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On the Accuracy of the Current Direct Strength Method (DSM) Design Curve for Columns Failing in Global Modes

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Abstract
This work presents and discusses the results of an in-depth and extensive numerical investigation aimed at assessing how accurately is the currently codified DSM design/strength curve able to predict the ultimate strength of cold-formed steel columns failing in global modes, namely flexural and flexural-torsional ones. This investigation deals with fixed-ended columns exhibiting a wide variety of cross-section shapes: plain channels, lipped channels, web-stiffened lipped channels, web/flange-stiffened lipped channels, lipped zed-sections, hat-sections, rack-sections and I-sections (formed by two back-to-back plain channels). The first part of the paper, which is devoted exclusively to plain channel columns, begins with a parametric study intended to gather failure loads of columns with continuously varying geometries and yield stresses such that (i) buckling occurs in either major-axis flexural-torsional or minor-axis flexural modes and (ii) a wide slenderness range is covered. These failure load data are then used to assess the quality of their estimates provided by the current global DSM strength curve and to propose two possible modifications that improve that quality. In the second part of the paper, the above two modified DSM-based global design curves, together with the current one, are used to estimate the numerical failure loads of a fairly large number of columns exhibiting the remaining six cross-section shapes: unstiffened, web-stiffened and web/flange-stiffened lipped channels, lipped zed-sections, hat-sections, rack-sections and I-sections. The outcome of this extensive parametric study is that the failure load predictions provided by either of the two proposed/modified DSM global design curves (i) exhibit a very high quality and (ii) clearly outperform those yielded by the currently codified strength curve, for the whole set of columns considered in this work. Moreover, the advantages and disadvantages of the two proposed/modified DSM global design curves are also discussed in some detail.

1. Introduction
Cold-formed steel members invariably display very slender thin-walled open cross-sections, a feature making them highly susceptible to several instability phenomena, namely local, distortional and global (flexural or flexural-torsional) buckling – Figs. 1(a)-(d), concerning rack-section columns, show buckled cross-sections associated with local, distortional, flexural-torsional and flexural buckling. Therefore, their overall structural response and ultimate strength are affected, to a larger or smaller extent, by such instability phenomena – this explains why they must be incorporated in cold-formed steel specifications (they can only be ignored in the design of stocky members exhibiting "compact" cross-sections).

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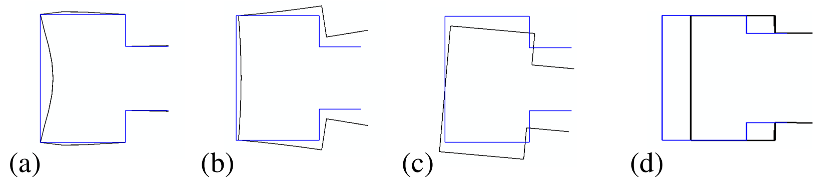

Figure 1: Rack column buckled cross-sections concerning (a) local, (b) distortional, (c) flexural-torsional and (d) flexural modes

Nowadays, it can be argued that the Direct Strength Method (DSM – *e.g.*, Schafer 2008 or Camotim *et al.* 2016), proposed by Schafer & Peköz (1998) based on an original idea of Hancock *et al.* (1994), is the most rational approach to the design of cold-formed steel columns and beams, which explains its fast growing and widespread popularity around the world – moreover, its domain of application will soon be extended to cover also beam-columns (Torabian & Schafer 2017). The currently codified design/strength curves are able to handle local, distortional, global and local-global interactive failures. Concerning local failures, DSM provided an efficient (and often very advantageous) alternative to the traditional "Effective Width Method", originally proposed by Von Kármán and later calibrated by Winter, which is included (in one form or another) in the current versions of nearly all codes (worldwide) dealing with steel structures – in the specific context of cold-formed steel structures, this method can still be found, for example, in the current AISI Specification (AISI 2016). Concerning distortional failures, DSM provided the first approach for the design of column and beams that can be termed "rational", in the sense that it incorporates the mechanics underlying the phenomenon under consideration – its codification took place almost simultaneously in North America (AISI 2005) and Australia/New Zealand (AS/NZS 2005). At this point, it is worth noting that the popularity of the DSM in predicting local and distortional failures loads and moments would never have happened without the universal dissemination and availability of user-friendly and easy-to-use software enabling the straightforward calculation of critical local and distortional buckling loads (columns) and moments (beams), a key requisite for the DSM application – software based on the Finite Strip Method (FSM – *e.g.*, Papangelis & Hancock 1995), the Constrained Finite Strip Method (cFSM – *e.g.*, Li *et al.* 2014) or Generalized Beam Theory (GBT – *e.g.*, Bebiano *et al.* 2017). This made it possible for Schafer (2002, 2008) (i) to collect a fairly large number of experimental local and distortional failure loads concerning cold-formed steel columns with various cross-section shapes, (ii) to determine the corresponding plastic and critical (local or distortional) buckling loads, (iii) to develop appropriate "Winter-type" strength curves/expressions to predict the above failure load data and (iv) to propose their inclusion in the codified DSM.

The genesis of the currently codified DSM column global strength/design curve was entirely different from that of their local and distortional counterparts, addressed in the previous paragraph. Indeed, this design curve, which combines Johnson parabola (Ziemian 2010) with the (lowered) Euler curve, was already included in the then existing cold-formed steel design manual (AISI 1996). Its inclusion in this specification was due to the work of Peköz & Sümer (1992), who showed that the above strength curve, codified in the context of hot-rolled steel members used in buildings (AISC 1986), provided better quality estimates than that adopted by the cold-formed steel community (AISI 1986). These authors based their findings on 214 test results concerning concentrically loaded cold-formed steel columns with various cross-sections (lipped channels, hat-section, box-sections and I-sections formed by back-to-back plain channels) and exhibiting low-to-moderate global slenderness values ($\lambda_G \leq 1.75$, where $\lambda_G=(f_y/f_{crG})^{0.5}$).

Recently, in the context of numerical investigations dealing with cold-formed steel fixed-ended columns undergoing local-distortional-global or distortional-global interaction, Dinis & Camotim (2016) and Martins *et al.* (2017) found that the current DSM column global strength curve underestimates, often by large amounts, the load-carrying capacity of several cold-formed steel columns failing in flexural-torsional modes, thus leading to uneconomic designs. Moreover, it was also found that the above strength curve estimates accurately failure loads of columns collapsing in flexural modes – this is not at all surprising if one recalls that this curve was developed in the context of hot-rolled steel columns, which exhibit almost exclusively doubly symmetric cross-sections. Obviously, the failure load estimation of columns affected by coupling phenomena involving global buckling, namely local-global, distortional-global or local-distortional-global interaction, is strongly influenced by the quality of the DSM global strength curve predictions. Thus, the objective of this work, which was prompted by the findings of the aforementioned numerical studies, is to present and discuss the results of an in-depth investigation aimed at assessing how accurately the currently codified DSM design curve is able to predict the failure loads of cold-formed steel columns collapsing in global modes, namely flexural and flexural-torsional ones. Fixed-ended columns exhibiting a wide variety of cross-section shapes (plain channels, lipped channels, web-stiffened lipped channels, web/flange-stiffened lipped channels, lipped zed-sections, hat-sections, rack-sections and I-sections formed by two back-to-back plain channels) are considered.

1.1 Organization of the paper

The first part of the paper is devoted exclusively to plain channel (U) columns and starts with a parametric study intended to gather failure loads of columns with continuously varying geometries and yield stresses such that (i) buckling occurs in either major-axis flexural-torsional or minor-axis flexural modes and (ii) a wide slenderness range is covered. This cross-section shape is particularly well suited to investigate how the presence of torsion influences the column critical buckling (due to the non-coincidence of the cross-section shear center and centroid). Indeed, by merely varying the flange width continuously it is possible to obtain a fairly smooth transition between columns buckling in flexural and flexural-torsional modes.

Initially, the global buckling behavior of columns sharing the same web width and wall thickness, and exhibiting five flange width (or flange-to-width ratio) values, is investigated by means of Generalized Beam Theory (GBT) analyses – in particular, the columns analyzed are divided into two sets, according to the nature of their critical buckling modes: either major-axis flexural-torsional (F_MT) or minor-axis flexural (F_m). Then, a parametric study, aimed at gathering representative sets of U column flexural-torsional and flexural failure loads, is performed – the columns analyzed exhibit the previously selected geometries and various yield stresses, in order to cover a wide slenderness range. Moreover, they contain critical-mode global initial imperfections with $L/1000$ amplitude (value often prescribed in specifications). The numerical failure loads are determined by means of ABAQUS shell finite element analyses (SFEA), based on an elastic-perfectly plastic model profusely employed by the authors in past studies: (i) columns discretized into fine meshes of 4-node isoparametric elements (length-to-width ratio roughly equal to 1), (ii) fixed-ended conditions modeled by attaching rigid plates to the column end sections and (iii) steel material behavior described by Prandtl-Reuss's model. Finally, the gathered failure loads are used (i) to assess the merits of the current DSM column global strength curve, which includes performing an imperfection-sensitivity study, and (ii) to propose modifications that improve the failure load prediction quality for U columns failing in F_MT and in F_m modes, respectively.

The second part of the paper deals with fixed-ended columns exhibiting other cross-section shapes: unstiffened (C), web-stiffened (WSC) and web/flange-stiffened (WFSC) lipped channels, zed-sections (Z), hat-sections (H), rack-sections (R) and I-sections (I) formed by back-to-back plain channels. An additional and more extensive parametric study is performed, now to obtain failure loads of C-H-Z (same cross-section dimensions), R, WSC, WFSC and I columns with various lengths and yield stresses (to cover wide slenderness ranges), and containing critical-mode (global) initial geometrical imperfections with L/1000 amplitude – a total of 1280 columns are analyzed (including the plain channel ones). Once again, the columns are divided in two groups, according to their buckling/failure mode nature (F_MT or F_m).

The two proposed/modified DSM-based column global design curves, which were developed exclusively in the context of U columns, are then employed to predict all the column global failure loads obtained in this work – for comparison purposes, the predictions of the current design curve are also calculated. After comparing and discussing the above predictions, for each set of columns sharing the same cross-section shape, the paper addresses the quality assessment of the whole set of available numerical failure load estimates – it is shown that the predictions provided by either of the two proposed/modified DSM-based global design curves (i) exhibit a very high quality and (ii) clearly outperform those yielded by the current strength curve. Finally, the paper closes with a discussion on the advantages and disadvantages of the two proposed/modified DSM global design curves, as well as on the possible needs of further validation.

2. Plain Channel (U) Columns

2.1 Buckling Behavior – Column Geometry Selection

The signature curves shown in Fig. 2(a), providing the variation of the critical buckling stress f_{cr} with the length L (in logarithmic scale), were obtained with the code GBTUL (Bebiano *et al.* 2017) and concern steel (E=210 GPa, ν=0.3) U columns with b_w=100 mm, t=20 mm and five flange widths, corresponding to b_w/b_f=5; 2.5; 1.67; 1.25; 1 (curves U_1 to U_5) – the GBT analyses included 7 deformation modes: 4 global (**1**-**4**) and 3 local (**5**-**7**). As for Fig. 2(b), it displays the associated GBT modal participation diagrams, providing the contributions of each deformation mode (p_i – modes **2**-**7** shown in Fig. 2(c)) to the column critical buckling modes. Finally, Fig. 2(c) also depicts the critical buckling mode in-plane shapes of U_3 columns with lengths L=100, 500, 900 cm. These buckling results prompt the following remarks:

(i) Each f_{cr} vs. L curve displays two distinct zones, one associated with local buckling in modes with several half-waves (p_5 is dominant) and the other with single half-wave global buckling – naturally, the length corresponding to the transition between local and global buckling increases with the flange width: variation from L_T=80 cm to L_T=550 cm as b_f increases from 20 to 100 mm.

(ii) However, depending on the b_f value, the curve (global) descending branch may be associated with different buckling mode natures: either F_MT (modes **2**+**4**) or F_m (mode **3** – F_m) – note that, for b_f=20 mm, the critical buckling mode combines modes **3** and **5** (p_5 gradually fades as the column length increases, until it vanishes at L≈150 cm). Moreover, note also that the intermediate (L=500 cm) and longer (L=900 cm) U_3 columns buckle in F_MT and F_m modes, respectively – see Fig. 2(c).

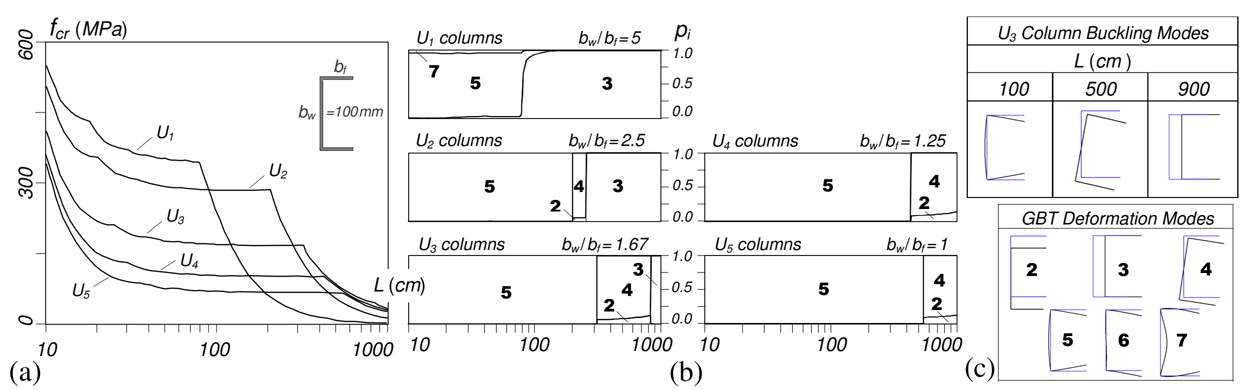

Figure 2: (a) f_{cr} vs. L signature curves and (b) GBT modal participation diagrams of columns with b_w=100 mm+b_w/b_f=5; 2.5; 1.67; 1.25; 1, and (c) 6 GBT deformations mode in-plane shapes and critical buckling modes of 3 U_3 columns (b_w/b_f=1.67)

Table 1: Selected column geometries: b_w, b_f, t, I_I, I_{II}, L, and f_{cr} values (mm and MPa)

Column	b_w	b_f	t	b_w/b_f	I_I ($\times 10^4$)	I_{II} ($\times 10^4$)	I_I/I_{II}	L_1	f_{cr}	L_2	f_{cr}	L_3	f_{cr}	L_4	f_{cr}	L_5	f_{cr}	L_6	f_{cr}
U_1	100	20	2.0	5	36.67	0.84	43.41	1500	111 (F_m)	2100	57 (F_m)	2700	34 (F_m)	3300	23 (F_m)	3900	17 (F_m)	4500	12 (F_m)
U_2		40		2.5	56.67	5.70	9.95	2100	273 (F_MT)	3000	145 (F_m)	3800	91 (F_m)	4600	62 (F_m)	5500	43 (F_m)	6300	33 (F_m)
U_3		60		1.67	76.68	17.02	4.50	3200	166 (F_MT)	4500	97 (F_MT)	5500	73 (F_MT)	5900	67 (F_MT)	6300	62 (F_MT)	8700	42 (F_m)
U_4		80		1.25	96.68	36.77	2.63	4400	100 (F_MT)	5500	70 (F_MT)	6500	54 (F_MT)	7500	45 (F_MT)	8500	38 (F_MT)	9000	35 (F_MT)
U_5		100		1	116.68	66.67	1.75	5500	67 (F_MT)	6000	58 (F_MT)	6500	51 (F_MT)	7500	41 (F_MT)	8500	34 (F_MT)	9500	29 (F_MT)

(iii) In order to assess the U column ultimate strength behavior, six intermediate-to-large lengths are selected for each U_1 to U_5 column set, by choosing approximately equally spaced values in the $L_T<L\leq\min(3L_T;\,950\,\text{cm})$[4] length range. The geometries (b_w, b_f, t, L) of the 30 columns analyzed in this work are given in Table 1, together with the corresponding f_{cr} values and global buckling mode natures – the table shaded cells correspond to the 12 columns found to buckle in F_m modes.

2.2 Failure Load Data

In order to assess the merits (accuracy and safety) of the current DSM global strength curve in predicting the failure loads of U columns buckling and failing in F_MT and in F_m modes, a parametric study is first carried out, in order to acquire significant failure load data. This study involves fixed-ended columns with the cross-section dimensions and lengths given in Table 1 – rounded corners and the residual stress effects are disregard, since they are known to practically cancel each other (*e.g.*, Ellobody & Young 2005). For each geometry, the columns analyzed have yield stresses f_y (elastic-perfectly plastic material model) selected to cover wide critical slenderness ranges – the values considered are 75, 150, 300, 450, 600 MPa (for the sake of slenderness completion, some of these f_y values are unrealistically low). A total of 120 columns are analyzed (90 buckle in F_MT modes and 30 in F_m modes), all containing critical-mode initial geometrical imperfections with amplitude $L/1000$ – value in line with the measurements reported for cold-formed steel columns (*e.g.*, Popovic *et al.* 1999). The ultimate strengths f_u obtained are presented, in tabular form, in Annex A (U columns). Figs. 3(a_1)-(a_2), concerning $U_4(L_1)$ and $U_1(L_6)$ columns with various yield stresses, illustrate column equilibrium paths associated with buckling in F_MT and F_m modes (their determination is necessary to obtain the numerical failure loads presented in Annex A) – note the pronounced difference in post-critical strength reserve exhibited by the two equilibrium path types. As for Figs. 3(b_1)-(b_2), they display the failure modes (deformed configurations at collapse) of $U_4(L_1)$ and $U_1(L_6)$ columns with $f_y/f_{cr}\approx 1.5$ – the features of the two column failure modes under consideration are clearly shown: while the former exhibits plastic strains at the mid-span and end cross-section top and bottom web-flange corner regions, the latter involve the full yielding of those same cross-sections. Moreover, in order to assess how the initial imperfection amplitude influences the column ultimate strength, a limited imperfection-sensitivity study is performed: comparison between the failure loads of typical columns buckling in F_m and F_MT modes (columns U_1 and U_4, respectively), exhibiting the above 5 yield stresses and containing critical-mode initial imperfections with amplitudes $L/2000$, $L/1000$ and $L/500$.

[4] The first and second upper limits were established to ensure, respectively, that (i) the column critical buckling stress is not excessively low and that (ii) the column length is not unrealistically high.

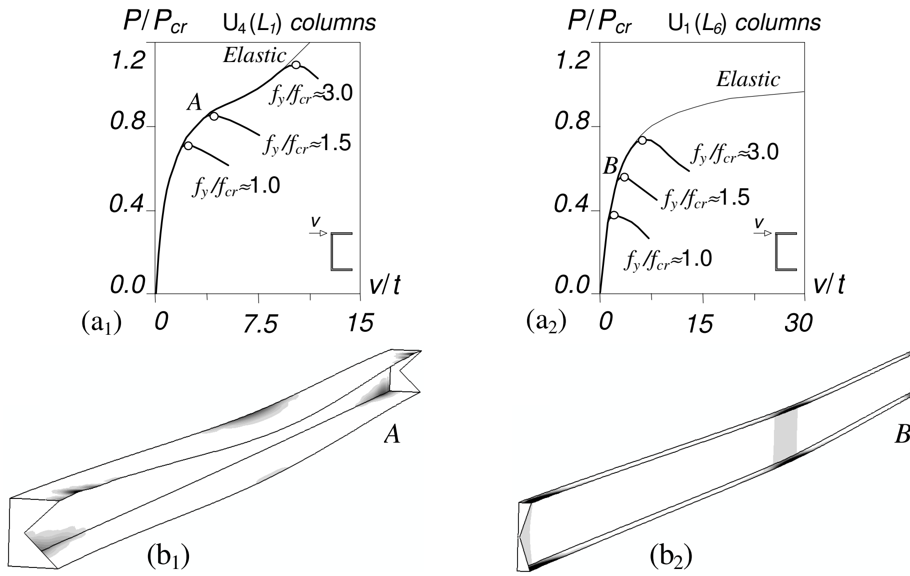

Figure 3: Column (a) elastic-plastic P/P_{cr} *vs.* v/t equilibrium paths ($f_y/f_{cr}\approx 1.0, 1.5, 3.0, \infty$) and (b) failure modes and plastic strains at collapse of the ($_1$) U_4 (L_1) and ($_2$) U_1 (L_6) columns with $f_y/f_{cr}\approx 1.5$

2.3 Predictions of the Current DSM Strength Curve

The current DSM column global strength/design curve, providing nominal strengths f_{nG}, is defined by

$$f_{nG}=\begin{cases} f_y\left(0.658^{\lambda_G^2}\right) & \text{if} \quad \lambda_G\le 1.5 \\ f_y\left(\dfrac{0.877}{\lambda_G^2}\right) & \text{if} \quad \lambda_G>1.5 \end{cases} \qquad \text{with} \qquad \lambda_G=\sqrt{\frac{f_y}{f_{crG}}} \quad , \quad (1)$$

where f_{crG} and $\lambda_G=(f_y/f_{crG})^{0.5}$ are the global critical buckling stress and slenderness. The nominal ultimate strengths (f_{nG}) concerning all the U columns analyzed in this wok, as well as the corresponding numerical-to-predicted strength ratios (f_u/f_{nG}) and relevant quantities involved in their calculation (*e.g.*, λ_G), are given in Tables A1 and A2, included in Annex A. Figs. 4(a_1)-(a_2) compare the DSM global design curve with the U column f_u/f_y ratios obtained in this work, grouped according to the critical buckling mode nature: F_MT (Fig. 4(a_1)) or F_m (Fig. 4(a_2)). As for Figs. 4(b_1)-(b_2), they plot the f_u/f_{nG} ratios against λ_G for the two U column sets – the associated averages, standard deviations and maximum/minimum values are also included in those figures. The observation of these results prompts the following remarks:

(i) The f_u/f_y values concerning the columns that buckle in F_MT modes are well aligned along the DSM global strength curve (marginally above and with small vertical dispersion) in the low-to-moderate slenderness range ($\lambda_G\le 1.5$) – f_u/f_{nG} averages, standard deviation and maximum/minimum values equal to 1.07/0.03/1.12/1.02. On the other hand, in the moderate and high slenderness range ($\lambda_G>1.5$) the f_u/f_y values of the columns buckling in F_MT modes lie well above that curve and are clearly more scattered (the vertical dispersion increases with λ_G) – the ultimate strength underestimation by the DSM design curve is often quite high (f_u/f_{nG} larger than 1.5 for 41 of the 90 columns analyzed). Naturally, this is reflected in the DSM prediction quality: f_u/f_{nG} average, standard deviation and maximum/minimum values equal to 1.86/0.54/3.14/1.12.

(ii) The excessive underestimation mentioned in the previous item stems from the following facts: (ii_1) in the moderate to large slenderness range ($\lambda_G>1.5$), the DSM global design curve is taken from a strength developed in the context of columns collapsing predominantly in flexural modes (most of them doubly symmetric), and (ii$_2$) restraining the end cross-section warping in columns buckling in F_MT modes leads to a considerable post-critical strength increase, which becomes much larger than that exhibited by columns buckling in F_m modes[5] – *e.g.*, see the work of Dinis & Camotim (2013), carried out in the context of thin-walled equal-leg angle and cruciform columns.

(iii) The above underestimation was already perceptible in the results reported by Peköz & Sümer (1992). Indeed, the f_u/f_y values of the five most slender specimens addressed in Figure 2 of this reference, concerning plain lipped channel and hat-section columns with λ_G>1.6, are visibly underestimated by the currently codified DSM global strength curve.

