (*Pcrl*, *Pcrd*, and *Pcrg*, respectively). The recent studies by Tai et al. [3], Andre et al. [4], Anbarasu and Murugapandian [5], Ziqi et al. [6], and Pedro et al. [7] demonstrated using experimental and numerical studies that DSM is not accurate for lipped channel compression members with intermediate stiffeners. The accuracy of DSM depends on the accuracy of the design equations for strength under independent buckling modes. This study evaluates the accuracy of local buckling strength equations in DSM.

The DSM considers the normalised local buckling strength, P_{ul}/P_y as a function of only nondimensional local buckling slenderness ratio, $\lambda_l = \sqrt{(P_y/P_{crl})}$. The local buckling strength of a CFS compression member based on DSM shall be computed using Equations (1a) and (1b). These equations were developed by Schafer (2002) using the results of the lipped channel section without any intermediate stiffeners. There are no studies reported in the literature for evaluating the accuracy of these equations for the local buckling strength of lipped channel compression members with intermediate stiffeners in the web as well as in flanges.

$$\lambda_l \leq 0.776,\ \frac{P_{ul}}{P_y} = 1 \tag{1a}$$

$$\lambda_l > 0.776,\ \frac{P_{ul}}{P_y} = \left[1 - 0.15\left(\frac{1}{\lambda_l}\right)^{0.8}\right]\left(\frac{1}{\lambda_l}\right)^{0.8} \tag{1b}$$

Kumar and Kalyanaraman [8] studied the accuracy of Equations (1a) and (1b) for lipped channel stub columns undergoing independent local buckling. As the strength from these equations is not accurate it is further modified by introducing additional factors as a function of web height to flange width ratio (*h/b*) into the formulae which are referred to as modified direct strength method (MDSM). In this study, the finite element (FE) models of lipped channels with intermediate stiffeners on both web and flanges were developed and validated using the experimental results. The validated FE models are used to generate additional data on the ultimate local buckling strength of such members. Short members are used in this study to eliminate the effect of global buckling. Also, restraints are used to eliminate distortional buckling initiated by lips and/or intermediate stiffeners. The results of this study show that DSM local buckling strength equations (Equations (1a) and (1b)) are inaccurate for independent local buckling strength of CFS lipped channel compression members with intermediate stiffeners.

2 Methods

Finite Element Modelling and Validation

The FE model was developed in ABAQUS version 6.7 [9] using four nodded shell elements with reduced integration (S4R elements) along the mid-thickness of the plate elements of the cross-section. The minimum number of elements used along the width direction was eight for both the flanges and the web, whereas a minimum of three elements was used for the lips. Stiff three-dimensional (B33) elements are used to avoid stress concentration at ends because of the application of load and/or boundary conditions. The eigenvalue buckling analysis was performed initially to determine the elastic buckling loads and mode shapes. The buckling mode shapes were used for generating the imperfect model for the nonlinear analysis. A displacement-controlled nonlinear analysis was conducted considering both material and geometric nonlinearity using the Newton-Raphson iteration scheme. A typical finite element model used for the parametric study is given in Figure 2. The restraints are lips and intermediate stiffeners that restrict the out-of-plane deformations which will eliminate the distortional buckling without influencing the local buckling behaviour. Similarly, the restraints at the web-flange junction eliminate global buckling deformations without affecting the local buckling behaviour.

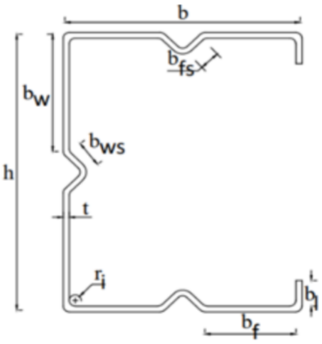

Figure 1: Stiffened Lipped Channel

Figure 2: Typical FE model

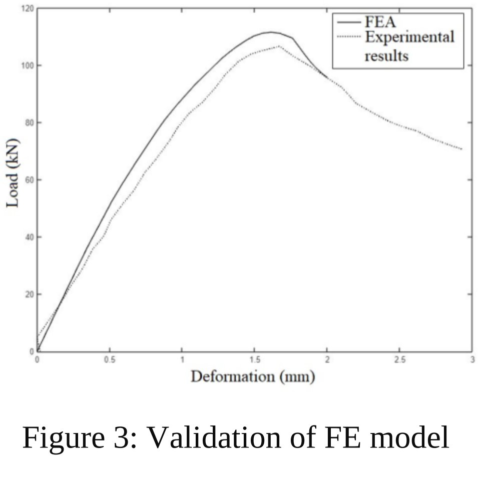

Figure 3: Validation of FE model

Figure 3. shows the comparison of load versus axial deformation from experiments reported by Kumar and Kalyanaraman [10] to the FE model developed in the present

study. The comparison shows the FE model accurately predicts the behaviour of CFS stiffened channel compression members. The validated model is then used for generating the local buckling strength of the members.