(iv) On the other hand, the f_u/f_y values of columns buckling in F_m modes (iv$_1$) lie a bit below the DSM global design curve for $\lambda_G \leq 2.0$, and (iv$_2$) are marginally above that curve for λ_G>2.0 – these features are reflected in the quality (statistical indicators) of the f_u/f_{nG} predictions in those two slenderness ranges: 0.91/0.06/1.01/0.80 ($\lambda_G \leq 2.0$) and 1.05/0.04/1.10/0.91 (λ_G>2.0). The overestimation in the $\lambda_G \leq 2.0$ slenderness range stems from the fact that Peköz & Sümer (1992) assessed the strength curve through its comparison with the ultimate strengths of columns buckling/failing in both F_MT and F_m modes – including the former had the net effect of "pushing" the curve slightly upwards.

(v) In view of what was mentioned in the previous items, it seems logical to expect that it is possible to improve the current DSM column global strength curve, so that the quality (statistical indicators) of its ultimate strength predictions becomes higher, particularly in the moderate-to-large slenderness range – the search for such improvements will be addressed in the next subsection.

Next, the influence of the initial geometrical imperfection amplitude on the U column ultimate strength is investigated – U_1 and U_4 columns, representing typical columns that buckle/fail in F_MT and F_m modes, containing critical-mode initial geometrical imperfections with amplitudes L/2000, L/1000 and L/500 are

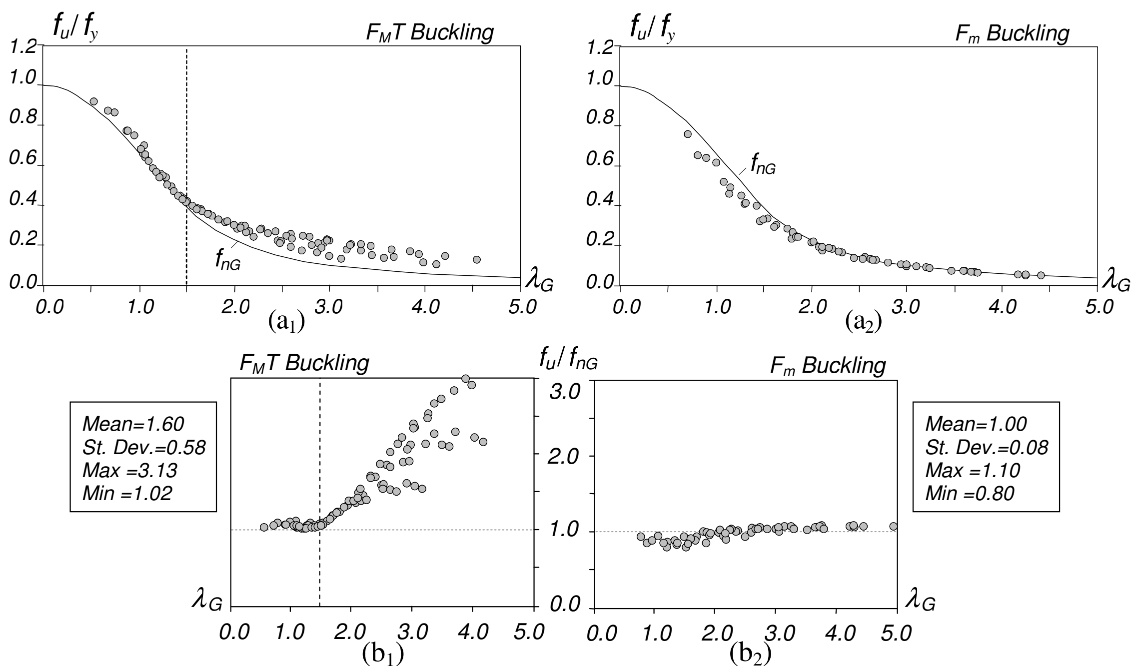

Figure 4: Plots of (a) f_u/f_y and (b) f_u/f_{nG} against λ_G for columns bucking/failing in ($_1$) F_MT or ($_2$) F_m modes

[5] At this stage, it is worth mentioning that, for certain technical-scientific communities dealing with steel structures, "global buckling" is viewed as a synonym of "flexural buckling" – most likely, because doubly symmetric columns are always "in the back of their minds".

analyzed. Figs. 5(a)-(b) plot the f_u/f_y and f_u/f_{nG} values obtained in this imperfection-sensitivity study against the global slenderness λ_G. The observation of these results leads to the following comments:

(i) The influence of the initial imperfection amplitude on the column failure load is in accordance with the current knowledge: more relevant in the low-to-moderate slenderness range. However, this influence is clearly more pronounced in the columns failing in F_m modes – as the initial imperfection amplitude increases, the minimum f_u/f_{nG} values are 0.92/0.80/0.65, for columns failing in F_m modes, and 1.10/1.03/0.92, for columns failing in F_MT modes.

(ii) In the moderate and high slenderness ranges, the initial imperfection amplitude has a minute influence on the column failure load, particularly in the columns failing F_MT modes – it is quite difficult to distinguish between the three sets of f_u/f_{nG} values.

(iii) The f_u/f_y values of the columns failing in F_MT modes and containing $L/1000$ initial imperfections follow quite well the current DSM global strength curve for $\lambda_G \leq 1.5$, which means that this curve is perfectly adequate for these columns within this slenderness range.

(iv) Conversely, the f_u/f_y values concerning the columns failing in F_m modes and containing $L/1000$ initial imperfections are visibly below the current DSM global strength curve for $\lambda_G \leq 2.0$, which means that the failure load predictions for these columns can be (slightly) improved inside this slenderness range.

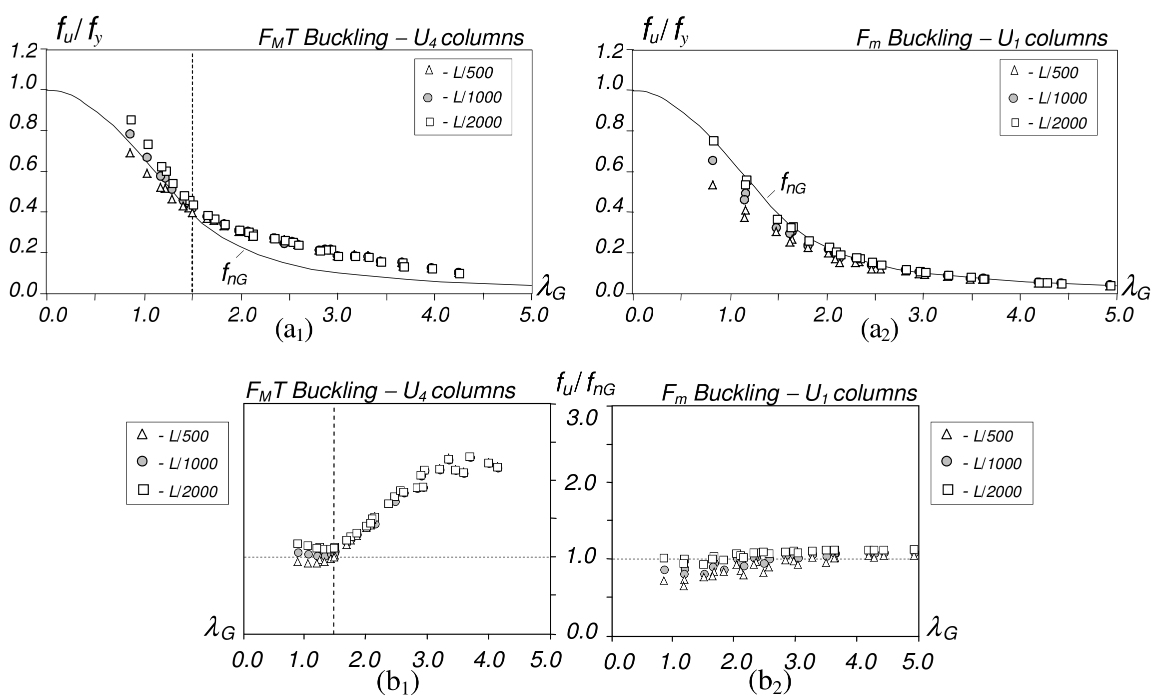

Figure 5: Imperfection-sensitivity study. Plots of (a) f_u/f_y and (b) f_u/f_{nG} against λ_G for columns failing in (1) F_MT or (2) F_m modes

2.4 DSM Design Considerations

As shown before, the U column global failure loads, visibly affected by the critical buckling mode nature, are not always adequately (safely and accurately) predicted by the current DSM strength curve. Indeed, the failure loads of columns buckling/failing in F_MT modes are underestimated in the moderate and high slenderness ranges ($\lambda_G > 1.5$). On the other hand, the failure loads of columns buckling/failing in F_m modes are slightly overestimated for $\lambda_G \leq 2.0$. The next subsections address possible improvements of the current DSM curve in order to overcome the shortcomings just identified.

2.4.1 Flexural-torsional strength

The first step towards improving, as much as possible, the ultimate strength prediction of the U columns buckling/failing in F_MT modes (columns U_2-U_5 in this study) was to group them according to the cross-section geometry. Note that the distance between the centroid and shear center increases continuously as one travels from the U_2 to the U_5 columns, which means that torsion plays a more important role in the column buckling and failure behaviors. Moreover, note also that the ratio $\beta=I_I/I_{II}$, relating the major (I_I) and minor (I_{II}) moments of inertia, decreases continuously as one travels from column U_2 to column U_5. Combining the two above assertions, it may be concluded that the role played by torsion in the column buckling and failure behaviors becomes more relevant as the inertia ratio β decreases[6].

Figs. 6(a)-(d) plot the f_u/f_y values against λ_{FT} (flexural-torsional slenderness) for columns U_2, U_3, U_4 and U_5, respectively, and compare them with the current DSM column global design curve. First of all, it is confirmed that, for $\lambda_{FT}\leq1.5$, the four sets of values are almost perfectly aligned along the current DSM curve – of course, this statement applies only to columns U_3, U_4 and U_5, since there is only one column U_2 that fails in an F_MT mode and has $\lambda_{FT}\leq1.5$. Then, it is observed that, for $\lambda_{FT}>1.5$, the f_u/f_y values concerning each of those four column sets are quite well aligned along "Euler-type" curves (fairly small vertical dispersion) that lie above the current DSM one. Moreover, it is also noted that the distance between the f_u/f_y values and the current DSM curve grows as β decreases, *i.e.*, as one travels from the U_2 to the U_5 columns – in the U_2 columns (β=9.95), this distance is barely perceptible.

On the basis of the remarks made in the previous paragraph and with the objective of improving the estimation quality of the column flexural-torsional ultimate (f_{nFT}), it was decided to propose a modification of the current DSM column global design curve for $\lambda_{FT}>1.5$ (moderate and high slenderness ranges) – of course, this means that the Johnson parabola is kept in the low-to-moderate slenderness range ($\lambda_{FT}\leq1.5$).

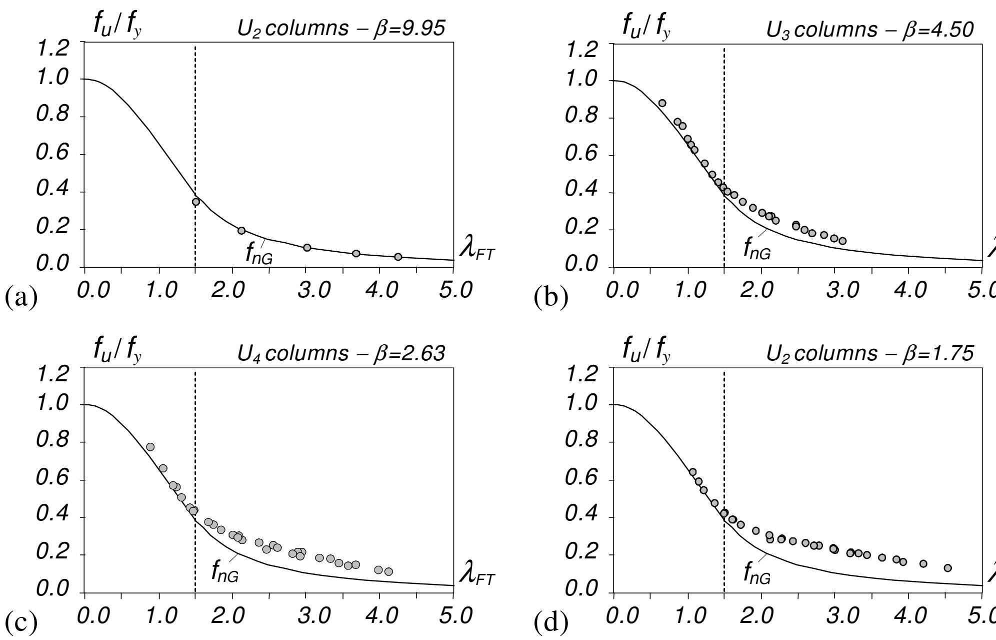

Figure 6: Comparison between the current DSM design curve (f_{nG}) and the f_u/f_y values concerning the U columns failing in F_MT modes and associated with β values equal to (a) 9.95 (U_2), (b) 4.50 (U_3), (c) 2.63 (U_4) and (d) 1.75 (U_5)

[6] Recall that this ratio plays a pivotal role in the lateral-torsional buckling behavior of beams subjected to major-axis bending: a larger β value means a higher susceptibility to lateral-torsional buckling.

For λ_{FT}>1.5, the curve becomes β-dependent and is defined by a general "Euler-type" expression similar to that appearing in the current DSM global strength curve (see Eq. (1)) – then, the whole curve reads

$$f_{nFT} = \begin{cases} f_y \left(0.658^{\lambda_{FT}^2}\right) & if \quad \lambda_{FT} \leq 1.5 \\ f_y \left(\dfrac{a}{\lambda_{FT}^b}\right) & if \quad \lambda_{FT} > 1.5 \end{cases} \qquad \text{with} \qquad \lambda_{FT} = \sqrt{\frac{f_y}{f_{crFT}}} \, , \tag{2}$$

where the β-dependence is felt through parameters a and b, which are functions of β given by

$$a = 0.39 \times 1.5^b \tag{3}$$

$$b = \begin{cases} 0.10\ \beta + 0.85 & if \quad \beta < 11.5 \\ 2 & if \quad \beta \geq 11.5 \end{cases} \, . \tag{4}$$

These expressions for a and b were obtained by means of a "trial-and-error curve-fitting procedure" based on the available ultimate strength data concerning U columns buckling/failing in F_MT modes. Note that Eq. (1) is recovered for $\beta \geq 11.5$, value beyond which the role played by torsion becomes completely negligible – one has then a=0.877 and b=2.0.

Figs. 7(a)-(d) plot again the f_u/f_y values of columns U_2, U_3, U_4, U_5 against λ_{FT}, and compare them with the modified f_{nFT} strength curves obtained from Eqs. (2)-(4) for β=9.95;4.50;2.63;1.75 (F_MT curves). On the other hand, Fig. 8 plots the f_u/f_{nFT} values against λ_{FT} for all the U columns buckling/failing in F_MT modes – their average, standard deviations, maximum/minimum values are also given in the figure. From the observation of the results presented in Figs. 7(a)-(d) and 8 the following conclusions can be drawn:

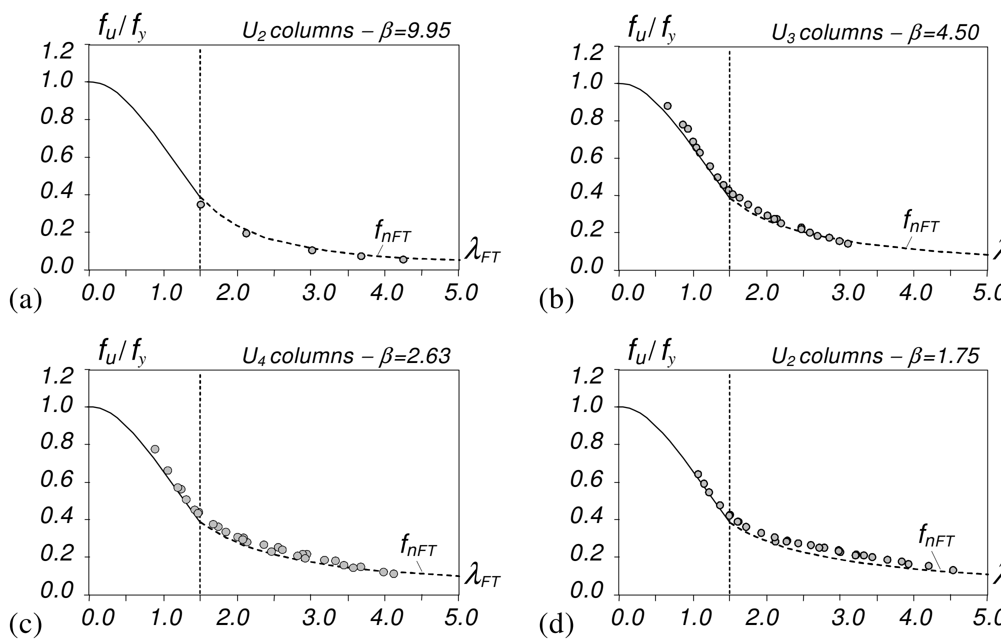

Figure 7: Comparison between the modified DSM-bases strength curves (f_{nFT}) and the f_u/f_y values concerning U columns failing in F_MT modes and associated with β values equal to (a) 9.95 (U_2), (b) 4.50 (U_3), (c) 2.63 (U_4) and (d) 1.75 (U_5)

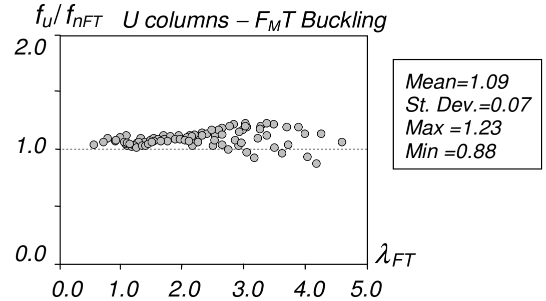

Figure 8: Plots of f_u/f_{nFT} vs. λ_{FT} for the whole set of U columns buckling/failing in F_MT modes

(i) Figs. 7(a)-(d) clearly show that the modified DSM strength curves are able to capture adequately the variation of the U column flexural-torsional ultimate strength with the cross-section geometry (flange width) – the feature responsible for the ultimate strength vertical dispersion observed in Fig. 4(a_1).

(ii) The strength curves depicted in Figs. 7(a)-(d) provide quite accurate and almost always safe estimates of the numerical f_u/f_y values – there are only a few overestimations, all occurring for fairly slender columns (λ_{FT}>3.0). This fact is reflected in the quality of the f_u/f_{nFT} statistical indicators: average, standard deviation and maximum/minimum values equal to 1.09/0.07/1.23/0.88 – recall that those associated with the current DSM curve (f_u/f_{nG}) read 1.60/0.58/3.13/1.02.

2.4.2 Flexural Strength

In order to improve the ultimate strength prediction quality concerning U columns buckling/failing in F_m modes, the failure loads of all the U_1 columns and part of the U_2 and U_3 columns analyzed in this work are considered. Then, a single "Winter-type" strength curve (f_{nF}) to estimate all of them as efficiently (safely and accurately) as possible is sought. Recall that it was shown earlier (see Section 2.3) that all the unsafe ultimate strength predictions provided by the current DSM design curve concern columns in the low-to-moderate slenderness range ($\lambda_G \leq 2.0$) – see Figs. 4(a_2)+(b_2). As in the case of the columns buckling/failing in F_MT modes, the above search was carried out by means of a "trial-and-error curve fitting procedure" that led to[7]

$$f_{nF}=\begin{cases} f_y & \text{if} \quad \lambda_F \leq 0.422 \\ f_y\left[1-0.24\left(\dfrac{1}{\lambda_F^2+0.42}\right)\right]\left(\dfrac{1}{\lambda_F^2+0.42}\right) & \text{if} \quad \lambda_F > 0.422 \end{cases} \qquad \text{with} \qquad \lambda_F=\sqrt{\frac{f_y}{f_{crF}}}\ , \tag{5}$$

where λ_F is the minor-axis flexural slenderness. Fig. 9(a) makes it possible to compare the f_u/f_y values concerning the U columns that buckle and fail in F_m modes with the current (solid – f_{nG}) and proposed (dashed – f_{nF}) DSM strength curves. One readily notices that the two strength curves only differ for $\lambda_F \leq 2.0$ (*i.e.*, they practically coincide outside this slenderness range). Moreover, it is also observed that the few f_u/f_y values concerning columns with $\lambda_F \leq 2.0$ are better predicted by the proposed ("Winter-type") design curve. The comparison between Figs. 4(b_2) and 9(b), which plot the f_u/f_{nG} and f_u/f_{nF} values against λ_G and λ_F, respectively, for all the U columns analyzed that buckle and fail in F_m modes, confirms the above assertion. Indeed, the corresponding statistical indicators, also given in these figures, quantify it: the averages, standard deviations and maximum/minimum values read 1.00/0.08/1.10/0.80 (f_u/f_{nG}) and 1.00/0.04/1.10/0.91 (f_u/f_{nF}) – the latter are only marginally better (except for the minimum value, which improves considerably) because the number of columns such that $\lambda_F \leq 2.0$ (or $\lambda_G \leq 2.0$) is relatively small.

[7] It should be pointed out that this curve practically coincides with the Eurocode 3 (CEN 2005) *curve c* if the coefficient 0.42 is replaced by 0.60.

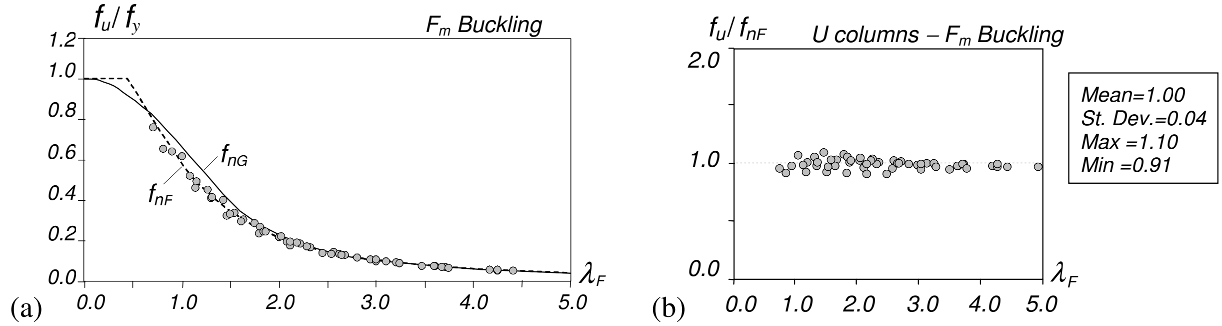

Figure 9: Plots of (a) f_u/f_y and (b) f_u/f_{nF} against λ_F for the whole set of U columns that fail in F_m modes

3. Columns with Other Cross-Section Shapes

The objective of this section is to assess the merits of the two DSM-based column global strength curves developed and proposed in the previous section, exclusively in the context of U columns buckling and failing in F_MT or F_m modes, in predicting failure loads of cold-formed steel columns with various other cross-sections shapes, namely those depicted in Fig. 10: unstiffened lipped channels (C), hat-sections (H), lipped zed-sections (Z), rack-sections (R), web-stiffened lipped channels (WSC), web-flange-stiffened lipped channels (WFSC) and I-sections formed by back-to-back plain channels (I). After obtaining a fairly extensive failure load data concerning columns with the cross-section shapes just mentioned, the paper addresses their prediction by means of the (i) currently codified DSM global strength curve, applicable to columns failing in both F_MT or F_m modes, and (ii) the two DSM-based developed/proposed in Sections 2.4.1 (columns failing in F_MT modes) and 2.4.2 (columns failing in F_m modes).

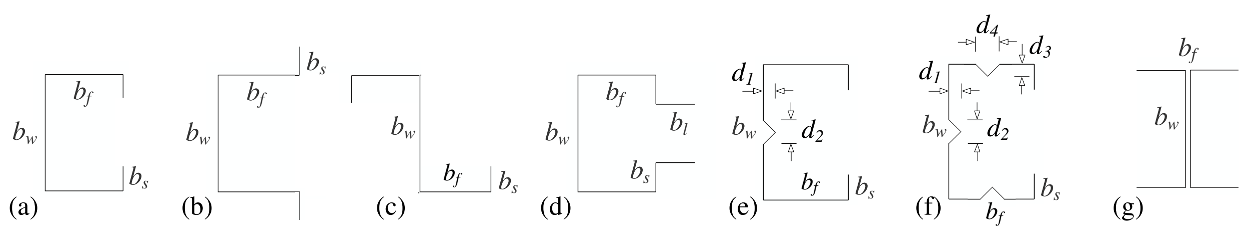

Figure 10: Cross-section shapes of the columns analyzed: (a) C, (b), H, (c) Z, (d) R, (e) WSC, (f) WFSC, (g) I (back-to-back Us)

3.1 Failure Load Data

This section deals with assembling numerical failure load data concerning (i) C, H and Z column trios sharing the same cross-section dimensions, such that $1.09 \leq b_w/b_f \leq 2.00$, (ii) R columns, such that $1.36 \leq b_w/b_f \leq 1.91$, (iii) WSC and WFSC columns, such that $1.31 \leq b_w/b_f \leq 1.60$, and (iv) I columns, such that $0.83 \leq b_w/b_f \leq 2.50$ – see Fig. 10. It is worth noting that (i) the WCS and WFSC column "v-shaped" intermediate stiffeners are such that $d_1=d_3=10$ mm and $d_2=d_4=20$ mm, and (ii) I column web thickness is equal to $2t$. The fixed-ended columns have lengths (i) selected to ensure buckling in F_MT or F_m modes, (ii) more or less equally spaced in the $L_T<L\leq \min\{3L_T; 1000\text{cm}\}$ range – all the cross-section dimensions and lengths are given in Tables 2 (columns buckling in F_MT modes) and 3 (columns buckling in F_m modes). A total of 1130 columns are analyzed, all containing L/1000 amplitude critical-mode initial geometrical imperfections and covering wide slenderness ranges (f_y=75,150,300,450,600MPa) – the parametric study involves 780 columns buckling/failing in F_MT modes (270 C, 270 H, 80 R, 80 WSC and 80 WFSC columns) and 350 columns buckling/failing in F_m modes (270 Z and 80 I columns). Their critical buckling stresses f_{cr} and ultimate strengths f_u (all obtained in this work) are given, in tabular form, in Annexes B to H – each Annex presents results concerning one cross-section shape.

Table 2: Geometries of the selected columns failing in F_MT modes: b_w, b_f, b_s, b_l, t, I_I, I_{II}, and L values (mm and mm^4)

Column	b_w	b_f	b_s	b_l	T	b_w/b_f	I_I ($\times 10^4$)	I_{II} ($\times 10^4$)	$\beta = I_I/I_{II}$	L_1	L_2	L_3	L_4	L_5	L_6
C_1	60	55	11	–	1.2	1.09	15.56	9.82	1.58	1700	2380	3060	3740	4420	5100
C_2	100	60	10	–	2.0	1.67	84.81	24.01	3.53	2300	3220	4140	5060	5980	6900
C_3	120	80	15	–	3.0	1.50	241.02	85.09	2.83	2500	3500	4500	5500	6500	7500
C_4	140	70	10	–	3.0	2.00	299.83	58.35	5.14	2900	4060	5220	6380	6940	7500
C_5	150	100	10	–	4.0	1.50	601.88	191.08	3.15	3600	5040	6480	7920	9360	10000
C_6	80	65	15	–	1.2	1.23	33.95	18.12	1.87	2600	3640	4680	5720	6760	7800
C_7	95	50	10	–	1.8	1.90	60.01	13.75	4.36	2100	2940	3780	4620	5060	5500
C_8	75	60	10	–	1.0	1.25	22.52	10.88	2.07	2600	3640	4680	5720	6760	7800
C_9	80	45	11	–	1.6	1.78	34.10	9.28	3.68	1700	2380	3060	3740	4420	5100
H_1	60	55	11	–	1.2	1.09	17.40	10.09	1.72	1000	1400	1800	2200	2600	3000
H_2	100	60	10	–	2.0	1.67	88.81	24.01	3.70	2000	2800	3600	4400	5200	6000
H_3	120	80	15	–	3.0	1.50	257.21	85.09	3.02	1900	2660	3420	4180	4940	5700
H_4	140	70	10	–	3.0	2.00	308.23	58.35	5.28	2600	3640	4680	5720	6760	7800
H_5	150	100	10	–	4.0	1.50	613.87	191.08	3.21	3300	4620	5940	7260	8580	9900
H_6	80	65	15	–	1.2	1.23	38.27	18.12	2.11	1900	2660	3420	4180	4940	5700
H_7	95	50	10	–	1.8	1.90	63.43	13.75	4.61	1800	2520	3240	3960	4680	5400
H_8	75	60	10	–	1.0	1.25	24.02	10.88	2.21	2100	2940	3780	4620	5460	6300
H_9	80	45	11	–	1.6	1.78	37.19	9.28	4.01	1400	1960	2520	3080	3640	4200
R_1	80	50	15	20	1.0	1.60	26.62	16.10	1.65	3500	4200	5200	7000	–	–
R_2	100	70	20	30	1.2	1.43	66.32	45.70	1.45	4500	5400	6700	9000	–	–
R_3	67	35	10	20	0.8	1.91	11.37	5.20	2.19	2700	3500	4500	5500	–	–
R_4	150	110	23	20	2.4	1.36	435.34	230.40	1.89	4600	5500	7000	9500	–	–
WSC_1	170	130	12	–	3.5	1.31	853.49	347.24	2.5	5500	7000	8000	9500	–	–
WSC_2	150	110	10	–	2.4	1.36	388.15	145.61	2.7	5500	7000	8000	9500	–	–
WSC_3	120	90	10	–	2.4	1.33	204.73	82.05	2.5	4000	5500	7000	9500	–	–
WSC_4	160	100	13	–	2.4	1.60	421.92	122.73	3.4	5000	6500	8000	9500	–	–
$WFSC_1$	170	130	13	–	3.5	1.31	879.22	350.00	2.51	5000	6500	8000	9500	–	–
$WFSC_2$	150	110	13	–	2.4	1.36	404.72	152.16	2.66	5000	6500	8000	9500	–	–
$WFSC_3$	120	90	13	–	1.2	1.33	106.82	43.11	2.48	4600	6000	7500	9000	–	–
$WFSC_4$	160	100	13	–	3.0	1.60	544.84	154.25	3.53	4600	6000	7500	9000	–	–

Table 3: Geometries of the selected columns failing in F_m modes: b_w, b_f, b_s, t, and L values (mm and mm^4)

Column	b_w	b_f	b_s	t	b_w/b_f	L_1	L_2	L_3	L_4	L_5	L_6
Z_1	60	55	11	1.2	1.09	2200	3000	4000	5000	6000	7000
Z_2	100	60	10	2.0	1.67	2600	3500	4500	5500	6500	7500
Z_3	120	80	15	3.0	1.50	2900	4000	5500	6500	7500	8500
Z_4	140	70	10	3.0	2.00	3100	4500	5500	6500	7500	8500
Z_5	150	100	10	4.0	1.50	4100	5500	6500	7500	8500	9500
Z_6	80	65	15	1.2	1.23	3200	4500	5500	6500	7500	8500
Z_7	95	50	10	1.8	1.90	2200	3000	4000	5000	6000	7000
Z_8	75	60	10	1.0	1.25	3300	4500	5500	6500	7500	8500
Z_9	80	45	11	1.6	1.78	1900	2500	3500	4500	5500	6500
I_1	100	40	–	2.0	2.50	1000	2000	3000	4000	–	–
I_2	100	80	–	2.0	1.25	2000	4000	6000	8000	–	–
I_3	100	100	–	2.0	1.00	3500	5000	6500	8000	–	–
I_4	100	120	–	2.0	0.83	5000	6500	8000	9500	–	–

3.2 Current DSM Strength Predictions

The tables included in Annexes B to H provide the f_{nG} estimates, corresponding numerical-to-predicted ratios f_u/f_{nG} and global slenderness values λ_G ($\lambda_G=\lambda_{FT}$ or $\lambda_G=\lambda_F$) for the C (Annex B), H (Annex C), R (Annex D), WSC (Annex E), WFSC (Annex F), Z (Annex G) and I (Annex H) columns analyzed in this work. Figs. 11(a)-(f) plot f_u/f_{nG} vs. λ_G for the U, C, H, R, WSC, WFSC columns buckling/failing in F_MT modes – the values concerning U columns, already presented in Fig. 4(b_1), are included for completion and comparison purposes. Table 4 provides, for each column set in the $\lambda_G \leq 1.5$ and $\lambda_G > 1.5$ slenderness ranges, the number of failure loads (n) and the f_u/f_{nG} average, standard deviation and maximum/minimum values. The observation of these results prompts the following remarks:

(i) The f_u/f_{nG} pairs of "clouds" are very similar for the U, C, H, R, WSC, WSFC column sets. Indeed, the f_{nG} curve provides (i_1) mostly accurate and safe ultimate strength estimates for $\lambda_G \leq 1.5$ and (i_2) mostly ultimate strength underestimations, leading to uneconomic designs, for $\lambda_G > 1.5$.

(ii) The above statements can be confirmed by looking at the averages and standard deviations of the six pairs of column sets: (ii_1) 1.065/0.027 (U), 1.056/0.033 (C), 1.073/0.037 (H), 1.039/0.032 (R), 1.054/0.026 (WSC), 1.048/0.028 (WFSC), for $\lambda_G \leq 1.5$, and (ii_2) 1.857/0.544 (U), 1.551/0.42 (C), 1.644/0.503 (H), 1.374/0.298 (R), 1.562/0.378 (WSC), 1.583/0.403 (WFSC), for $\lambda_G > 1.5$.

(iii) The lowest average and standard deviation, amongst the six column sets with $\lambda_G > 1.5$, are exhibited by the R columns – the corresponding f_u/f_{nG} "cloud", shown in Fig. 11(d), clearly back this assertion, since it "surrounds" the "almost straight line" with the lowest slope[8].

(iv) It seems logical to expect that the ultimate strength prediction quality improvement achieved by the DSM-based strength curve developed/proposed in the context of U columns (f_{nFT}) will also occur, to a larger or smaller extent, for the columns exhibiting the other cross-section shapes considered in this work (probably less so for the R columns) – this issue will be addressed in Section 3.3.

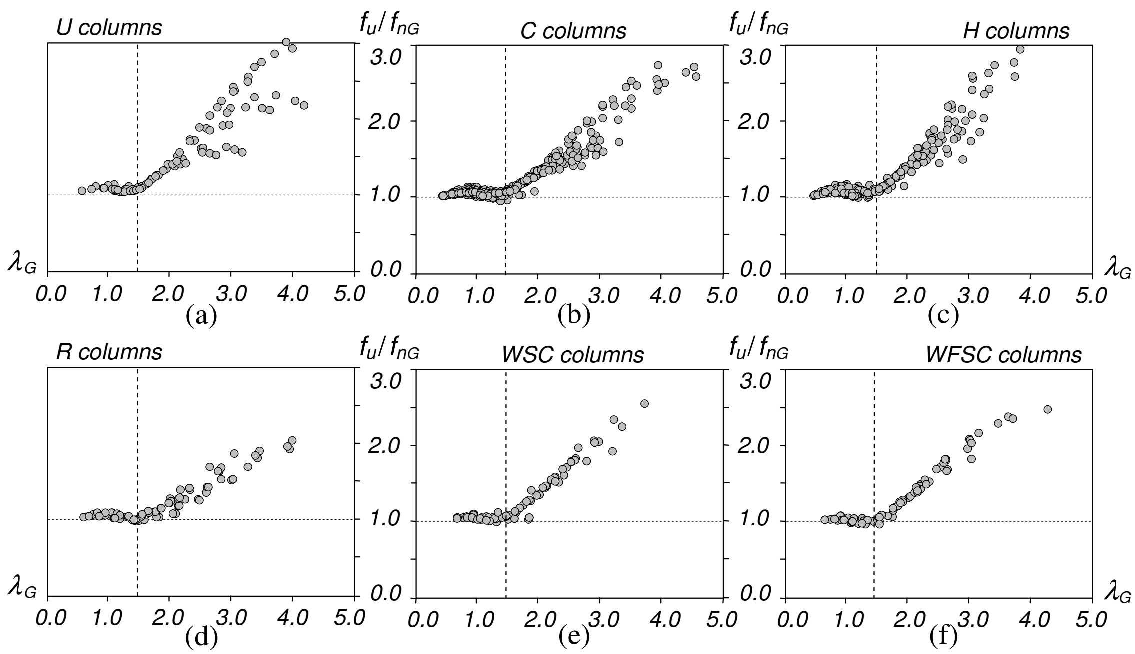

Figure 11: Plots f_u/f_{nG} vs. λ_G for (a) U, (b) C, (c) H, (d) R, (e) WSC, (f) WFSC columns failing in F_MT modes

[8] Note that R columns were also found to exhibit distinct behavioral features, stemming from lower flexural-torsional ultimate strengths, in the context of a study dealing with local-distortional-global mode interaction in fixed-ended cold-formed steel columns (Dinis & Camotim 2016).

Table 4: Means, standard deviations and maximum/minimum values of the failure-to-predicted ultimate strength ratios provided by the current DSM global curve for columns failing in F_MT modes

	U columns		C columns		H columns		R columns		WSC columns		WFSC columns		All columns	
λ_G	≤1.5	>1.5	≤1.5	>1.5	≤1.5	>1.5	≤1.5	>1.5	≤1.5	>1.5	≤1.5	>1.5	≤1.5	>1.5
n	29	61	129	141	134	136	33	47	33	47	31	49	389	486
Mean	1.065	1.857	1.056	1.551	1.073	1.644	1.039	1.374	1.054	1.562	1.048	1.583	1.061	1.607
Sd. Dev.	0.027	0.544	0.033	0.422	0.037	0.503	0.032	0.298	0.026	0.378	0.028	0.403	0.035	0.461
Max	1.124	3.135	1.141	2.741	1.172	3.323	1.094	2.039	1.126	2.555	1.105	2.500	1.172	3.323
Min	1.018	1.122	0.952	1.027	0.994	1.074	0.984	1.000	1.002	1.037	0.989	0.990	0.952	0.990

A similar investigation was carried out for the columns buckling/failing in F_m modes. Figs. 12(a)-(c) plot the f_u/f_{nG} vs. λ_G for the U, Z, I columns under these circumstances – once more, the values concerning U columns, previously displayed in Fig. 4(b$_2$), are included for completion and comparison purposes. As before, Table 5 provides, for each column set in the λ_G≤2.0 and λ_G>2.0 slenderness ranges, the number of failure loads (n) and the f_u/f_{nG} average, standard deviation and maximum/minimum values. These results lead to the following comments:

(i) The f_u/f_{nG} pairs of "clouds" are again very similar, now for the U, Z, I column sets, with the f_{nG} curve providing (i$_1$) mostly accurate and safe ultimate strength estimates for λ_G>2.0 and (i$_2$) mostly ultimate strength overestimations (by fairly small amounts, though), leading to unsafe designs, for λ_G≤2.0. Moreover, there is a quite low scatter in both slenderness ranges for all column sets.

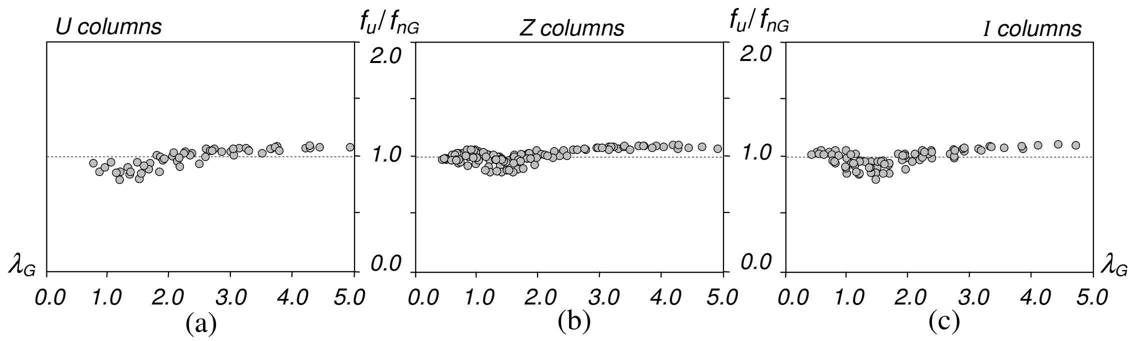

Figure 12: Plots of f_u/f_{nG} vs. λ_G for (a) U, (b) Z, (c) I columns failing in F_m modes

Table 5: Means, standard deviations and maximum/minimum values of the failure-to-predicted ultimate strength ratios provided by the current DSM global curve for columns failing in F_m modes

	U columns		Z columns		I columns		All columns	
λ_G	≤2.0	>2.0	≤2.0	>2.0	≤2.0	>2.0	≤2.0	>2.0
n	21	39	163	107	50	30	233	177
Mean	0.905	1.048	0.965	1.062	0.952	1.047	0.957	1.056
Sd. Dev.	0.060	0.043	0.054	0.024	0.066	0.041	0.059	0.033
Max	1.012	1.095	1.064	1.104	1.057	1.107	1.064	1.107
Min	0.800	0.912	0.836	0.994	0.800	0.953	0.800	0.912

(ii) Once more, the above statements are backed by the averages and standard deviations of the three pairs of column sets; (ii$_1$) 0.905/0.800 (U), 0.965/0.836 (Z) and 0.952/0.800 (I), for $\lambda_G \leq 2.0$, and (ii$_2$) 1.048/0.912 (U), 1.062/0.994 (Z) and 1.047/0.953 (I), for $\lambda_G > 2.0$.

(iii) Also for these columns, it is logical to expect an ultimate strength prediction quality improvement similar to that achieved in the context of U columns when the developed/proposed DSM-based strength curve (f_{nF}) is employed – this issue will be addressed in Section 3.3.

3.3 Predictions of the Proposed DSM-Based Strength Curves

Attention is now turned to investigating whether the strength curves proposed in Sections 2.4.1 (f_{nFT}) and 2.4.2 (f_{nF}), exclusively in the context of U columns buckling/failing in F_MT and F_m modes, can be successfully applied to predict the global failure loads of columns with other cross-section shapes. In order to assess the performance/merits of these design curves, one determines next the ultimate strength predictions f_{nFT} (columns buckling in F_MT modes) and f_{nF} (columns buckling in F_m modes), as well as the corresponding numerical-to-predicted ultimate strength ratios (f_u/f_{nFT} or f_u/f_{nF}), for the six column sets considered in this work – their values are also given, in tabular form, in Annexes B to H.

Figs. 13(a)-(f) plot f_u/f_{nFT} against λ_{FT} for the U, C, H, R, WSC, WFSC columns buckling/failing in F_MT modes – Table 6 provides, for each column set, the number of failure loads (n) and the f_u/f_{nFT} average, standard deviation and maximum/minimum values. These results prompt the following remarks:

(i) As anticipated, on the basis of the similarity between the f_u/f_{nG} "clouds" of concerning the six column sets, the quality of the f_{nFT} ultimate strength estimates is expected to be also quite similar for all of them. The corresponding f_u/f_{nFT} averages, standard deviations and maximum/minimum values are equal to 1.091/0.067/1.230/0.882 (U), 1.049/0.048/1.215/0.854 (C), 1.107/0.065/1.346/0.920 (H), 0.952/0.099/1.094/0.750 (R), 1.073/0.054/1.190/0.878 (WSC) and 1.066/0.038/1.142/0.966 (WFSC). However, it is worth mentioning that, unlike its five counterparts, the average of the f_u/f_{nFT} values concerning the R columns is lower than 1.0.

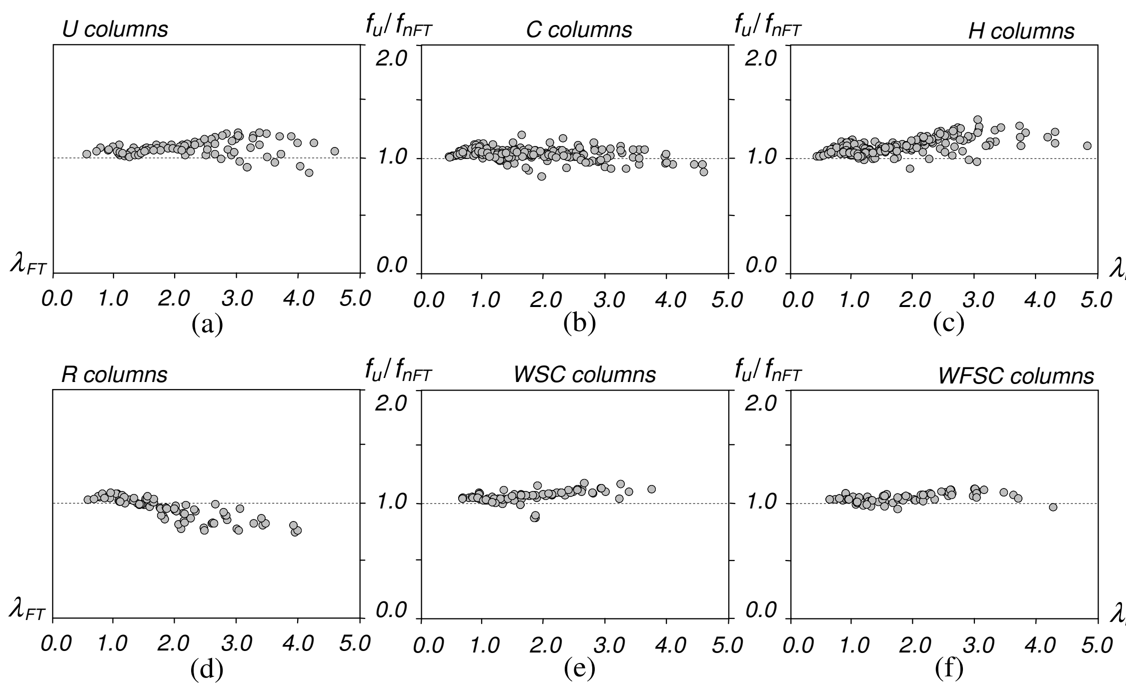

Figure 13: Plots f_u/f_{nFT} vs. λ_{FT} for (a) U, (b) C, (c) H, (d) R, (e) WSC, (f) WFSC columns failing in F_MT modes

Table 6: Means, standard deviations, maximum/minimum values of the failure-to-predicted ultimate strength ratios provided by the proposed DSM global curve for columns failing in F_MT modes

	U columns	C columns	H columns	R columns	WSC columns	WFSC columns	All columns
n	90	270	270	80	80	80	870
Mean	1.091	1.049	1.107	0.952	1.073	1.066	1.066
Sd. Dev.	0.067	0.048	0.065	0.099	0.054	0.038	0.075
Max	1.230	1.215	1.346	1.094	1.190	1.142	1.346
Min	0.882	0.854	0.920	0.750	0.878	0.966	0.750

(ii) The improvement, with respect to the predictions provided by the current global design curve, is very significant: in the λ_{FT}>1.5 slenderness range, the statistical indicators concerning all the columns analyzed (six column sets) read 1.070/0.096/1.346/0.750 (f_u/f_{nFT}) vs. 1.607/0.461/3.323/0.952 (f_u/f_{nG}).