3 Results

The FE models of stiffened lipped channels having web height to flange width ratio (*h/b*) of 1.0, and 2.0 are analyzed for non-dimensional slenderness, λ_l values varying from 1.0 to 3.5. Different values of λ_l were obtained by changing the thickness of the channel section. The material properties used for the parametric study are Young's modulus of steel, E = 2x10^5 N/mm^2, Poisson's ratio, ν = 0.30, yield stress, f_y = 250 N/mm^2 and ultimate stress, f_u = 410 N/mm^2.

The normalized ultimate strength (P_{ul}/P_y) of the specimens obtained from finite element analysis (FEA) for different values of *h/b* (=1.0 and 2.0) are plotted against λ_l in Figure 4. The DSM local buckling strength equation (Equation (1)) and elastic local buckling stress are also plotted for comparison. The ratio of ultimate strength of FEA ($P_{u\text{-}FEA}$) to that of DSM ($P_{ul\text{-}DSM}$) versus λ_l are plotted in Figure 5.

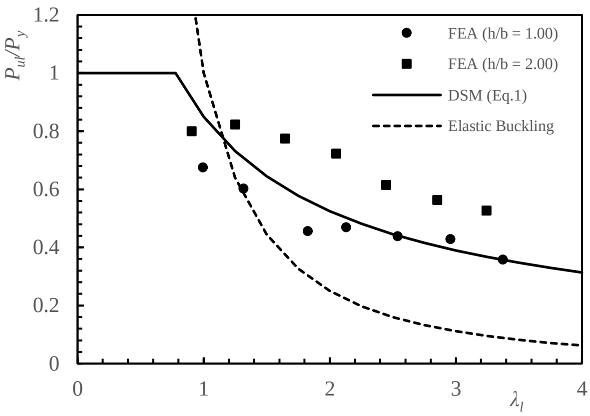

Figure 4: P_{ul}/P_y vs. λ_l

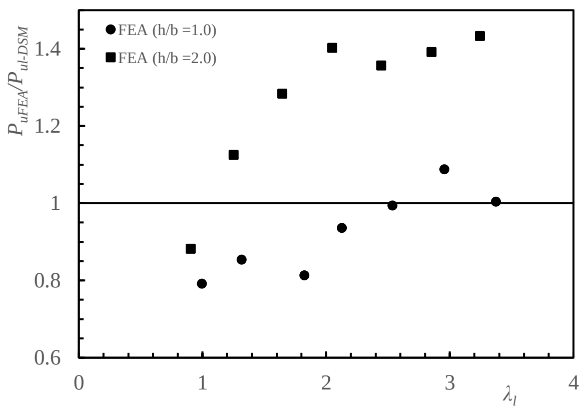

Figure5: $P_{uFEA}/P_{ul\text{-}DSM}$ vs. λ_l

The observations from Figures 4 and 5 are listed below:

1. The normalized local buckling strength (P_{ul}/P_y) of stiffened lipped channel compression members is function of web height to flange width ratio (*h/b*) in addition to nondimensional local buckling slenderness, λ_l.
2. The DSM gives very conservative (up to 40%) estimate of local buckling strength as *h/b* increases.

4 Conclusions

The DSM was found to be not accurate for determining the strength of CFS lipped channel compression members with intermediate stiffeners in both flanges and the web. The accuracy of design equations for predicting the strength under independent buckling modes may be one of the reasons for the inadequate strength estimate by DSM. In this study, the DSM-local buckling strength equation is evaluated using the results from FEA for two values of web height to flange with ratio (*h*/*b*). The conclusion of this study is given below.

1. The normalised local buckling strength (P_{ul}/P_y) is a function of web height to flange width ratio (*h/b*) in addition to nondimensional slenderness. A similar observation was made by Kumar and Kalyanaraman [8] for lipped channel compression members.
2. As *h/b* increases, the strength obtained from DSM was found to be conservative up to 40%.

Hence, a detailed experimental and numerical study needs to be planned to suggest a necessary modification to DSM local buckling strength equations for CFS stiffened channel compression members.

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