(iii) Although it can be rightfully argued that the proposed f_{nFT} adequately estimates the whole set of columns analyzed in this work (the corresponding statistical indicators are 1.066/0.075/1.346/0.750), it is noticeable that the quality of the R column ultimate strength predictions falls clearly below that of the remaining five column sets: f_{nFT} average below 1.0 (0.952), largest standard deviation (0.099) and highest overestimation (0.750), as well as the lowest underestimation (1.094). Moreover, Fig. 13(d) clearly shows that the ultimate strengths of practically all the R columns with λ_{FT}>1.5 are overestimated by the f_{nFT} values. Obviously, it is possible to handle the R columns separately, which would automatically increase the quality of the overall f_u/f_{nFT} indicators (only concerning the remaining five column sets) – this possibility is addressed in the next item.

(iv) Following the strategy adopted for the U columns in Section 2.4.1, a new set of strength curves was sought, aimed at predicting, as accurately as possible, R column flexural-torsional failure loads. After grouping the R columns according to their β values, a "trial-and-error curve-fitting procedure" was employed to reach a new expression for the parameter $b(\beta)$ – note that parameter a is still given by Eq. (3) and the new flexural-torsional strength curve still coincides with Eq. (1) for columns with high β values (*i.e.*, a=0.877 and b=2) – in such columns, torsion has a minute influence on the post-buckling behavior. The output of this procedure was

$$b = \begin{cases} 0.20\ \beta + 1.0 & if \quad \beta < 5 \\ \\ 2 & if \quad \beta \geq 5 \end{cases} \tag{6}$$

In order to illustrate the prediction quality improvement achieved by replacing Eq. (4) with Eq. (6), Figs. 14(a_1)-(a_2) compare the ensuing strength curves (solid and dashed lines, respectively) with the f_u/f_y values of the columns with β=1.45 and β=2.19 – it is noted that these values lie in between the two curves, *i.e.*, the original unsafe ultimate strength predictions are "transformed" into safe ones. Moreover, Fig. 14(b) plots the numerical-to-predicted failure load ratios against λ_{FT} and provides ample evidence concerning the prediction quality improvement achieved with the new strength curves. Indeed, the corresponding statistical indicators (average, standard deviation, maximum and minimum values) improve from 0.952/0.099/1.094/0.750 (see Table 6) to 1.030/0.067/1.209/0.858 – this significant improvement brings the prediction quality of the R column failure loads to a "level" similar to that already achieved for the columns exhibiting all the other cross-section shapes (see again Table 6).

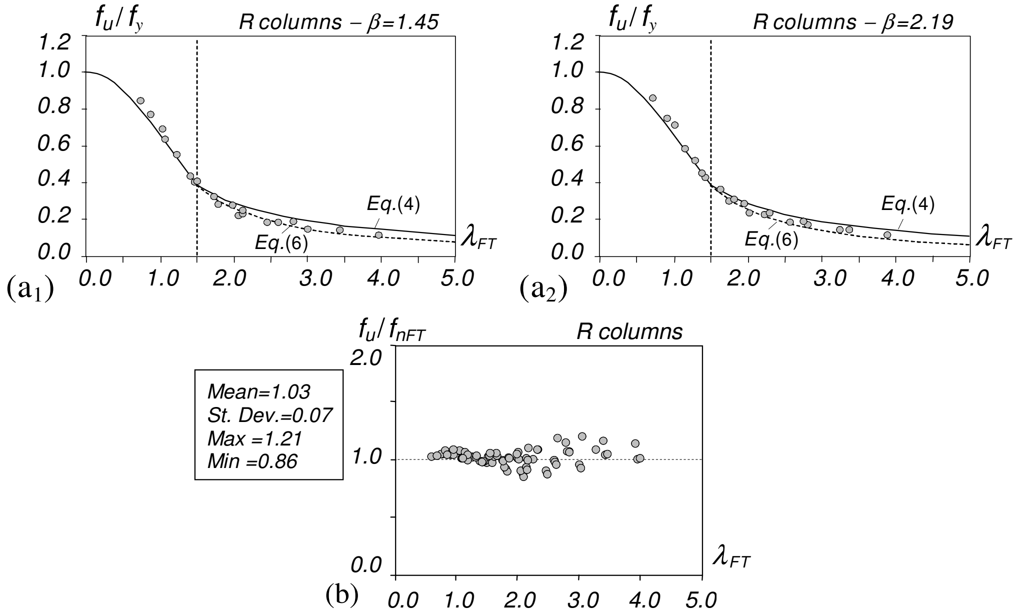

Figure 14: (a) Comparison between the two proposed f_{nFT} strength curves for R columns and their f_u/f_y values concerning ($_1$) β=1.45 and ($_2$) β=2.19 and (b) plot, against λ_{FT}, of the improved f_u/f_{nFT} values of all R columns failing in F_MT modes

Next, in order to assess the performance/merits of the proposed f_{nF} strength curve, Figs. 15(a)-(c) plot, against λ_F, the f_u/f_{nF} values concerning the U, Z, I column failing in F_m modes considered in this work – Table 7 provides, for each column set, the number of columns analyzed (n) and the statistical indicators of their f_u/f_{nF} values. The observation of these results leads to the following comments:

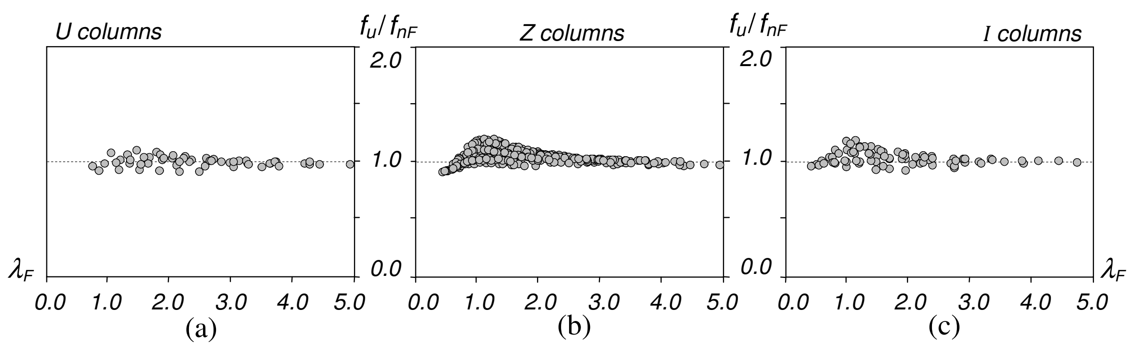

Figure 15: Plots f_u/f_{nF} vs. λ_F for the (a) U, (b) Z, (c) I columns buckling/failing in F_m modes

Table 7: Means, standard deviations, maximum/minimum values of the failure-to-predicted ultimate strength ratios provided by the proposed DSM global curve for columns failing in F_m modes

	U columns	Z columns	I columns	All Column s
n	60	270	80	410
Mean	0.995	1.042	1.023	1.031
Sd. Dev.	0.040	0.059	0.055	0.059
Max	1.100	1.198	1.183	1.198
Min	0.914	0.912	0.920	0.912

(i) The similarity between the f_u/f_{nG} "clouds" exhibited by the three column sets makes it logical to expect an equally similar quality of the f_{nF} ultimate strength prediction for the three column sets. Indeed, the f_u/f_{nF} average, standard deviation and maximum/minimum values are 0.995/0.040/1.100/0.914 (U), 1.042/0.059/1.198/0.912 (Z) and (i_3) 1.023/0.055/1.183/0.920 (I) – all this indicators are quite close to those obtained for the whole set of numerical failure loads: 1.031/0.059/1.198/0.912.

(ii) Although the ultimate strength prediction quality improvement achieved by the f_{nF} strength curve is much less pronounced than that of its f_{nFT} counterpart, it is by no means negligible for $\lambda_F \leq 2.0$. Indeed, the minor-axis flexural failure loads obtained in this work, for the above slenderness range, lead to numerical-to-predicted ultimate strength ratios whose averages and minimum values are equal to 1.049/0.912 (f_u/f_{nF}) and 0.957/0.800 (f_u/f_{nG}), respectively – a visible improvement.

4. Summary of the Proposed Strength Curves and Reliability Assessment

On the basis of the numerical fixed-ended column failure loads obtained in this work, it was found that it is essential to distinguish between the DSM-based global strength curves used to design columns against major-axis flexural-torsional (f_{nFT}) and minor-axis flexural (f_{nF}) failures[9]. In the first case, two strength curve sets were proposed, both (i) dependent on $\beta = I_I/I_{II}$ (I_I, I_{II}: cross-section major and minor moments of inertia) and (ii) differing from the current global curve only for $\lambda_{FT}>1.5$ – they are given by the expressions

$$f_{nFT} = \begin{cases} f_y \left(0.658^{\lambda_{FT}^2}\right) & if \quad \lambda_{FT} \leq 1.5 \\ f_y \left(\dfrac{a}{\lambda_{FT}^b}\right) & if \quad \lambda_{FT} > 1.5 \end{cases} \qquad \text{with} \qquad \lambda_{FT} = \sqrt{\frac{f_y}{f_{crFT}}} \,, \tag{7}$$

where $a = 0.39 \times 1.5^b$ and b is obtained from either

$$b = \begin{cases} 0.10\ \beta + 0.85 & if \quad \beta < 11.5 \\ 2 & if \quad \beta \geq 11.5 \end{cases} \,, \tag{8}$$

for all the U, C, H, WSC and WFSC columns analyzed in this work, or

$$b = \begin{cases} 0.20\ \beta + 1.0 & if \quad \beta < 5 \\ 2 & if \quad \beta \geq 5 \end{cases} \,, \tag{9}$$

for the all the R columns analyzed in this work. Recall that the strength curves obtained from Eq. (8) were found to consistently overestimate the R column failure loads – this fact prompted the decision to lower those curves for the columns with this particular cross-section shape[10].

As for the columns buckling/failing in F_m modes, a "Winter-type" DSM-based strength curve is proposed. It only differs from the current one for $\lambda_F \leq 2.0$ (there a virtual coincidence for $\lambda_F > 2.0$ – see Fig. 9(a)) and is defined by the expressions

[9] Although no columns buckling/failing in major-axis flexural modes (due to bracing arrangements, of course) were considered in this work, it is expected that their failure loads will be also adequately predicted by the f_{nF} strength curve.

[10] The authors believe that the "singular behavior" associated with the R column failure load estimation is related to the presence of the horizontal end stiffeners (absent from the remaining cross-sections considered in this work), which have a marked influence on the value of the parameter $\beta = I_I/I_{II}$. This issue is currently under investigation, namely by considering other cross-sections with horizontal end stiffeners, and the findings obtained will be reported in the near future.

$$f_{nF} = \begin{cases} f_y & \text{if} \quad \lambda_F \leq 0.422 \\ f_y \left[1 - 0.24\left(\dfrac{1}{\lambda_F^2 + 0.42}\right)\right]\left(\dfrac{1}{\lambda_F^2 + 0.42}\right) & \text{if} \quad \lambda_F > 0.422 \end{cases} \quad \text{where} \quad \lambda_F = \sqrt{\frac{f_y}{f_{crF}}} \quad . \tag{10}$$

4.1 Reliability Assessment

The reliability of the failure load predictions provided by the DSM-based strength curves proposed for the design of columns buckling/failing in (global) F_MT or F_m modes is assessed in this section, through the determination of the LRFD (Load and Resistance Factor Design) resistance factors associated with the estimates provided by those strength curves for the numerical failure loads obtained in this work. In particular, it is intended to check whether values equal or higher than ϕ_c=0.85 are achieved – this is the value recommended by the current North American Specification (AISI 2016) for compression members. According to this specification (Chapter K – Section K2.1.1), ϕ_c can be calculated using the expression

$$\phi_c = C_\phi (M_m F_m P_m)\, e^{-\beta_0 \sqrt{V_M^2 + V_F^2 + C_P V_P^2 + V_Q^2}} \quad \text{with} \quad C_P = \left(1 + \frac{1}{n}\right)\frac{m}{m-2} \quad , \tag{11}$$

where (i) C_ϕ is a calibration coefficient (C_ϕ=1.52 for LRFD), (ii) M_m=1.10 and F_m=1.00 are the mean values of the material and fabrication factors, respectively, (iii) β_0 is the target reliability index (β_0=2.5 for structural members in LRFD), (iv) V_M=0.10, V_F=0.05 and V_Q=0.21 are the coefficients of variation of the material factor, fabrication factor and load effect, respectively, (v) C_P is a correction factor depending on the numbers of tests (n) and degrees of freedom (m=n–1), and (vi) P_m and V_P are the mean and the coefficient of variation of the "exact"-to-predicted ultimate strength ratios (f_u/f_{nFT} or f_u/f_{nF}).

4.1.1 Flexural-torsional strength

Figs. 16(a)-(c) plot, against λ_{FT}, the f_u/f_{nFT} values obtained with Eq. (8) for (i) all the columns analyzed in this work ("All columns" – Fig. 16(a)) and (ii) all but the R columns considered in this work ("all but R columns" – Fig. 16(b)). As for Fig. 16(c), it concerns exclusively the R columns and plots, against λ_{FT}, the

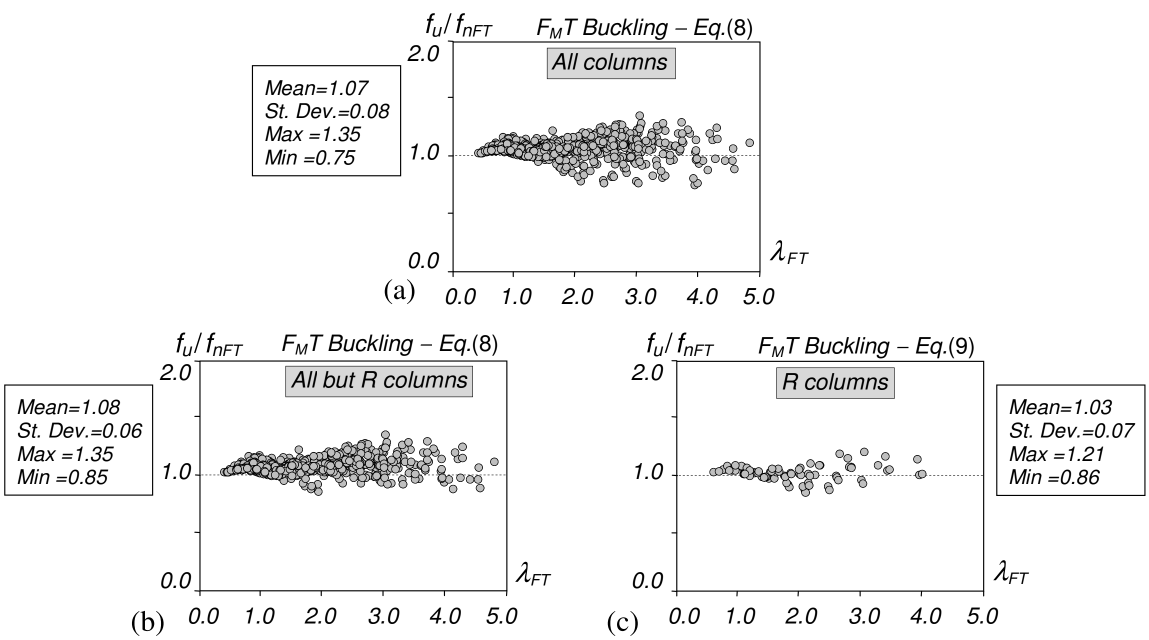

Figure 16: Plots f_u/f_{nFT} vs. λ_{FT} for (a) "All columns" (Eq. (8)), (b) "All but R columns" (Eq. (8)), and (c) "R columns" (Eq. (9))

Table 8: Calculation of the LRFD resistance factors (ϕ_c) concerning the numerical-to-predicted ultimate strength ratios provided by the proposed DSM-based global design curves for columns buckling/failing in F_MT modes.

	All columns (Eq. (8))			All but R columns (Eq. (8))			R columns (Eq. (9))		
λ_{FT}	≤ 1.5	>1.5	All	≤ 1.5	>1.5	All	≤ 1.5	>1.5	All
n	388	481	870	355	435	790	33	47	80
P_m	1.061	1.070	1.066	1.063	1.090	1.078	1.039	1.024	1.030
V_P	0.033	0.090	0.071	0.033	0.069	0.057	0.031	0.081	0.065
ϕ_c	0.97	0.95	0.96	0.97	0.98	0.98	0.95	0.91	0.93

f_u/f_{nFT} values obtained with Eq. (9) – recall that the values obtained with Eq. (8) were plotted in Fig. 13(d). The associated f_u/f_{nFT} averages, standard deviations and maximum/minimum values are also given in the above figures. Finally, Table 8 shows the calculation of the ϕ_c values corresponding to the three column failure load sets, making a distinction between the columns with $\lambda_{FT}\leq 1.5$ and $\lambda_{FT}>1.5$. The observation of these results prompts the following remarks:

(i) The most efficient (safe and accurate) DSM-based column strength curves against F_MT failures (f_{nFT}) lead to high-quality failure load predictions. Indeed, the f_u/f_{nFT} averages, standard deviations and maximum/minimum values are 1.08/0.06/1.35/0.85 and 1.03/0.07/1.21/0.86, respectively for the "all but R columns" and "R columns". For $\lambda_{FT}\leq 1.5$ and $\lambda_{FT}>1.5$, these statistical indicators read (i_1) 1.06/0.04/1.17/0.95 and 1.09/0.08/1.35/0.85 ("all but R columns"), and (i_2) 1.04/0.03/1.09/0.98 and 1.02/0.08/1.21/0.86 ("R columns"), which means that the failure load prediction quality is quite similar in both slenderness ranges. Moreover, the associated LRFD resistance factors are ϕ_c=0.98 ("all but R columns") and ϕ_c=0.93 ("R columns"), both well above the value currently recommended by the North American Specification (AISI 2016) for compression members – ϕ_c=0.85. For $\lambda_{FT}\leq 1.5$ and $\lambda_{FT}>1.5$, the resistance factors are (i_1) ϕ_c=0.97 and ϕ_c=0.98 ("all but R columns"), and (i_2) ϕ_c=0.95 and ϕ_c=0.91 ("R columns") – again, equally good values in both slenderness ranges.

(ii) Although the use of Eq. (8) for all the columns considered in this work also leads to quite good failure load predictions (f_u/f_{nFT} averages, standard deviations and maximum/minimum values equal to 1.07/0.08/1.35/0.75 and ϕ_c=0.96), the fact that there is a clear "negative bias" concerning the R columns makes it is prudent to use Eq. (9) for such columns.

(iii) Naturally, an alternative that immediately springs to mind is to adopt the conservative approach of using Eq. (9) for all the columns considered in this work. Figs. 17(a)-(f) plot, against λ_{FT}, the f_u/f_{nFT} values obtained with Eq. (9) for each column set sharing the same cross-section shape. The plot in Fig. 17(g), on the other hand, makes it possible to assess the failure load prediction quality for the whole set of columns analyzed in this work – the corresponding f_u/f_{nFT} statistical indicators read 1.19/0.18/1.81/0.86 (1.06/0.04/1.17/0.95 for $\lambda_{FT}\leq 1.5$, and 1.29/0.19/1.81/0.86 for $\lambda_{FT}>1.5$). These plot and indicators show clearly that this alternative approach leads to excessively conservative and very scattered failure load predictions (even if less so than the currently codified design curve). Moreover, by looking at the plots in Figs. 17(a)-(f), namely at their "right sides" ($\lambda_{FT}>1.5$), it is readily concluded that all but the R columns have their failures loads considerably underestimated, thus confirming the inadequacy of using Eq. (9) to obtain accurate failure load predictions for other than R columns.

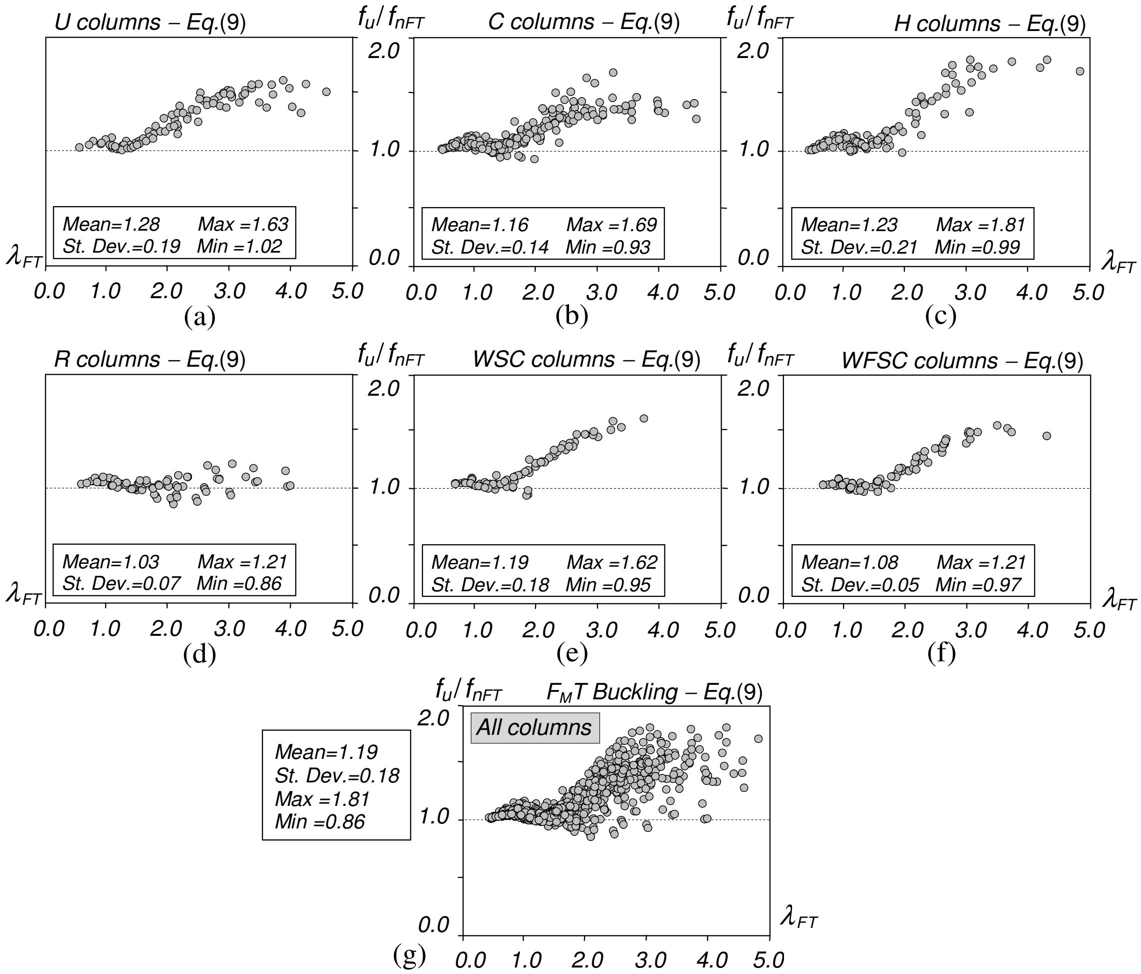

Figure 17: Plots f_u/f_{nFT} vs. λ_{FT} for (a) U, (b) C, (c) H, (d) R, (e) WSC, (f) WFSC, (g) all columns, obtained using Eq. (9)

4.1.2 Flexural strength

Fig. 18 plots, against λ_F, the f_u/f_{nFT} values obtained with Eq. (10) for all the columns buckling/failing in F_m modes – also given are the f_u/f_{nFT} value statistical indicators. The associated LRFD resistance factor is ϕ_c=0.94 (n=410, P_m=1.031, V_P=0.057). For $\lambda_F \leq 2.0$ and $\lambda_F > 2.0$, one has ϕ_c=0.95 (n=232, P_m=1.049, V_P=0.065) and ϕ_c=0.93 (n=177, P_m=1.008, V_P=0.028), respectively – this means that the failure load prediction quality is now the same in both slenderness ranges. It can be readily concluded that the proposed DSM-based design curve leads to high-quality failure loads along the whole slenderness range, visibly improving the estimates yielded by the currently codified strength curve for columns with $\lambda_F \leq 2.0$.

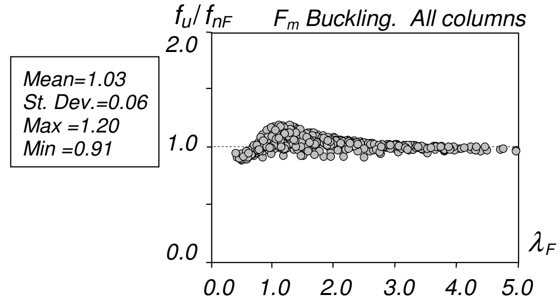

Figure 18: Plots of f_u/f_{nF} vs. λ_F for the whole set of numerical results

5. Conclusion

This work reported the results of a fairly extensive numerical investigation aimed at assessing the accuracy of the currently codified DSM strength curve to predict the load-carrying capacity of fixed-ended cold-formed steel columns buckling and failing in global modes, namely major-axis flexural-torsional (F_MT) and minor-axis flexural (F_m) modes. Initially, the paper focused on the behavior and strength of plain channel (U) columns with several web/flange width ratios – by varying this ratio it is possible to obtain U columns buckling and failing in F_MT or F_m modes. Column geometries (cross-section dimensions and lengths) associated with F_MT and F_m buckling were identified/selected and subsequently used to (i) highlight the main differences between the post-critical strength of columns buckling/failing in F_MT and F_m modes, and (ii) to perform a parametric study aimed at gathering global failure load data concerning both F_MT and F_m failures and covering wide slenderness ranges. This failure load data clearly showed that a single DSM global design curve, namely the currently codified one, is unable to handle adequately columns failing in both mode types. Indeed, it was found that the currently codified strength curve (i) underestimates, often by large amounts, the failure loads of columns with moderate or high slenderness (λ_G>1.5) that fail in F_MT modes, and (ii) overestimates, usually by small amounts, the failure loads of columns with low-to-moderate slenderness ($\lambda_G \leq 2.0$) that fail in F_m modes. Moreover, the U column ultimate strength data assembled provided the means to propose and validate (preliminary) strength curves to improve the failure load prediction quality for columns buckling/failing in F_MT and F_m modes and exhibiting slenderness values falling inside the above ranges – such curves provide ultimate strength estimates termed f_{nFT} and f_{nF}, respectively. In the case of f_{nFT}, the ultimate strength prediction depends on a parameter β, which relates the cross-section major and minor moments of inertia ($\beta=I_I/I_{II}$) – in other words, the proposal consists of a β-dependent strength curve set.

In order to assess whether the proposed DSM-based strength curves (developed exclusively on the basis of U column numerical failure loads) are adequate to estimate the failure loads of columns with other cross-section shapes, a second (and more extensive) parametric study was carried out. It involved (i) 780 columns buckling/failing in F_MT modes, exhibiting plain, web-stiffened and web/flange-stiffened lipped channel and rack cross-sections, and (ii) 350 columns buckling/failing in F_m modes, with zed and I (back-to-back plain channels) cross-sections. The above parametric study led to the following conclusions:

(i) Like for the U columns, the currently codified DSM global design curve also does not predict efficiently (safely and reliably) the failure loads concerning columns with the other cross-section shapes considered in this work – it (i_1) underestimates substantially the failure loads of columns with moderate or high slenderness (λ_G>1.5) that fail in F_MT modes, and (ii) overestimates slightly the failure loads of columns with low-to-moderate slenderness ($\lambda_G \leq 2.0$) that fail in F_m modes.

(ii) The β-dependent DSM-based strength curve set proposed for the U columns buckling/failing in F_MT modes provide high-quality failure load predictions for the columns with plain, web-stiffened and web/flange-stiffened lipped channel cross-sections – *i.e.*, all the columns analyzed in this work except those exhibiting rack cross-sections.

(iii) In the case of the R column, it was found high-quality F_MT failure load predictions can only be obtained if the DSM-based strength curve set proposed for the U columns buckling/failing in F_MT modes is modified. The modification proposed involved exclusively the β-dependency and led and brought the quality of the R column failure load prediction to the same level found for the columns with other cross-section shapes.

(iv) The DSM-based strength curve proposed for the U columns buckling/failing in F_m modes provide high-quality failure load predictions for the columns with Zed and I (back-to-back plain channels) cross-sections – *i.e.*, all the columns analyzed in this work.

(v) For all the columns analyzed in this work, the proposed DSM-based strength curves lead to LRFD resistance factors higher than 0.90, *i.e.*, considerably above the value currently recommended by the North American Specification (AISI 2016) for compression members – ϕ_c=0.85.

It should also be pointed out that the authors still believe that it is possible to achieve the desirable goal of having a single flexural-torsional strength curve set to predict adequately the failure loads of columns with arbitrary cross-section shapes. Work is currently under way to explore this possibility – if successful, the outcome of this research effort will be reported in the near future.

Finally, one last word to mention that (i) additional numerical and (mostly) (ii) experimental validation is indispensable before the above (possibly modified/improved) DSM-based columns global design curves are ready for the codification stage. In particular, it is essential to assess how efficiently they predict the available experimental column failure loads associated with global (flexural-torsional and flexural) modes.

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ANNEX A: U COLUMN DATA

Table A1: Columns failing in F_MT modes: (i) geometries, (ii) buckling stresses and ultimate strengths, (iii) ultimate strength predictions by current and proposed DSM design curves, and (iv) numerical-to-predicted ultimate strength ratios (mm and MPa)

	Geometry						SFEA		DSM Design							
Column	b_w	b_f	t	b_w/b_t	$\beta=I_I/I_{II}$	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	b	a	f_{nFT}	f_u/f_{nFT}
U2_L1	100	40	2	2.5	9.95	2100	75	69.6	273	0.52	66.9	1.04	1.85	0.82	66.9	1.04
	100	40	2	2.5	9.95	2100	150	131.0	273	0.74	119.2	1.10	1.85	0.82	119.2	1.10
	100	40	2	2.5	9.95	2100	300	213.0	273	1.05	189.4	1.12	1.85	0.82	189.4	1.12
	100	40	2	2.5	9.95	2100	450	247.0	273	1.28	225.8	1.09	1.85	0.82	225.8	1.09
	100	40	2	2.5	9.95	2100	600	260.0	273	1.48	239.2	1.09	1.85	0.82	239.2	1.09
U3_L1	100	60	2	1.7	4.50	3200	75	66.2	166	0.67	62.1	1.07	1.30	0.66	62.1	1.07
	100	60	2	1.7	4.50	3200	150	114.0	166	0.95	102.8	1.11	1.30	0.66	102.8	1.11
	100	60	2	1.7	4.50	3200	300	150.0	166	1.34	141.0	1.06	1.30	0.66	141.0	1.06
	100	60	2	1.7	4.50	3200	450	174.0	166	1.64	145.8	1.19	1.30	0.66	155.6	1.12
	100	60	2	1.7	4.50	3200	600	193.0	166	1.90	145.8	1.32	1.30	0.66	172.1	1.12
U4_L1	100	80	2	1.3	2.63	4400	75	58.7	100	0.87	54.8	1.07	1.11	0.61	54.8	1.07
	100	80	2	1.3	2.63	4400	150	84.7	100	1.22	80.1	1.06	1.11	0.61	80.1	1.06
	100	80	2	1.3	2.63	4400	300	109.0	100	1.73	87.8	1.24	1.11	0.61	99.7	1.09
	100	80	2	1.3	2.63	4400	450	126.0	100	2.12	87.8	1.44	1.11	0.61	119.4	1.06
	100	80	2	1.3	2.63	4400	600	140.0	100	2.45	87.8	1.59	1.11	0.61	135.6	1.03
U5_L1	100	100	2	3.0	1.75	5500	75	48.5	67	1.06	46.9	1.03	1.03	0.59	46.9	1.03
	100	100	2	1.0	1.75	5500	150	64.1	67	1.50	58.7	1.09	1.03	0.59	58.7	1.09
	100	100	2	1.0	1.75	5500	300	84.9	67	2.12	58.7	1.45	1.03	0.59	82.2	1.03
	100	100	2	1.0	1.75	5500	450	119.0	67	2.59	58.7	2.03	1.03	0.59	100.1	1.19
	100	100	2	1.0	1.75	5500	600	138.0	67	2.99	58.7	2.35	1.03	0.59	115.2	1.20
U3_L2	100	60	2	1.7	4.50	4500	75	58.5	97	0.88	54.3	1.08	1.30	0.66	54.3	1.08
	100	60	2	1.7	4.50	4500	150	83.6	97	1.24	78.5	1.06	1.30	0.66	78.5	1.06
	100	60	2	1.7	4.50	4500	300	106.0	97	1.76	85.1	1.25	1.30	0.66	95.1	1.11
	100	60	2	1.7	4.50	4500	450	124.0	97	2.15	85.1	1.46	1.30	0.66	109.6	1.13
	100	60	2	1.7	4.50	4500	600	136.0	97	2.49	85.1	1.60	1.30	0.66	121.2	1.12
U4_L2	100	80	2	1.3	2.63	5500	75	50.1	70	1.04	47.8	1.05	1.11	0.61	47.8	1.05
	100	80	2	1.3	2.63	5500	150	66.4	70	1.47	61.0	1.09	1.11	0.61	61.0	1.09
	100	80	2	1.3	2.63	5500	300	91.4	70	2.07	61.2	1.49	1.11	0.61	81.6	1.12
	100	80	2	1.3	2.63	5500	450	114.0	70	2.54	61.2	1.86	1.11	0.61	97.7	1.17
	100	80	2	1.3	2.63	5500	600	130.0	70	2.93	61.2	2.12	1.11	0.61	111.0	1.17
U5_L2	100	100	2	3.0	1.75	6000	75	44.6	58	1.14	43.6	1.02	1.03	0.59	43.6	1.02
	100	100	2	1.0	1.75	6000	150	58.8	58	1.61	50.8	1.16	1.03	0.59	54.4	1.08
	100	100	2	1.0	1.75	6000	300	87.2	58	2.28	50.8	1.72	1.03	0.59	76.3	1.14
	100	100	2	1.0	1.75	6000	450	113.0	58	2.79	50.8	2.23	1.03	0.59	93.0	1.22
	100	100	2	1.0	1.75	6000	600	129.0	58	3.22	50.8	2.54	1.03	0.59	107.0	1.21
U3_L3	100	60	2	1.7	4.50	5500	75	51.9	73	1.01	48.8	1.06	1.30	0.66	48.8	1.06
	100	60	2	1.7	4.50	5500	150	68.7	73	1.43	63.6	1.08	1.30	0.66	63.6	1.08
	100	60	2	1.7	4.50	5500	300	87.7	73	2.02	64.2	1.37	1.30	0.66	79.2	1.11
	100	60	2	1.7	4.50	5500	450	98.8	73	2.48	64.2	1.54	1.30	0.66	91.3	1.08
	100	60	2	1.7	4.50	5500	600	104.0	73	2.86	64.2	1.62	1.30	0.66	101.0	1.03
U4_L3	100	80	2	1.3	2.63	6500	75	43.3	54	1.18	42.1	1.03	1.11	0.61	42.1	1.03
	100	80	2	1.3	2.63	6500	150	56.8	54	1.66	47.6	1.19	1.11	0.61	52.2	1.09
	100	80	2	1.3	2.63	6500	300	80.8	54	2.35	47.6	1.70	1.11	0.61	71.0	1.14
	100	80	2	1.3	2.63	6500	450	98.0	54	2.88	47.6	2.06	1.11	0.61	84.9	1.15
	100	80	2	1.3	2.63	6500	600	108.0	54	3.32	47.6	2.27	1.11	0.61	96.5	1.12
U5_L3	100	100	2	3.0	1.75	6500	75	41.2	51	1.21	40.5	1.02	1.03	0.59	40.5	1.02
	100	100	2	1.0	1.75	6500	150	54.7	51	1.72	44.6	1.23	1.03	0.59	50.9	1.07
	100	100	2	1.0	1.75	6500	300	83.4	51	2.43	44.6	1.87	1.03	0.59	71.4	1.17
	100	100	2	1.0	1.75	6500	450	107.0	51	2.97	44.6	2.40	1.03	0.59	87.0	1.23
	100	100	2	1.0	1.75	6500	600	122.0	51	3.43	44.6	2.73	1.03	0.59	100.1	1.22
U3_L4	100	60	2	1.7	4.50	5900	75	49.5	67	1.06	46.9	1.06	1.30	0.66	46.9	1.06
	100	60	2	1.7	4.50	5900	150	64.4	67	1.50	58.7	1.10	1.30	0.66	58.7	1.10
	100	60	2	1.7	4.50	5900	300	81.5	67	2.12	58.7	1.39	1.30	0.66	74.7	1.09
	100	60	2	1.7	4.50	5900	450	89.9	67	2.59	58.7	1.53	1.30	0.66	86.1	1.04
	100	60	2	1.7	4.50	5900	600	93.0	67	2.99	58.7	1.59	1.30	0.66	95.2	0.98
U4_L4	100	80	2	1.3	2.63	7500	75	38.2	45	1.30	37.0	1.03	1.11	0.61	37.0	1.03
	100	80	2	1.3	2.63	7500	150	50.8	45	1.84	39.0	1.30	1.11	0.61	46.7	1.09
	100	80	2	1.3	2.63	7500	300	71.6	45	2.60	39.0	1.83	1.11	0.61	63.5	1.13
	100	80	2	1.3	2.63	7500	450	83.5	45	3.18	39.0	2.14	1.11	0.61	76.0	1.10
	100	80	2	1.3	2.63	7500	600	89.6	45	3.67	39.0	2.30	1.11	0.61	86.4	1.04
U5_L4	100	100	2	3.0	1.75	7500	75	35.8	41	1.36	34.7	1.03	1.03	0.59	34.7	1.03
	100	100	2	1.0	1.75	7500	150	49.4	41	1.92	35.7	1.38	1.03	0.59	45.4	1.09
	100	100	2	1.0	1.75	7500	300	76.4	41	2.71	35.7	2.14	1.03	0.59	63.7	1.20
	100	100	2	1.0	1.75	7500	450	95.3	41	3.33	35.7	2.67	1.03	0.59	77.6	1.23
	100	100	2	1.0	1.75	7500	600	107.0	41	3.84	35.7	3.00	1.03	0.59	89.3	1.20

	Geometry						SFEA		DSM Design							
Column	b_w	b_f	t	b_w/b_t	$\beta=I_I/I_{II}$	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	b	a	f_{nFT}	f_u/f_{nFT}
U3_L5	100	60	2	1.7	4.50	6300	75	47.2	62	1.10	45.1	1.05	1.30	0.66	45.1	1.05
	100	60	2	1.7	4.50	6300	150	60.7	62	1.56	54.1	1.12	1.30	0.66	55.6	1.09
	100	60	2	1.7	4.50	6300	300	75.6	62	2.21	54.1	1.40	1.30	0.66	70.9	1.07
	100	60	2	1.7	4.50	6300	450	81.7	62	2.70	54.1	1.51	1.30	0.66	81.7	1.00
	100	60	2	1.7	4.50	6300	600	83.5	62	3.12	54.1	1.54	1.30	0.66	90.3	0.92
U4_L5	100	80	2	1.3	2.63	8500	75	34.3	38	1.41	32.8	1.05	1.11	0.61	32.8	1.05
	100	80	2	1.3	2.63	8500	150	46.2	38	1.99	33.2	1.39	1.11	0.61	42.7	1.08
	100	80	2	1.3	2.63	8500	300	62.9	38	2.81	33.2	1.89	1.11	0.61	58.1	1.08
	100	80	2	1.3	2.63	8500	450	70.6	38	3.45	33.2	2.12	1.11	0.61	69.5	1.02
	100	80	2	1.3	2.63	8500	600	73.8	38	3.98	33.2	2.22	1.11	0.61	79.0	0.93
U5_L5	100	100	2	3.0	1.75	8500	75	31.9	34	1.49	29.7	1.07	1.03	0.59	29.7	1.07
	100	100	2	1.0	1.75	8500	150	45.9	34	2.10	29.7	1.54	1.03	0.59	41.4	1.11
	100	100	2	1.0	1.75	8500	300	69.7	34	2.97	29.7	2.34	1.03	0.59	58.0	1.20
	100	100	2	1.0	1.75	8500	450	84.3	34	3.64	29.7	2.84	1.03	0.59	70.7	1.19
	100	100	2	1.0	1.75	8500	600	92.7	34	4.21	29.7	3.12	1.03	0.59	81.3	1.14
U4_L6	100	80	2	1.3	2.63	9000	75	32.8	35	1.46	30.8	1.06	1.11	0.61	30.8	1.06
	100	80	2	1.3	2.63	9000	150	44.2	35	2.06	31.0	1.43	1.11	0.61	41.1	1.08
	100	80	2	1.3	2.63	9000	300	58.9	35	2.92	31.0	1.90	1.11	0.61	55.8	1.05
	100	80	2	1.3	2.63	9000	450	64.9	35	3.57	31.0	2.10	1.11	0.61	66.8	0.97
	100	80	2	1.3	2.63	9000	600	67.0	35	4.12	31.0	2.16	1.11	0.61	75.9	0.88
U5_L6	100	100	2	3.0	1.75	9500	75	29.2	29	1.61	25.5	1.14	1.03	0.59	27.3	1.07
	100	100	2	1.0	1.75	9500	150	43.0	29	2.27	25.5	1.68	1.03	0.59	38.2	1.12
	100	100	2	1.0	1.75	9500	300	63.2	29	3.21	25.5	2.48	1.03	0.59	53.6	1.18
	100	100	2	1.0	1.75	9500	450	74.3	29	3.93	25.5	2.91	1.03	0.59	65.3	1.14
	100	100	2	1.0	1.75	9500	600	80.0	29	4.54	25.5	3.13	1.03	0.59	75.2	1.06
										Mean		1.36		Mean		1.09
										Sd. Dev.		0.44		Sd. Dev.		0.07
										Max		3.32		Max		1.23
										Min		0.95		Min		0.88

Table A2: Columns failing in F_m modes: (i) geometries, (ii) buckling stresses and ultimate strengths, (iii) ultimate strength predictions by current and proposed DSM design curves, and (iv) numerical-to-predicted ultimate strength ratios (mm and MPa)

	Geometry					SFEA		DSM Design					
Column	b_w	b_f	t	b_w/b_t	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	f_{nF}	f_u/f_{nF}
U1_L1	100	20	2.0	5.0	1500	75	49.0	111	0.82	56.5	0.87	53.4	0.92
	100	20	2.0	5.0	1500	150	73.8	111	1.17	85.0	0.87	73.0	1.01
	100	20	2.0	5.0	1500	300	91.5	111	1.65	96.9	0.94	88.4	1.04
	100	20	2.0	5.0	1500	450	97.4	111	2.02	96.9	1.01	94.8	1.03
	100	20	2.0	5.0	1500	600	99.6	111	2.33	96.9	1.03	98.4	1.01
U1_L2	100	20	2.0	5.0	2100	75	34.5	57	1.15	43.1	0.80	37.1	0.93
	100	20	2.0	5.0	2100	150	44.4	57	1.63	49.7	0.89	45.1	0.98
	100	20	2.0	5.0	2100	300	50.4	57	2.30	49.7	1.01	50.3	1.00
	100	20	2.0	5.0	2100	450	52.1	57	2.82	49.7	1.05	52.3	1.00
	100	20	2.0	5.0	2100	600	52.7	57	3.25	49.7	1.06	53.3	0.99
U2_L2	100	40	2.0	2.5	3000	75	57.1	145	0.72	60.4	0.94	59.6	0.96
	100	40	2.0	2.5	3000	150	92.5	145	1.02	97.4	0.95	86.2	1.07
	100	40	2.0	2.5	3000	300	120.0	145	1.44	126.5	0.95	109.1	1.10
	100	40	2.0	2.5	3000	450	129.0	145	1.76	127.5	1.01	119.3	1.08
	100	40	2.0	2.5	3000	600	132.0	145	2.03	127.5	1.04	125.0	1.06
U1_L3	100	20	2.0	5.0	2700	75	24.2	34	1.48	30.0	0.81	26.1	0.93
	100	20	2.0	5.0	2700	150	28.8	34	2.09	30.1	0.96	29.7	0.97
	100	20	2.0	5.0	2700	300	31.5	34	2.96	30.1	1.05	31.9	0.99
	100	20	2.0	5.0	2700	450	32.2	34	3.62	30.1	1.07	32.6	0.99
	100	20	2.0	5.0	2700	600	32.4	34	4.18	30.1	1.08	33.0	0.98
U2_L3	100	40	2.0	2.5	3800	75	47.9	91	0.91	53.1	0.90	48.6	0.99
	100	40	2.0	2.5	3800	150	67.8	91	1.29	75.1	0.90	64.0	1.06
	100	40	2.0	2.5	3800	300	79.7	91	1.82	79.6	1.00	75.4	1.06
	100	40	2.0	2.5	3800	450	83.3	91	2.23	79.6	1.05	80.0	1.04
	100	40	2.0	2.5	3800	600	84.7	91	2.57	79.6	1.06	82.5	1.03
U1_L4	100	20	2.0	5.0	3300	75	17.5	23	1.81	20.2	0.87	19.0	0.92
	100	20	2.0	5.0	3300	150	20.1	23	2.55	20.2	1.00	20.9	0.96
	100	20	2.0	5.0	3300	300	21.5	23	3.61	20.2	1.07	21.9	0.98
	100	20	2.0	5.0	3300	450	21.8	23	4.42	20.2	1.08	22.2	0.98
	100	20	2.0	5.0	3300	600	21.9	23	5.11	20.2	1.09	22.4	0.98
U2_L4	100	40	2.0	2.5	4600	75	39.0	62	1.10	45.2	0.86	39.2	0.99
	100	40	2.0	2.5	4600	150	50.1	62	1.56	54.4	0.92	48.4	1.04
	100	40	2.0	2.5	4600	300	56.1	62	2.20	54.4	1.03	54.4	1.03
	100	40	2.0	2.5	4600	450	57.9	62	2.69	54.4	1.06	56.8	1.02
	100	40	2.0	2.5	4600	600	58.6	62	3.11	54.4	1.08	58.0	1.01
U1_L5	100	20	2.0	5.0	3900	75	13.2	17	2.13	14.5	0.91	14.4	0.92
	100	20	2.0	5.0	3900	150	14.7	17	3.02	14.5	1.02	15.4	0.96
	100	20	2.0	5.0	3900	300	15.5	17	4.26	14.5	1.07	15.9	0.97
	100	20	2.0	5.0	3900	450	15.7	17	5.22	14.5	1.08	16.1	0.97
	100	20	2.0	5.0	3900	600	15.8	17	6.03	14.5	1.09	16.2	0.97
U2_L5	100	40	2.0	2.5	5500	75	30.6	43	1.31	36.4	0.84	31.0	0.99
	100	40	2.0	2.5	5500	150	36.8	43	1.86	38.1	0.97	36.3	1.01
	100	40	2.0	2.5	5500	300	40.0	43	2.63	38.1	1.05	39.6	1.01
	100	40	2.0	2.5	5500	450	41.0	43	3.22	38.1	1.08	40.8	1.01
	100	40	2.0	2.5	5500	600	41.4	43	3.72	38.1	1.09	41.4	1.00
U1_L6	100	20	2.0	5.0	4500	75	10.2	12	2.46	10.9	0.94	11.2	0.91
	100	20	2.0	5.0	4500	150	11.2	12	3.48	10.9	1.03	11.8	0.95
	100	20	2.0	5.0	4500	300	11.8	12	4.92	10.9	1.09	12.1	0.98
	100	20	2.0	5.0	4500	450	11.9	12	6.02	10.9	1.09	12.2	0.98
	100	20	2.0	5.0	4500	600	11.9	12	6.96	10.9	1.09	12.2	0.97
U2_L6	100	40	2.0	2.5	6300	75	24.8	33	1.51	29.0	0.85	25.4	0.98
	100	40	2.0	2.5	6300	150	28.8	33	2.13	29.0	0.99	28.8	1.00
	100	40	2.0	2.5	6300	300	30.9	33	3.01	29.0	1.06	30.8	1.00
	100	40	2.0	2.5	6300	450	31.5	33	3.69	29.0	1.09	31.6	1.00
	100	40	2.0	2.5	6300	600	31.8	33	4.26	29.0	1.10	31.9	1.00
U3_L6	100	60	2.0	1.7	8700	75	30.9	42	1.33	35.8	0.86	30.5	1.01
	100	60	2.0	1.7	8700	150	36.6	42	1.88	37.2	0.98	35.6	1.03
	100	60	2.0	1.7	8700	300	39.0	42	2.66	37.2	1.05	38.7	1.01
	100	60	2.0	1.7	8700	450	39.0	42	3.26	37.2	1.05	39.9	0.98
	100	60	2.0	1.7	8700	600	39.0	42	3.76	37.2	1.05	40.5	0.96
										Mean	1.00	Mean	1.00
										Sd. Dev.	0.07	Sd. Dev.	0.04
										Max	1.11	Max	1.10
										Min	0.80	Min	0.91

ANNEX B: C COLUMN DATA

Table B1: Columns failing in F_MT modes: (i) geometries, (ii) buckling stresses and ultimate strengths, (iii) ultimate strength predictions by current and proposed DSM design curves, and (iv) numerical-to-predicted ultimate strength ratios (mm and MPa)

	Geometry							SFEA		DSM Design							
Column	b_w	b_f	b_s	t	b_w/b_t	$\beta=I_I/I_{II}$	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	b	a	f_{nFT}	f_u/f_{nFT}
C1_L1	60	55	11	1.2	1.1	1.58	1700	75	69	263	0.53	66.6	1.04	1.01	0.59	66.6	1.04
	60	55	11	1.2	1.1	1.58	1700	150	128	263	0.76	118.1	1.08	1.01	0.59	118.1	1.08
	60	55	11	1.2	1.1	1.58	1700	300	193	263	1.07	186.1	1.04	1.01	0.59	186.1	1.04
	60	55	11	1.2	1.1	1.58	1700	450	217	263	1.31	219.9	0.99	1.01	0.59	219.9	0.99
	60	55	11	1.2	1.1	1.58	1700	600	238	263	1.51	230.7	1.03	1.01	0.59	232.3	1.02
C2_L1	100	60	10	2	1.7	3.53	2300	75	70	333	0.47	68.3	1.03	1.20	0.64	68.3	1.03
	100	60	10	2	1.7	3.53	2300	150	135	333	0.67	124.2	1.09	1.20	0.64	124.2	1.09
	100	60	10	2	1.7	3.53	2300	300	228	333	0.95	205.8	1.11	1.20	0.64	205.8	1.11
	100	60	10	2	1.7	3.53	2300	450	268	333	1.16	255.6	1.05	1.20	0.64	255.6	1.05
	100	60	10	2	1.7	3.53	2300	600	282	333	1.34	282.2	1.00	1.20	0.64	282.2	1.00
C3_L1	120	80	15	3	3.0	2.83	2500	75	71	435	0.42	69.8	1.02	1.13	0.62	69.8	1.02
	120	80	15	3	3.0	2.83	2500	150	139	435	0.59	129.8	1.07	1.13	0.62	129.8	1.07
	120	80	15	3	3.0	2.83	2500	300	255	435	0.83	224.8	1.13	1.13	0.62	224.8	1.13
	120	80	15	3	3.0	2.83	2500	450	321	435	1.02	291.9	1.10	1.13	0.62	291.9	1.10
	120	80	15	3	3.0	2.83	2500	600	354	435	1.17	336.8	1.05	1.13	0.62	336.8	1.05
C4_L1	140	70	10	3	3.0	5.14	2900	75	71	369	0.45	68.9	1.03	1.36	0.68	68.9	1.03
	140	70	10	3	3.0	5.14	2900	150	137	369	0.64	126.5	1.08	1.36	0.68	126.5	1.08
	140	70	10	3	3.0	5.14	2900	300	243	369	0.90	213.5	1.14	1.36	0.68	213.5	1.14
	140	70	10	3	3.0	5.14	2900	450	295	369	1.10	270.1	1.09	1.36	0.68	270.1	1.09
	140	70	10	3	3.0	5.14	2900	600	316	369	1.28	303.8	1.04	1.36	0.68	303.8	1.04
C5_L1	150	100	10	4	1.5	3.15	3600	75	70	316	0.49	67.9	1.04	1.16	0.63	67.9	1.04
	150	100	10	4	1.5	3.15	3600	150	135	316	0.69	123.0	1.10	1.16	0.63	123.0	1.10
	150	100	10	4	1.5	3.15	3600	300	230	316	0.97	201.6	1.14	1.16	0.63	201.6	1.14
	150	100	10	4	1.5	3.15	3600	450	267	316	1.19	247.9	1.08	1.16	0.63	247.9	1.08
	150	100	10	4	1.5	3.15	3600	600	280	316	1.38	271.0	1.03	1.16	0.63	271.0	1.03
C6_L1	80	65	15	1.2	1.2	1.87	2600	75	67	205	0.60	64.4	1.04	1.04	0.59	64.4	1.04
	80	65	15	1.2	1.2	1.87	2600	150	118	205	0.86	110.4	1.07	1.04	0.59	110.4	1.07
	80	65	15	1.2	1.2	1.87	2600	300	163	205	1.21	162.6	1.00	1.04	0.59	162.6	1.00
	80	65	15	1.2	1.2	1.87	2600	450	173	205	1.48	179.6	0.96	1.04	0.59	179.6	0.96
	80	65	15	1.2	1.2	1.87	2600	600	185	205	1.71	179.8	1.03	1.04	0.59	204.1	0.91
C7_L1	95	50	10	1.8	1.9	4.36	2100	75	70	349	0.46	68.5	1.03	1.29	0.66	68.5	1.03
	95	50	10	1.8	1.9	4.36	2100	150	136	349	0.66	125.3	1.09	1.29	0.66	125.3	1.09
	95	50	10	1.8	1.9	4.36	2100	300	234	349	0.93	209.3	1.12	1.29	0.66	209.3	1.12
	95	50	10	1.8	1.9	4.36	2100	450	280	349	1.14	262.3	1.07	1.29	0.66	262.3	1.07
	95	50	10	1.8	1.9	4.36	2100	600	297	349	1.31	292.2	1.02	1.29	0.66	292.2	1.02
C8_L1	75	60	10	1	1.3	2.07	2600	75	64	161	0.68	61.7	1.04	1.06	0.60	61.7	1.04
	75	60	10	1	1.3	2.07	2600	150	103	161	0.97	101.6	1.01	1.06	0.60	101.6	1.01
	75	60	10	1	1.3	2.07	2600	300	131	161	1.37	137.5	0.95	1.06	0.60	137.5	0.95
	75	60	10	1	1.3	2.07	2600	450	145	161	1.67	141.2	1.03	1.06	0.60	156.5	0.93
	75	60	10	1	1.3	2.07	2600	600	153	161	1.93	141.2	1.08	1.06	0.60	179.2	0.85
C9_L1	80	45	11	1.6	1.8	3.68	1700	75	71	411	0.43	69.5	1.02	1.22	0.64	69.5	1.02
	80	45	11	1.6	1.8	3.68	1700	150	138	411	0.60	128.8	1.07	1.22	0.64	128.8	1.07
	80	45	11	1.6	1.8	3.68	1700	300	249	411	0.85	221.0	1.13	1.22	0.64	221.0	1.13
	80	45	11	1.6	1.8	3.68	1700	450	310	411	1.05	284.6	1.09	1.22	0.64	284.6	1.09
	80	45	11	1.6	1.8	3.68	1700	600	338	411	1.21	325.7	1.04	1.22	0.64	325.7	1.04
C1_L2	60	55	11	1.2	1.1	1.58	2380	75	63	146	0.72	60.5	1.04	1.01	0.59	60.5	1.04
	60	55	11	1.2	1.1	1.58	2380	150	103	146	1.01	97.6	1.06	1.01	0.59	97.6	1.06
	60	55	11	1.2	1.1	1.58	2380	300	133	146	1.43	126.9	1.05	1.01	0.59	126.9	1.05
	60	55	11	1.2	1.1	1.58	2380	450	153	146	1.76	128.0	1.19	1.01	0.59	149.7	1.02
	60	55	11	1.2	1.1	1.58	2380	600	176	146	2.03	128.0	1.37	1.01	0.59	172.7	1.02
C2_L2	100	60	10	2	1.7	3.53	3220	75	66	184	0.64	63.2	1.05	1.20	0.64	63.2	1.05
	100	60	10	2	1.7	3.53	3220	150	117	184	0.90	106.6	1.10	1.20	0.64	106.6	1.10
	100	60	10	2	1.7	3.53	3220	300	162	184	1.28	151.6	1.07	1.20	0.64	151.6	1.07
	100	60	10	2	1.7	3.53	3220	450	180	184	1.56	161.4	1.12	1.20	0.64	166.9	1.08
	100	60	10	2	1.7	3.53	3220	600	197	184	1.81	161.4	1.22	1.20	0.64	187.2	1.05
C3_L2	120	80	15	3	3.0	2.83	3500	75	69	242	0.56	65.9	1.04	1.13	0.62	65.9	1.04
	120	80	15	3	3.0	2.83	3500	150	127	242	0.79	115.7	1.10	1.13	0.62	115.7	1.10
	120	80	15	3	3.0	2.83	3500	300	196	242	1.11	178.4	1.10	1.13	0.62	178.4	1.10
	120	80	15	3	3.0	2.83	3500	450	222	242	1.36	206.4	1.08	1.13	0.62	206.4	1.08
	120	80	15	3	3.0	2.83	3500	600	238	242	1.58	211.9	1.12	1.13	0.62	221.2	1.08
C4_L2	140	70	10	3	3.0	5.14	4060	75	68	206	0.60	64.4	1.05	1.36	0.68	64.4	1.05
	140	70	10	3	3.0	5.14	4060	150	122	206	0.85	110.6	1.10	1.36	0.68	110.6	1.10
	140	70	10	3	3.0	5.14	4060	300	177	206	1.21	163.1	1.09	1.36	0.68	163.1	1.09
	140	70	10	3	3.0	5.14	4060	450	198	206	1.48	180.4	1.10	1.36	0.68	180.4	1.10
	140	70	10	3	3.0	5.14	4060	600	214	206	1.71	180.7	1.18	1.36	0.68	196.2	1.09

	Geometry							SFEA		DSM Design							
Column	b_w	b_f	b_s	t	b_w/b_t	$\beta=I_I/I_{II}$	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	b	a	f_{nFT}	f_u/f_{nFT}
C5_L2	150	100	10	4	1.5	3.15	5040	75	67	179	0.65	63.0	1.06	1.16	0.63	63.0	1.06
	150	100	10	4	1.5	3.15	5040	150	117	179	0.91	105.7	1.11	1.16	0.63	105.7	1.11
	150	100	10	4	1.5	3.15	5040	300	161	179	1.29	149.0	1.08	1.16	0.63	149.0	1.08
	150	100	10	4	1.5	3.15	5040	450	181	179	1.58	157.3	1.15	1.16	0.63	164.7	1.10
	150	100	10	4	1.5	3.15	5040	600	201	179	1.83	157.3	1.28	1.16	0.63	185.7	1.08
C6_L2	80	65	15	1.2	1.2	1.87	3640	75	59	111	0.82	56.5	1.03	1.04	0.59	56.5	1.03
	80	65	15	1.2	1.2	1.87	3640	150	88	111	1.16	85.2	1.03	1.04	0.59	85.2	1.03
	80	65	15	1.2	1.2	1.87	3640	300	110	111	1.64	97.3	1.13	1.04	0.59	106.4	1.03
	80	65	15	1.2	1.2	1.87	3640	450	128	111	2.01	97.3	1.31	1.04	0.59	129.3	0.99
	80	65	15	1.2	1.2	1.87	3640	600	138	111	2.32	97.3	1.42	1.04	0.59	148.5	0.93
C7_L2	95	50	10	1.8	1.9	4.36	2940	75	67	191	0.63	63.6	1.05	1.29	0.66	63.6	1.05
	95	50	10	1.8	1.9	4.36	2940	150	118	191	0.89	108.0	1.09	1.29	0.66	108.0	1.09
	95	50	10	1.8	1.9	4.36	2940	300	166	191	1.25	155.6	1.07	1.29	0.66	155.6	1.07
	95	50	10	1.8	1.9	4.36	2940	450	185	191	1.53	167.7	1.10	1.29	0.66	170.5	1.09
	95	50	10	1.8	1.9	4.36	2940	600	200	191	1.77	167.7	1.19	1.29	0.66	188.9	1.06
C8_L2	75	60	10	1	1.3	2.07	3640	75	54	87	0.93	52.4	1.03	1.06	0.60	52.4	1.03
	75	60	10	1	1.3	2.07	3640	150	75	87	1.31	73.1	1.02	1.06	0.60	73.1	1.02
	75	60	10	1	1.3	2.07	3640	300	97	87	1.85	76.6	1.26	1.06	0.60	93.6	1.03
	75	60	10	1	1.3	2.07	3640	450	110	87	2.27	76.6	1.44	1.06	0.60	113.3	0.97
	75	60	10	1	1.3	2.07	3640	600	120	87	2.62	76.6	1.57	1.06	0.60	129.8	0.92
C9_L2	80	45	11	1.6	1.8	3.68	2380	75	68	224	0.58	65.2	1.04	1.22	0.64	65.2	1.04
	80	45	11	1.6	1.8	3.68	2380	150	124	224	0.82	113.3	1.09	1.22	0.64	113.3	1.09
	80	45	11	1.6	1.8	3.68	2380	300	185	224	1.16	171.2	1.08	1.22	0.64	171.2	1.08
	80	45	11	1.6	1.8	3.68	2380	450	207	224	1.42	194.0	1.07	1.22	0.64	194.0	1.07
	80	45	11	1.6	1.8	3.68	2380	600	221	224	1.64	196.4	1.13	1.22	0.64	210.4	1.05
C1_L3	60	55	11	1.2	1.1	1.58	3060	75	55	92	0.90	53.4	1.03	1.01	0.59	53.4	1.03
	60	55	11	1.2	1.1	1.58	3060	150	78	92	1.27	76.0	1.03	1.01	0.59	76.0	1.03
	60	55	11	1.2	1.1	1.58	3060	300	100	92	1.80	81.0	1.23	1.01	0.59	97.2	1.03
	60	55	11	1.2	1.1	1.58	3060	450	124	92	2.21	81.0	1.53	1.01	0.59	118.9	1.04
	60	55	11	1.2	1.1	1.58	3060	600	145	92	2.55	81.0	1.79	1.01	0.59	137.1	1.06
C2_L3	100	60	10	2	1.7	3.53	4140	75	61	119	0.79	57.6	1.06	1.20	0.64	57.6	1.06
	100	60	10	2	1.7	3.53	4140	150	94	119	1.12	88.5	1.06	1.20	0.64	88.5	1.06
	100	60	10	2	1.7	3.53	4140	300	119	119	1.59	104.4	1.14	1.20	0.64	109.2	1.09
	100	60	10	2	1.7	3.53	4140	450	138	119	1.94	104.4	1.32	1.20	0.64	128.4	1.07
	100	60	10	2	1.7	3.53	4140	600	155	119	2.25	104.4	1.49	1.20	0.64	144.0	1.08
C3_L3	120	80	15	3	3.0	2.83	4500	75	65	157	0.69	61.4	1.06	1.13	0.62	61.4	1.06
	120	80	15	3	3.0	2.83	4500	150	110	157	0.98	100.5	1.09	1.13	0.62	100.5	1.09
	120	80	15	3	3.0	2.83	4500	300	145	157	1.38	134.8	1.08	1.13	0.62	134.8	1.08
	120	80	15	3	3.0	2.83	4500	450	164	157	1.69	137.6	1.19	1.13	0.62	152.9	1.07
	120	80	15	3	3.0	2.83	4500	600	183	157	1.96	137.6	1.33	1.13	0.62	173.2	1.06
C4_L3	140	70	10	3	3.0	5.14	5220	75	64	138	0.74	59.7	1.07	1.36	0.68	59.7	1.07
	140	70	10	3	3.0	5.14	5220	150	103	138	1.04	95.0	1.08	1.36	0.68	95.0	1.08
	140	70	10	3	3.0	5.14	5220	300	132	138	1.48	120.4	1.10	1.36	0.68	120.4	1.10
	140	70	10	3	3.0	5.14	5220	450	150	138	1.81	120.6	1.24	1.36	0.68	135.9	1.10
	140	70	10	3	3.0	5.14	5220	600	164	138	2.09	120.6	1.36	1.36	0.68	148.9	1.10
C5_L3	150	100	10	4	1.5	3.15	6480	75	62	121	0.79	57.9	1.08	1.16	0.63	57.9	1.08
	150	100	10	4	1.5	3.15	6480	150	94	121	1.11	89.4	1.06	1.16	0.63	89.4	1.06
	150	100	10	4	1.5	3.15	6480	300	122	121	1.57	106.5	1.15	1.16	0.63	110.8	1.10
	150	100	10	4	1.5	3.15	6480	450	143	121	1.93	106.5	1.34	1.16	0.63	131.2	1.09
	150	100	10	4	1.5	3.15	6480	600	162	121	2.22	106.5	1.52	1.16	0.63	147.9	1.10
C6_L3	80	65	15	1.2	1.2	1.87	4680	75	48	70	1.04	47.9	1.01	1.04	0.59	47.9	1.01
	80	65	15	1.2	1.2	1.87	4680	150	64	70	1.46	61.1	1.05	1.04	0.59	61.1	1.05
	80	65	15	1.2	1.2	1.87	4680	300	86	70	2.07	61.3	1.39	1.04	0.59	83.7	1.02
	80	65	15	1.2	1.2	1.87	4680	450	101	70	2.54	61.3	1.65	1.04	0.59	101.7	0.99
	80	65	15	1.2	1.2	1.87	4680	600	111	70	2.93	61.3	1.81	1.04	0.59	116.8	0.95
C7_L3	95	50	10	1.8	1.9	4.36	3780	75	62	125	0.78	58.3	1.06	1.29	0.66	58.3	1.06
	95	50	10	1.8	1.9	4.36	3780	150	96	125	1.10	90.6	1.06	1.29	0.66	90.6	1.06
	95	50	10	1.8	1.9	4.36	3780	300	122	125	1.55	109.2	1.12	1.29	0.66	111.9	1.09
	95	50	10	1.8	1.9	4.36	3780	450	139	125	1.90	109.2	1.27	1.29	0.66	129.4	1.07
	95	50	10	1.8	1.9	4.36	3780	600	153	125	2.20	109.2	1.40	1.29	0.66	143.3	1.07
C8_L3	75	60	10	1	1.3	2.07	4680	75	42	55	1.16	42.5	0.99	1.06	0.60	42.5	0.99
	75	60	10	1	1.3	2.07	4680	150	56	55	1.65	48.5	1.15	1.06	0.60	53.0	1.05
	75	60	10	1	1.3	2.07	4680	300	78	55	2.33	48.5	1.61	1.06	0.60	73.5	1.06
	75	60	10	1	1.3	2.07	4680	450	90	55	2.85	48.5	1.85	1.06	0.60	89.0	1.01
	75	60	10	1	1.3	2.07	4680	600	98	55	3.29	48.5	2.02	1.06	0.60	101.9	0.96
C9_L3	80	45	11	1.6	1.8	3.68	3060	75	64	144	0.72	60.3	1.05	1.22	0.64	60.3	1.05
	80	45	11	1.6	1.8	3.68	3060	150	104	144	1.02	97.0	1.07	1.22	0.64	97.0	1.07
	80	45	11	1.6	1.8	3.68	3060	300	135	144	1.44	125.4	1.08	1.22	0.64	125.4	1.08
	80	45	11	1.6	1.8	3.68	3060	450	152	144	1.77	126.3	1.20	1.22	0.64	143.7	1.06
	80	45	11	1.6	1.8	3.68	3060	600	167	144	2.04	126.3	1.32	1.22	0.64	160.8	1.04

	Geometry							SFEA		DSM Design							
Column	b_w	b_f	b_s	t	b_w/b_t	$\beta=I_I/I_{II}$	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	b	a	f_{nFT}	f_u/f_{nFT}
C1_L4	60	55	11	1.2	1.1	1.58	3740	75	47	65	1.08	46.2	1.01	1.01	0.59	46.2	1.01
	60	55	11	1.2	1.1	1.58	3740	150	62	65	1.52	56.8	1.08	1.01	0.59	57.7	1.07
	60	55	11	1.2	1.1	1.58	3740	300	85	65	2.15	56.8	1.49	1.01	0.59	81.3	1.04
	60	55	11	1.2	1.1	1.58	3740	450	107	65	2.64	56.8	1.88	1.01	0.59	99.4	1.08
	60	55	11	1.2	1.1	1.58	3740	600	125	65	3.04	56.8	2.20	1.01	0.59	114.7	1.09
C2_L4	100	60	10	2	1.7	3.53	5060	75	55	87	0.93	52.3	1.05	1.20	0.64	52.3	1.05
	100	60	10	2	1.7	3.53	5060	150	76	87	1.31	72.9	1.04	1.20	0.64	72.9	1.04
	100	60	10	2	1.7	3.53	5060	300	97	87	1.86	76.3	1.27	1.20	0.64	90.5	1.07
	100	60	10	2	1.7	3.53	5060	450	114	87	2.27	76.3	1.49	1.20	0.64	106.3	1.07
	100	60	10	2	1.7	3.53	5060	600	127	87	2.63	76.3	1.66	1.20	0.64	119.3	1.06
C3_L4	120	80	15	3	3.0	2.83	5500	75	61	113	0.81	56.9	1.06	1.13	0.62	56.9	1.06
	120	80	15	3	3.0	2.83	5500	150	91	113	1.15	86.2	1.06	1.13	0.62	86.2	1.06
	120	80	15	3	3.0	2.83	5500	300	115	113	1.63	99.4	1.16	1.13	0.62	106.7	1.08
	120	80	15	3	3.0	2.83	5500	450	134	113	1.99	99.4	1.35	1.13	0.62	127.2	1.05
	120	80	15	3	3.0	2.83	5500	600	153	113	2.30	99.4	1.54	1.13	0.62	144.1	1.06
C4_L4	140	70	10	3	3.0	5.14	6380	75	59	103	0.85	55.2	1.07	1.36	0.68	55.2	1.07
	140	70	10	3	3.0	5.14	6380	150	86	103	1.21	81.3	1.06	1.36	0.68	81.3	1.06
	140	70	10	3	3.0	5.14	6380	300	107	103	1.71	90.0	1.19	1.36	0.68	97.8	1.09
	140	70	10	3	3.0	5.14	6380	450	121	103	2.09	90.0	1.34	1.36	0.68	111.3	1.09
	140	70	10	3	3.0	5.14	6380	600	129	103	2.42	90.0	1.43	1.36	0.68	122.0	1.06
C5_L4	150	100	10	4	1.5	3.15	7920	75	57	92	0.90	53.2	1.07	1.16	0.63	53.2	1.07
	150	100	10	4	1.5	3.15	7920	150	80	92	1.28	75.6	1.06	1.16	0.63	75.6	1.06
	150	100	10	4	1.5	3.15	7920	300	101	92	1.81	80.3	1.26	1.16	0.63	94.0	1.07
	150	100	10	4	1.5	3.15	7920	450	120	92	2.22	80.3	1.49	1.16	0.63	111.3	1.08
	150	100	10	4	1.5	3.15	7920	600	134	92	2.56	80.3	1.67	1.16	0.63	125.6	1.07
C6_L4	80	65	15	1.2	1.2	1.87	5720	75	39	49	1.24	39.4	0.99	1.04	0.59	39.4	0.99
	80	65	15	1.2	1.2	1.87	5720	150	51	49	1.76	42.7	1.20	1.04	0.59	49.7	1.03
	80	65	15	1.2	1.2	1.87	5720	300	73	49	2.48	42.7	1.71	1.04	0.59	69.4	1.05
	80	65	15	1.2	1.2	1.87	5720	450	87	49	3.04	42.7	2.04	1.04	0.59	84.3	1.04
	80	65	15	1.2	1.2	1.87	5720	600	93	49	3.51	42.7	2.17	1.04	0.59	96.9	0.96
C7_L4	95	50	10	1.8	1.9	4.36	4620	75	56	91	0.91	53.0	1.05	1.29	0.66	53.0	1.05
	95	50	10	1.8	1.9	4.36	4620	150	78	91	1.29	75.0	1.04	1.29	0.66	75.0	1.04
	95	50	10	1.8	1.9	4.36	4620	300	98	91	1.82	79.4	1.23	1.29	0.66	91.2	1.07
	95	50	10	1.8	1.9	4.36	4620	450	112	91	2.23	79.4	1.41	1.29	0.66	105.4	1.06
	95	50	10	1.8	1.9	4.36	4620	600	122	91	2.57	79.4	1.54	1.29	0.66	116.8	1.04
C8_L4	75	60	10	1	1.3	2.07	5720	75	34	39	1.39	33.4	1.02	1.06	0.60	33.4	1.02
	75	60	10	1	1.3	2.07	5720	150	46	39	1.97	34.0	1.36	1.06	0.60	43.9	1.05
	75	60	10	1	1.3	2.07	5720	300	67	39	2.78	34.0	1.98	1.06	0.60	60.9	1.10
	75	60	10	1	1.3	2.07	5720	450	75	39	3.41	34.0	2.21	1.06	0.60	73.8	1.02
	75	60	10	1	1.3	2.07	5720	600	82	39	3.93	34.0	2.40	1.06	0.60	84.5	0.97
C9_L4	80	45	11	1.6	1.8	3.68	3740	75	58	103	0.85	55.3	1.05	1.22	0.64	55.3	1.05
	80	45	11	1.6	1.8	3.68	3740	150	85	103	1.21	81.6	1.04	1.22	0.64	81.6	1.04
	80	45	11	1.6	1.8	3.68	3740	300	106	103	1.71	90.4	1.17	1.22	0.64	100.0	1.06
	80	45	11	1.6	1.8	3.68	3740	450	122	103	2.09	90.4	1.35	1.22	0.64	117.2	1.04
	80	45	11	1.6	1.8	3.68	3740	600	135	103	2.41	90.4	1.49	1.22	0.64	131.2	1.03
C1_L5	60	55	11	1.2	1.1	1.58	4420	75	39	49	1.24	39.4	1.00	1.01	0.59	39.4	1.00
	60	55	11	1.2	1.1	1.58	4420	150	52	49	1.76	42.7	1.21	1.01	0.59	49.9	1.04
	60	55	11	1.2	1.1	1.58	4420	300	75	49	2.48	42.7	1.76	1.01	0.59	70.4	1.07
	60	55	11	1.2	1.1	1.58	4420	450	95	49	3.04	42.7	2.21	1.01	0.59	86.1	1.10
	60	55	11	1.2	1.1	1.58	4420	600	108	49	3.51	42.7	2.53	1.01	0.59	99.3	1.09
C2_L5	100	60	10	2	1.7	3.53	5980	75	49	67	1.06	46.9	1.04	1.20	0.64	46.9	1.04
	100	60	10	2	1.7	3.53	5980	150	64	67	1.50	58.8	1.09	1.20	0.64	58.8	1.09
	100	60	10	2	1.7	3.53	5980	300	83	67	2.12	58.8	1.41	1.20	0.64	77.3	1.07
	100	60	10	2	1.7	3.53	5980	450	96	67	2.59	58.8	1.63	1.20	0.64	90.9	1.05
	100	60	10	2	1.7	3.53	5980	600	103	67	2.99	58.8	1.75	1.20	0.64	101.9	1.01
C3_L5	120	80	15	3	3.0	2.83	6500	75	56	88	0.92	52.5	1.06	1.13	0.62	52.5	1.06
	120	80	15	3	3.0	2.83	6500	150	77	88	1.31	73.5	1.05	1.13	0.62	73.5	1.05
	120	80	15	3	3.0	2.83	6500	300	98	88	1.85	77.2	1.26	1.13	0.62	92.4	1.05
	120	80	15	3	3.0	2.83	6500	450	116	88	2.26	77.2	1.50	1.13	0.62	110.2	1.05
	120	80	15	3	3.0	2.83	6500	600	130	88	2.61	77.2	1.68	1.13	0.62	124.8	1.04
C4_L5	140	70	10	3	3.0	5.14	6940	75	57	92	0.91	53.2	1.07	1.36	0.68	53.2	1.07
	140	70	10	3	3.0	5.14	6940	150	80	92	1.28	75.5	1.05	1.36	0.68	75.5	1.05
	140	70	10	3	3.0	5.14	6940	300	98	92	1.81	80.2	1.22	1.36	0.68	90.5	1.08
	140	70	10	3	3.0	5.14	6940	450	109	92	2.22	80.2	1.36	1.36	0.68	103.0	1.06
	140	70	10	3	3.0	5.14	6940	600	114	92	2.56	80.2	1.42	1.36	0.68	112.8	1.01
C5_L5	150	100	10	4	1.5	3.15	9360	75	52	74	1.01	49.1	1.06	1.16	0.63	49.1	1.06
	150	100	10	4	1.5	3.15	9360	150	69	74	1.42	64.4	1.07	1.16	0.63	64.4	1.07
	150	100	10	4	1.5	3.15	9360	300	88	74	2.01	65.1	1.34	1.16	0.63	83.2	1.05
	150	100	10	4	1.5	3.15	9360	450	101	74	2.46	65.1	1.55	1.16	0.63	98.5	1.03
	150	100	10	4	1.5	3.15	9360	600	109	74	2.84	65.1	1.68	1.16	0.63	111.1	0.98

	Geometry							SFEA		DSM Design							
Column	b_w	b_f	b_s	t	b_w/b_t	$\beta=I_I/I_{II}$	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	b	a	f_{nFT}	f_u/f_{nFT}
C6_L5	80	65	15	1.2	1.2	1.87	6760	75	32	37	1.43	31.7	1.02	1.04	0.59	31.7	1.02
	80	65	15	1.2	1.2	1.87	6760	150	44	37	2.03	32.0	1.37	1.04	0.59	42.8	1.02
	80	65	15	1.2	1.2	1.87	6760	300	64	37	2.87	32.0	1.99	1.04	0.59	59.7	1.07
	80	65	15	1.2	1.2	1.87	6760	450	73	37	3.51	32.0	2.29	1.04	0.59	72.6	1.01
	80	65	15	1.2	1.2	1.87	6760	600	80	37	4.05	32.0	2.50	1.04	0.59	83.4	0.96
C7_L5	95	50	10	1.8	1.9	4.36	5060	75	53	71	1.03	48.1	1.09	1.29	0.66	48.1	1.09
	95	50	10	1.8	1.9	4.36	5060	150	71	71	1.46	61.8	1.15	1.29	0.66	61.8	1.15
	95	50	10	1.8	1.9	4.36	5060	300	89	71	2.06	62.1	1.43	1.29	0.66	77.9	1.14
	95	50	10	1.8	1.9	4.36	5060	450	101	71	2.52	62.1	1.63	1.29	0.66	90.0	1.12
	95	50	10	1.8	1.9	4.36	5060	600	108	71	2.91	62.1	1.74	1.29	0.66	99.7	1.08
C8_L5	75	60	10	1	1.3	2.07	6760	75	29	29	1.60	25.6	1.11	1.06	0.60	27.3	1.05
	75	60	10	1	1.3	2.07	6760	150	41	29	2.27	25.6	1.59	1.06	0.60	37.8	1.08
	75	60	10	1	1.3	2.07	6760	300	59	29	3.21	25.6	2.29	1.06	0.60	52.4	1.12
	75	60	10	1	1.3	2.07	6760	450	65	29	3.93	25.6	2.55	1.06	0.60	63.5	1.03
	75	60	10	1	1.3	2.07	6760	600	70	29	4.53	25.6	2.72	1.06	0.60	72.7	0.96
C9_L5	80	45	11	1.6	1.8	3.68	4420	75	53	80	0.97	50.5	1.04	1.22	0.64	50.5	1.04
	80	45	11	1.6	1.8	3.68	4420	150	71	80	1.37	68.1	1.04	1.22	0.64	68.1	1.04
	80	45	11	1.6	1.8	3.68	4420	300	89	80	1.94	69.7	1.28	1.22	0.64	85.4	1.04
	80	45	11	1.6	1.8	3.68	4420	450	102	80	2.38	69.7	1.46	1.22	0.64	100.1	1.02
	80	45	11	1.6	1.8	3.68	4420	600	111	80	2.75	69.7	1.59	1.22	0.64	112.0	0.99
C1_L6	60	55	11	1.2	1.1	1.58	5100	75	34	39	1.39	33.3	1.02	1.01	0.59	33.3	1.02
	60	55	11	1.2	1.1	1.58	5100	150	46	39	1.97	33.9	1.35	1.01	0.59	44.4	1.03
	60	55	11	1.2	1.1	1.58	5100	300	68	39	2.79	33.9	2.00	1.01	0.59	62.6	1.08
	60	55	11	1.2	1.1	1.58	5100	450	83	39	3.41	33.9	2.45	1.01	0.59	76.6	1.09
	60	55	11	1.2	1.1	1.58	5100	600	93	39	3.94	33.9	2.74	1.01	0.59	88.3	1.05
C2_L6	100	60	10	2	1.7	3.53	6900	75	43	55	1.17	42.4	1.02	1.20	0.64	42.4	1.02
	100	60	10	2	1.7	3.53	6900	150	56	55	1.65	48.2	1.15	1.20	0.64	52.1	1.07
	100	60	10	2	1.7	3.53	6900	300	71	55	2.34	48.2	1.48	1.20	0.64	68.7	1.04
	100	60	10	2	1.7	3.53	6900	450	80	55	2.86	48.2	1.65	1.20	0.64	80.7	0.99
	100	60	10	2	1.7	3.53	6900	600	83	55	3.30	48.2	1.72	1.20	0.64	90.5	0.92
C3_L6	120	80	15	3	3.0	2.83	7500	75	51	72	1.02	48.5	1.04	1.13	0.62	48.5	1.04
	120	80	15	3	3.0	2.83	7500	150	67	72	1.44	62.7	1.06	1.13	0.62	62.7	1.06
	120	80	15	3	3.0	2.83	7500	300	86	72	2.04	63.1	1.36	1.13	0.62	82.5	1.04
	120	80	15	3	3.0	2.83	7500	450	101	72	2.50	63.1	1.60	1.13	0.62	98.4	1.03
	120	80	15	3	3.0	2.83	7500	600	111	72	2.89	63.1	1.76	1.13	0.62	111.4	1.00
C4_L6	140	70	10	3	3.0	5.14	7500	75	55	82	0.95	51.2	1.07	1.36	0.68	51.2	1.07
	140	70	10	3	3.0	5.14	7500	150	74	82	1.35	70.0	1.06	1.36	0.68	70.0	1.06
	140	70	10	3	3.0	5.14	7500	300	90	82	1.91	72.2	1.25	1.36	0.68	84.2	1.07
	140	70	10	3	3.0	5.14	7500	450	99	82	2.34	72.2	1.36	1.36	0.68	95.8	1.03
	140	70	10	3	3.0	5.14	7500	600	102	82	2.70	72.2	1.41	1.36	0.68	104.9	0.97
C5_L6	150	100	10	4	1.5	3.15	10000	75	50	69	1.05	47.5	1.05	1.16	0.63	47.5	1.05
	150	100	10	4	1.5	3.15	10000	150	65	69	1.48	60.1	1.08	1.16	0.63	60.1	1.08
	150	100	10	4	1.5	3.15	10000	300	82	69	2.09	60.2	1.36	1.16	0.63	79.4	1.03
	150	100	10	4	1.5	3.15	10000	450	93	69	2.56	60.2	1.55	1.16	0.63	94.1	0.99
	150	100	10	4	1.5	3.15	10000	600	99	69	2.96	60.2	1.65	1.16	0.63	106.1	0.94
C6_L6	80	65	15	1.2	1.2	1.87	7800	75	28	29	1.61	25.3	1.10	1.04	0.59	27.1	1.03
	80	65	15	1.2	1.2	1.87	7800	150	39	29	2.28	25.3	1.55	1.04	0.59	37.8	1.03
	80	65	15	1.2	1.2	1.87	7800	300	56	29	3.23	25.3	2.21	1.04	0.59	52.8	1.06
	80	65	15	1.2	1.2	1.87	7800	450	63	29	3.95	25.3	2.48	1.04	0.59	64.2	0.97
	80	65	15	1.2	1.2	1.87	7800	600	65	29	4.56	25.3	2.59	1.04	0.59	73.8	0.89
C7_L6	95	50	10	1.8	1.9	4.36	5500	75	50	58	1.13	43.8	1.13	1.29	0.66	43.8	1.13
	95	50	10	1.8	1.9	4.36	5500	150	65	58	1.60	51.1	1.28	1.29	0.66	53.7	1.22
	95	50	10	1.8	1.9	4.36	5500	300	82	58	2.27	51.1	1.59	1.29	0.66	68.7	1.19
	95	50	10	1.8	1.9	4.36	5500	450	91	58	2.78	51.1	1.78	1.29	0.66	79.4	1.14
	95	50	10	1.8	1.9	4.36	5500	600	95	58	3.21	51.1	1.86	1.29	0.66	88.0	1.08
C8_L6	75	60	10	1	1.3	2.07	7800	75	25	23	1.80	20.3	1.23	1.06	0.60	24.1	1.04
	75	60	10	1	1.3	2.07	7800	150	37	23	2.54	20.3	1.81	1.06	0.60	33.5	1.10
	75	60	10	1	1.3	2.07	7800	300	50	23	3.60	20.3	2.47	1.06	0.60	46.4	1.08
	75	60	10	1	1.3	2.07	7800	450	54	23	4.40	20.3	2.65	1.06	0.60	56.2	0.96
	75	60	10	1	1.3	2.07	7800	600	55	23	5.09	20.3	2.72	1.06	0.60	64.4	0.86
C9_L6	80	45	11	1.6	1.8	3.68	5100	75	47	65	1.08	46.1	1.02	1.22	0.64	46.1	1.02
	80	45	11	1.6	1.8	3.68	5100	150	61	65	1.52	56.6	1.08	1.22	0.64	57.3	1.06
	80	45	11	1.6	1.8	3.68	5100	300	77	65	2.16	56.6	1.35	1.22	0.64	75.2	1.02
	80	45	11	1.6	1.8	3.68	5100	450	86	65	2.64	56.6	1.52	1.22	0.64	88.1	0.98
	80	45	11	1.6	1.8	3.68	5100	600	91	65	3.05	56.6	1.60	1.22	0.64	98.6	0.92
											Mean		1.31		Mean		1.05
											Sd. Dev.		0.39		Sd. Dev.		0.05
											Max		2.74		Max		1.22
											Min		0.95		Min		0.85

ANNEX C: H Column Data

Table C1: Columns failing in F_MT modes: (i) geometries, (ii) buckling stresses and ultimate strengths, (iii) ultimate strength predictions by current and proposed DSM design curves, and (iv) numerical-to-predicted ultimate strength ratios (mm and MPa)

	Geometry							SFEA		DSM Design							
Column	b_w	b_f	b_s	t	b_w/b_t	$\beta=I_I/I_{II}$	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	b	a	f_{nFT}	f_u/f_{nFT}
H1_L1	60	55	11	1.2	1.1	1.72	1000	75	71	330	0.48	68.2	1.05	1.02	0.59	68.2	1.05
	60	55	11	1.2	1.1	1.72	1000	150	138	330	0.67	124.0	1.11	1.02	0.59	124.0	1.11
	60	55	11	1.2	1.1	1.72	1000	300	239	330	0.95	205.1	1.17	1.02	0.59	205.1	1.17
	60	55	11	1.2	1.1	1.72	1000	450	292	330	1.17	254.3	1.15	1.02	0.59	254.3	1.15
	60	55	11	1.2	1.1	1.72	1000	600	324	330	1.35	280.3	1.16	1.02	0.59	280.3	1.16
H2_L1	100	60	10	2	1.7	3.70	2000	75	70	334	0.47	68.3	1.03	1.22	0.64	68.3	1.03
	100	60	10	2	1.7	3.70	2000	150	136	334	0.67	124.3	1.09	1.22	0.64	124.3	1.09
	100	60	10	2	1.7	3.70	2000	300	236	334	0.95	206.0	1.15	1.22	0.64	206.0	1.15
	100	60	10	2	1.7	3.70	2000	450	278	334	1.16	256.0	1.09	1.22	0.64	256.0	1.09
	100	60	10	2	1.7	3.70	2000	600	292	334	1.34	282.8	1.03	1.22	0.64	282.8	1.03
H3_L1	120	80	15	3	1.5	3.02	1900	75	72	476	0.40	70.2	1.03	1.15	0.62	70.2	1.03
	120	80	15	3	1.5	3.02	1900	150	142	476	0.56	131.5	1.08	1.15	0.62	131.5	1.08
	120	80	15	3	1.5	3.02	1900	300	267	476	0.79	230.4	1.16	1.15	0.62	230.4	1.16
	120	80	15	3	1.5	3.02	1900	450	355	476	0.97	302.8	1.17	1.15	0.62	302.8	1.17
	120	80	15	3	1.5	3.02	1900	600	397	476	1.12	353.9	1.12	1.15	0.62	353.9	1.12
H4_L1	140	70	10	3	3.0	5.28	2600	75	71	385	0.44	69.1	1.02	1.38	0.68	69.1	1.02
	140	70	10	3	2.0	5.28	2600	150	138	385	0.62	127.4	1.08	1.38	0.68	127.4	1.08
	140	70	10	3	2.0	5.28	2600	300	249	385	0.88	216.5	1.15	1.38	0.68	216.5	1.15
	140	70	10	3	2.0	5.28	2600	450	311	385	1.08	275.9	1.13	1.38	0.68	275.9	1.13
	140	70	10	3	2.0	5.28	2600	600	334	385	1.25	312.5	1.07	1.38	0.68	312.5	1.07
H5_L1	150	100	10	4	1.5	3.21	3300	75	71	330	0.48	68.2	1.04	1.17	0.63	68.2	1.04
	150	100	10	4	1.5	3.21	3300	150	136	330	0.67	124.0	1.10	1.17	0.63	124.0	1.10
	150	100	10	4	1.5	3.21	3300	300	236	330	0.95	205.1	1.15	1.17	0.63	205.1	1.15
	150	100	10	4	1.5	3.21	3300	450	281	330	1.17	254.4	1.10	1.17	0.63	254.4	1.10
	150	100	10	4	1.5	3.21	3300	600	296	330	1.35	280.4	1.06	1.17	0.63	280.4	1.06
H6_L1	80	65	15	1.2	1.2	2.11	1900	75	68	204	0.61	64.3	1.05	1.06	0.60	64.3	1.05
	80	65	15	1.2	1.2	2.11	1900	150	123	204	0.86	110.2	1.12	1.06	0.60	110.2	1.12
	80	65	15	1.2	1.2	2.11	1900	300	177	204	1.21	162.0	1.09	1.06	0.60	162.0	1.09
	80	65	15	1.2	1.2	2.11	1900	450	197	204	1.49	178.6	1.10	1.06	0.60	178.6	1.10
	80	65	15	1.2	1.2	2.11	1900	600	206	204	1.72	178.7	1.15	1.06	0.60	202.9	1.02
H7_L1	95	50	10	1.8	1.9	4.61	1800	75	70	346	0.47	68.5	1.03	1.31	0.66	68.5	1.03
	95	50	10	1.8	1.9	4.61	1800	150	136	346	0.66	125.1	1.09	1.31	0.66	125.1	1.09
	95	50	10	1.8	1.9	4.61	1800	300	239	346	0.93	208.7	1.14	1.31	0.66	208.7	1.14
	95	50	10	1.8	1.9	4.61	1800	450	288	346	1.14	261.2	1.10	1.31	0.66	261.2	1.10
	95	50	10	1.8	1.9	4.61	1800	600	305	346	1.32	290.5	1.05	1.31	0.66	290.5	1.05
H8_L1	75	60	10	1	1.3	2.21	2100	75	66	164	0.68	61.9	1.06	1.07	0.60	61.9	1.06
	75	60	10	1	1.3	2.21	2100	150	112	164	0.96	102.3	1.09	1.07	0.60	102.3	1.09
	75	60	10	1	1.3	2.21	2100	300	147	164	1.35	139.6	1.05	1.07	0.60	139.6	1.05
	75	60	10	1	1.3	2.21	2100	450	158	164	1.66	144.0	1.10	1.07	0.60	157.9	1.00
	75	60	10	1	1.3	2.21	2100	600	166	164	1.91	144.0	1.15	1.07	0.60	180.5	0.92
H9_L1	80	45	11	1.6	1.8	4.01	1400	75	71	381	0.44	69.1	1.03	1.25	0.65	69.1	1.03
	80	45	11	1.6	1.8	4.01	1400	150	138	381	0.63	127.2	1.09	1.25	0.65	127.2	1.09
	80	45	11	1.6	1.8	4.01	1400	300	248	381	0.89	215.7	1.15	1.25	0.65	215.7	1.15
	80	45	11	1.6	1.8	4.01	1400	450	310	381	1.09	274.3	1.13	1.25	0.65	274.3	1.13
	80	45	11	1.6	1.8	4.01	1400	600	336	381	1.26	310.1	1.08	1.25	0.65	310.1	1.08
H1_L2	60	55	11	1.2	1.1	1.72	1400	75	69	225	0.58	65.2	1.05	1.02	0.59	65.2	1.05
	60	55	11	1.2	1.1	1.72	1400	150	127	225	0.82	113.4	1.12	1.02	0.59	113.4	1.12
	60	55	11	1.2	1.1	1.72	1400	300	189	225	1.16	171.5	1.10	1.02	0.59	171.5	1.10
	60	55	11	1.2	1.1	1.72	1400	450	217	225	1.42	194.5	1.12	1.02	0.59	194.5	1.12
	60	55	11	1.2	1.1	1.72	1400	600	246	225	1.63	197.0	1.25	1.02	0.59	214.3	1.15
H2_L2	100	60	10	2	1.7	3.70	2800	75	67	189	0.63	63.5	1.05	1.22	0.64	63.5	1.05
	100	60	10	2	1.7	3.70	2800	150	119	189	0.89	107.7	1.11	1.22	0.64	107.7	1.11
	100	60	10	2	1.7	3.70	2800	300	166	189	1.26	154.6	1.07	1.22	0.64	154.6	1.07
	100	60	10	2	1.7	3.70	2800	450	187	189	1.54	166.1	1.13	1.22	0.64	169.7	1.10
	100	60	10	2	1.7	3.70	2800	600	209	189	1.78	166.1	1.26	1.22	0.64	189.9	1.10
H3_L2	120	80	15	3	1.5	3.02	2660	75	70	291	0.51	67.3	1.04	1.15	0.62	67.3	1.04
	120	80	15	3	1.5	3.02	2660	150	133	291	0.72	120.9	1.10	1.15	0.62	120.9	1.10
	120	80	15	3	1.5	3.02	2660	300	221	291	1.02	194.9	1.13	1.15	0.62	194.9	1.13
	120	80	15	3	1.5	3.02	2660	450	257	291	1.24	235.6	1.09	1.15	0.62	235.6	1.09
	120	80	15	3	1.5	3.02	2660	600	276	291	1.44	253.2	1.09	1.15	0.62	253.2	1.09
H4_L2	140	70	10	3	3.0	5.28	3640	75	68	217	0.59	64.9	1.05	1.38	0.68	64.9	1.05
	140	70	10	3	2.0	5.28	3640	150	124	217	0.83	112.3	1.10	1.38	0.68	112.3	1.10
	140	70	10	3	2.0	5.28	3640	300	184	217	1.18	168.1	1.09	1.38	0.68	168.1	1.09
	140	70	10	3	2.0	5.28	3640	450	207	217	1.44	188.7	1.10	1.38	0.68	188.7	1.10
	140	70	10	3	2.0	5.28	3640	600	226	217	1.66	190.0	1.19	1.38	0.68	202.8	1.11

	Geometry							SFEA		DSM Design							
Column	b_w	b_f	b_s	t	b_w/b_t	$\beta=I_I/I_{II}$	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	b	a	f_{nFT}	f_u/f_{nFT}
H5_L2	150	100	10	4	1.5	3.21	4620	75	67	189	0.63	63.5	1.06	1.17	0.63	63.5	1.06
	150	100	10	4	1.5	3.21	4620	150	120	189	0.89	107.6	1.12	1.17	0.63	107.6	1.12
	150	100	10	4	1.5	3.21	4620	300	167	189	1.26	154.4	1.08	1.17	0.63	154.4	1.08
	150	100	10	4	1.5	3.21	4620	450	189	189	1.54	165.8	1.14	1.17	0.63	169.8	1.11
	150	100	10	4	1.5	3.21	4620	600	211	189	1.78	165.8	1.27	1.17	0.63	191.3	1.10
H6_L2	80	65	15	1.2	1.2	2.11	2660	75	61	121	0.79	57.8	1.05	1.06	0.60	57.8	1.05
	80	65	15	1.2	1.2	2.11	2660	150	94	121	1.12	89.1	1.05	1.06	0.60	89.1	1.05
	80	65	15	1.2	1.2	2.11	2660	300	121	121	1.58	105.7	1.14	1.06	0.60	110.9	1.09
	80	65	15	1.2	1.2	2.11	2660	450	145	121	1.93	105.7	1.37	1.06	0.60	134.1	1.08
	80	65	15	1.2	1.2	2.11	2660	600	154	121	2.23	105.7	1.46	1.06	0.60	153.5	1.00
H7_L2	95	50	10	1.8	1.9	4.61	2520	75	67	195	0.62	63.8	1.05	1.31	0.66	63.8	1.05
	95	50	10	1.8	1.9	4.61	2520	150	119	195	0.88	108.6	1.10	1.31	0.66	108.6	1.10
	95	50	10	1.8	1.9	4.61	2520	300	169	195	1.24	157.4	1.07	1.31	0.66	157.4	1.07
	95	50	10	1.8	1.9	4.61	2520	450	191	195	1.52	170.7	1.12	1.31	0.66	172.4	1.11
	95	50	10	1.8	1.9	4.61	2520	600	212	195	1.76	170.7	1.24	1.31	0.66	190.3	1.11
H8_L2	75	60	10	1	1.3	2.21	2940	75	56	96	0.88	54.0	1.04	1.07	0.60	54.0	1.04
	75	60	10	1	1.3	2.21	2940	150	81	96	1.25	77.9	1.03	1.07	0.60	77.9	1.03
	75	60	10	1	1.3	2.21	2940	300	105	96	1.77	84.0	1.25	1.07	0.60	98.0	1.07
	75	60	10	1	1.3	2.21	2940	450	121	96	2.17	84.0	1.44	1.07	0.60	118.3	1.02
	75	60	10	1	1.3	2.21	2940	600	132	96	2.50	84.0	1.57	1.07	0.60	135.3	0.98
H9_L2	80	45	11	1.6	1.8	4.01	1960	75	68	218	0.59	64.9	1.04	1.25	0.65	64.9	1.04
	80	45	11	1.6	1.8	4.01	1960	150	123	218	0.83	112.5	1.09	1.25	0.65	112.5	1.09
	80	45	11	1.6	1.8	4.01	1960	300	183	218	1.17	168.6	1.09	1.25	0.65	168.6	1.09
	80	45	11	1.6	1.8	4.01	1960	450	207	218	1.44	189.7	1.09	1.25	0.65	189.7	1.09
	80	45	11	1.6	1.8	4.01	1960	600	228	218	1.66	191.2	1.19	1.25	0.65	206.3	1.11
H1_L3	60	55	11	1.2	1.1	1.72	1800	75	65	154	0.70	61.2	1.06	1.02	0.59	61.2	1.06
	60	55	11	1.2	1.1	1.72	1800	150	108	154	0.99	99.8	1.08	1.02	0.59	99.8	1.08
	60	55	11	1.2	1.1	1.72	1800	300	143	154	1.40	132.7	1.08	1.02	0.59	132.7	1.08
	60	55	11	1.2	1.1	1.72	1800	450	169	154	1.71	135.1	1.25	1.02	0.59	153.5	1.10
	60	55	11	1.2	1.1	1.72	1800	600	198	154	1.97	135.1	1.47	1.02	0.59	176.7	1.12
H2_L3	100	60	10	2	1.7	3.70	3600	75	62	124	0.78	58.2	1.06	1.22	0.64	58.2	1.06
	100	60	10	2	1.7	3.70	3600	150	96	124	1.10	90.4	1.07	1.22	0.64	90.4	1.07
	100	60	10	2	1.7	3.70	3600	300	124	124	1.56	108.7	1.14	1.22	0.64	111.9	1.11
	100	60	10	2	1.7	3.70	3600	450	148	124	1.91	108.7	1.36	1.22	0.64	131.1	1.13
	100	60	10	2	1.7	3.70	3600	600	172	124	2.20	108.7	1.58	1.22	0.64	146.7	1.17
H3_L3	120	80	15	3	1.5	3.02	3420	75	67	192	0.63	63.7	1.05	1.15	0.62	63.7	1.05
	120	80	15	3	1.5	3.02	3420	150	119	192	0.89	108.1	1.10	1.15	0.62	108.1	1.10
	120	80	15	3	1.5	3.02	3420	300	168	192	1.25	155.7	1.08	1.15	0.62	155.7	1.08
	120	80	15	3	1.5	3.02	3420	450	190	192	1.53	167.9	1.13	1.15	0.62	171.1	1.11
	120	80	15	3	1.5	3.02	3420	600	214	192	1.77	167.9	1.27	1.15	0.62	193.3	1.11
H4_L3	140	70	10	3	3.0	5.28	4680	75	64	145	0.72	60.4	1.07	1.38	0.68	60.4	1.07
	140	70	10	3	2.0	5.28	4680	150	106	145	1.02	97.2	1.09	1.38	0.68	97.2	1.09
	140	70	10	3	2.0	5.28	4680	300	138	145	1.44	125.9	1.10	1.38	0.68	125.9	1.10
	140	70	10	3	2.0	5.28	4680	450	160	145	1.76	126.8	1.26	1.38	0.68	140.3	1.14
	140	70	10	3	2.0	5.28	4680	600	179	145	2.04	126.8	1.41	1.38	0.68	153.5	1.17
H5_L3	150	100	10	4	1.5	3.21	5940	75	63	128	0.77	58.7	1.08	1.17	0.63	58.7	1.08
	150	100	10	4	1.5	3.21	5940	150	99	128	1.08	91.8	1.08	1.17	0.63	91.8	1.08
	150	100	10	4	1.5	3.21	5940	300	127	128	1.53	112.2	1.13	1.17	0.63	114.2	1.11
	150	100	10	4	1.5	3.21	5940	450	150	128	1.88	112.2	1.34	1.17	0.63	135.1	1.11
	150	100	10	4	1.5	3.21	5940	600	174	128	2.17	112.2	1.55	1.17	0.63	152.2	1.14
H6_L3	80	65	15	1.2	1.2	2.11	3420	75	51	78	0.98	50.1	1.02	1.06	0.60	50.1	1.02
	80	65	15	1.2	1.2	2.11	3420	150	70	78	1.39	67.0	1.05	1.06	0.60	67.0	1.05
	80	65	15	1.2	1.2	2.11	3420	300	98	78	1.96	68.3	1.44	1.06	0.60	88.0	1.12
	80	65	15	1.2	1.2	2.11	3420	450	119	78	2.40	68.3	1.74	1.06	0.60	106.4	1.12
	80	65	15	1.2	1.2	2.11	3420	600	133	78	2.78	68.3	1.95	1.06	0.60	121.8	1.09
H7_L3	95	50	10	1.8	1.9	4.61	3240	75	62	128	0.77	58.6	1.06	1.31	0.66	58.6	1.06
	95	50	10	1.8	1.9	4.61	3240	150	98	128	1.08	91.7	1.07	1.31	0.66	91.7	1.07
	95	50	10	1.8	1.9	4.61	3240	300	126	128	1.53	111.9	1.13	1.31	0.66	113.7	1.11
	95	50	10	1.8	1.9	4.61	3240	450	150	128	1.88	111.9	1.34	1.31	0.66	130.7	1.15
	95	50	10	1.8	1.9	4.61	3240	600	172	128	2.17	111.9	1.54	1.31	0.66	144.3	1.19
H8_L3	75	60	10	1	1.3	2.21	3780	75	45	62	1.10	45.0	1.00	1.07	0.60	45.0	1.00
	75	60	10	1	1.3	2.21	3780	150	60	62	1.56	53.9	1.11	1.07	0.60	56.0	1.07
	75	60	10	1	1.3	2.21	3780	300	87	62	2.21	53.9	1.61	1.07	0.60	77.3	1.12
	75	60	10	1	1.3	2.21	3780	450	102	62	2.71	53.9	1.89	1.07	0.60	93.3	1.09
	75	60	10	1	1.3	2.21	3780	600	113	62	3.12	53.9	2.10	1.07	0.60	106.7	1.06
H9_L3	80	45	11	1.6	1.8	4.01	2520	75	63	142	0.73	60.2	1.05	1.25	0.65	60.2	1.05
	80	45	11	1.6	1.8	4.01	2520	150	104	142	1.03	96.5	1.08	1.25	0.65	96.5	1.08
	80	45	11	1.6	1.8	4.01	2520	300	136	142	1.45	124.2	1.09	1.25	0.65	124.2	1.09
	80	45	11	1.6	1.8	4.01	2520	450	160	142	1.78	124.9	1.28	1.25	0.65	141.9	1.13
	80	45	11	1.6	1.8	4.01	2520	600	186	142	2.05	124.9	1.49	1.25	0.65	158.0	1.18

	Geometry							SFEA		DSM Design							
Column	b_w	b_f	b_s	t	b_w/b_t	$\beta=I_I/I_{II}$	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	b	a	f_{nFT}	f_u/f_{nFT}
H1_L4	60	55	11	1.2	1.1	1.72	2200	75	59	110	0.83	56.4	1.05	1.02	0.59	56.4	1.05
	60	55	11	1.2	1.1	1.72	2200	150	89	110	1.17	84.8	1.05	1.02	0.59	84.8	1.05
	60	55	11	1.2	1.1	1.72	2200	300	115	110	1.65	96.5	1.19	1.02	0.59	106.0	1.08
	60	55	11	1.2	1.1	1.72	2200	450	146	110	2.02	96.5	1.51	1.02	0.59	129.3	1.13
	60	55	11	1.2	1.1	1.72	2200	600	173	110	2.34	96.5	1.79	1.02	0.59	148.8	1.16
H2_L4	100	60	10	2	1.7	3.70	4400	75	56	90	0.91	53.0	1.05	1.22	0.64	53.0	1.05
	100	60	10	2	1.7	3.70	4400	150	79	90	1.29	74.8	1.05	1.22	0.64	74.8	1.05
	100	60	10	2	1.7	3.70	4400	300	103	90	1.82	79.1	1.30	1.22	0.64	92.2	1.12
	100	60	10	2	1.7	3.70	4400	450	128	90	2.23	79.1	1.62	1.22	0.64	108.0	1.19
	100	60	10	2	1.7	3.70	4400	600	147	90	2.58	79.1	1.86	1.22	0.64	120.8	1.22
H3_L4	120	80	15	3	1.5	3.02	4180	75	64	138	0.74	59.8	1.06	1.15	0.62	59.8	1.06
	120	80	15	3	1.5	3.02	4180	150	103	138	1.04	95.2	1.08	1.15	0.62	95.2	1.08
	120	80	15	3	1.5	3.02	4180	300	134	138	1.47	120.8	1.11	1.15	0.62	120.8	1.11
	120	80	15	3	1.5	3.02	4180	450	158	138	1.81	121.1	1.30	1.15	0.62	141.8	1.11
	120	80	15	3	1.5	3.02	4180	600	185	138	2.08	121.1	1.53	1.15	0.62	160.1	1.16
H4_L4	140	70	10	3	3.0	5.28	5720	75	60	108	0.83	56.0	1.07	1.38	0.68	56.0	1.07
	140	70	10	3	2.0	5.28	5720	150	89	108	1.18	83.7	1.06	1.38	0.68	83.7	1.06
	140	70	10	3	2.0	5.28	5720	300	114	108	1.67	94.5	1.21	1.38	0.68	101.0	1.13
	140	70	10	3	2.0	5.28	5720	450	133	108	2.04	94.5	1.41	1.38	0.68	114.5	1.16
	140	70	10	3	2.0	5.28	5720	600	147	108	2.36	94.5	1.56	1.38	0.68	125.3	1.17
H5_L4	150	100	10	4	1.5	3.21	7260	75	58	96	0.88	54.2	1.08	1.17	0.63	54.2	1.08
	150	100	10	4	1.5	3.21	7260	150	83	96	1.25	78.2	1.06	1.17	0.63	78.2	1.06
	150	100	10	4	1.5	3.21	7260	300	107	96	1.76	84.5	1.27	1.17	0.63	96.7	1.11
	150	100	10	4	1.5	3.21	7260	450	129	96	2.16	84.5	1.53	1.17	0.63	114.4	1.13
	150	100	10	4	1.5	3.21	7260	600	147	96	2.49	84.5	1.74	1.17	0.63	128.9	1.14
H6_L4	80	65	15	1.2	1.2	2.11	4180	75	42	55	1.17	42.3	0.99	1.06	0.60	42.3	0.99
	80	65	15	1.2	1.2	2.11	4180	150	57	55	1.65	48.1	1.18	1.06	0.60	52.8	1.08
	80	65	15	1.2	1.2	2.11	4180	300	88	55	2.34	48.1	1.82	1.06	0.60	73.1	1.20
	80	65	15	1.2	1.2	2.11	4180	450	104	55	2.86	48.1	2.16	1.06	0.60	88.4	1.18
	80	65	15	1.2	1.2	2.11	4180	600	117	55	3.31	48.1	2.43	1.06	0.60	101.1	1.16
H7_L4	95	50	10	1.8	1.9	4.61	3960	75	56	93	0.90	53.5	1.05	1.31	0.66	53.5	1.05
	95	50	10	1.8	1.9	4.61	3960	150	80	93	1.27	76.4	1.05	1.31	0.66	76.4	1.05
	95	50	10	1.8	1.9	4.61	3960	300	105	93	1.80	81.6	1.29	1.31	0.66	92.4	1.14
	95	50	10	1.8	1.9	4.61	3960	450	128	93	2.20	81.6	1.57	1.31	0.66	106.3	1.20
	95	50	10	1.8	1.9	4.61	3960	600	144	93	2.54	81.6	1.76	1.31	0.66	117.4	1.23
H8_L4	75	60	10	1	1.3	2.21	4620	75	36	43	1.32	36.3	1.00	1.07	0.60	36.3	1.00
	75	60	10	1	1.3	2.21	4620	150	51	43	1.86	38.0	1.33	1.07	0.60	46.4	1.09
	75	60	10	1	1.3	2.21	4620	300	77	43	2.63	38.0	2.03	1.07	0.60	64.1	1.20
	75	60	10	1	1.3	2.21	4620	450	90	43	3.22	38.0	2.36	1.07	0.60	77.4	1.16
	75	60	10	1	1.3	2.21	4620	600	99	43	3.72	38.0	2.59	1.07	0.60	88.4	1.11
H9_L4	80	45	11	1.6	1.8	4.01	3080	75	58	103	0.85	55.3	1.05	1.25	0.65	55.3	1.05
	80	45	11	1.6	1.8	4.01	3080	150	85	103	1.21	81.5	1.05	1.25	0.65	81.5	1.05
	80	45	11	1.6	1.8	4.01	3080	300	112	103	1.71	90.3	1.24	1.25	0.65	99.5	1.13
	80	45	11	1.6	1.8	4.01	3080	450	139	103	2.09	90.3	1.54	1.25	0.65	115.9	1.20
	80	45	11	1.6	1.8	4.01	3080	600	161	103	2.41	90.3	1.78	1.25	0.65	129.1	1.25
H1_L5	60	55	11	1.2	1.1	1.72	2600	75	53	83	0.95	51.3	1.03	1.02	0.59	51.3	1.03
	60	55	11	1.2	1.1	1.72	2600	150	73	83	1.35	70.1	1.04	1.02	0.59	70.1	1.04
	60	55	11	1.2	1.1	1.72	2600	300	101	83	1.91	72.4	1.39	1.02	0.59	91.6	1.10
	60	55	11	1.2	1.1	1.72	2600	450	134	83	2.33	72.4	1.85	1.02	0.59	111.7	1.20
	60	55	11	1.2	1.1	1.72	2600	600	157	83	2.70	72.4	2.17	1.02	0.59	128.5	1.22
H2_L5	100	60	10	2	1.7	3.70	5200	75	50	71	1.03	48.0	1.04	1.22	0.64	48.0	1.04
	100	60	10	2	1.7	3.70	5200	150	67	71	1.46	61.6	1.08	1.22	0.64	61.6	1.08
	100	60	10	2	1.7	3.70	5200	300	92	71	2.06	61.8	1.48	1.22	0.64	79.3	1.15
	100	60	10	2	1.7	3.70	5200	450	112	71	2.53	61.8	1.81	1.22	0.64	92.9	1.21
	100	60	10	2	1.7	3.70	5200	600	124	71	2.92	61.8	2.01	1.22	0.64	103.9	1.19
H3_L5	120	80	15	3	1.5	3.02	4940	75	59	107	0.84	55.9	1.06	1.15	0.62	55.9	1.06
	120	80	15	3	1.5	3.02	4940	150	88	107	1.19	83.3	1.05	1.15	0.62	83.3	1.05
	120	80	15	3	1.5	3.02	4940	300	114	107	1.68	93.7	1.22	1.15	0.62	102.9	1.11
	120	80	15	3	1.5	3.02	4940	450	141	107	2.05	93.7	1.51	1.15	0.62	122.2	1.15
	120	80	15	3	1.5	3.02	4940	600	166	107	2.37	93.7	1.77	1.15	0.62	138.1	1.20
H4_L5	140	70	10	3	3.0	5.28	6760	75	56	86	0.93	52.1	1.06	1.38	0.68	52.1	1.06
	140	70	10	3	2.0	5.28	6760	150	77	86	1.32	72.5	1.06	1.38	0.68	72.5	1.06
	140	70	10	3	2.0	5.28	6760	300	98	86	1.86	75.7	1.29	1.38	0.68	86.7	1.13
	140	70	10	3	2.0	5.28	6760	450	112	86	2.28	75.7	1.48	1.38	0.68	98.3	1.14
	140	70	10	3	2.0	5.28	6760	600	119	86	2.64	75.7	1.57	1.38	0.68	107.5	1.11
H5_L5	150	100	10	4	1.5	3.21	8580	75	53	78	0.98	50.2	1.06	1.17	0.63	50.2	1.06
	150	100	10	4	1.5	3.21	8580	150	72	78	1.39	67.1	1.07	1.17	0.63	67.1	1.07
	150	100	10	4	1.5	3.21	8580	300	93	78	1.96	68.4	1.37	1.17	0.63	85.5	1.09
	150	100	10	4	1.5	3.21	8580	450	111	78	2.40	68.4	1.62	1.17	0.63	101.1	1.10
	150	100	10	4	1.5	3.21	8580	600	122	78	2.77	68.4	1.78	1.17	0.63	113.9	1.07

	Geometry							SFEA		DSM Design							
Column	b_w	b_f	b_s	t	b_w/b_t	$\beta=I_I/I_{II}$	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	b	a	f_{nFT}	f_u/f_{nFT}
H6_L5	80	65	15	1.2	1.2	2.11	4940	75	35	41	1.35	35.1	1.01	1.06	0.60	35.1	1.01
	80	65	15	1.2	1.2	2.11	4940	150	51	41	1.90	36.3	1.39	1.06	0.60	45.4	1.11
	80	65	15	1.2	1.2	2.11	4940	300	80	41	2.69	36.3	2.21	1.06	0.60	62.9	1.28
	80	65	15	1.2	1.2	2.11	4940	450	96	41	3.30	36.3	2.64	1.06	0.60	76.1	1.26
	80	65	15	1.2	1.2	2.11	4940	600	107	41	3.81	36.3	2.95	1.06	0.60	87.1	1.23
H7_L5	95	50	10	1.8	1.9	4.61	4680	75	51	73	1.01	48.8	1.04	1.31	0.66	48.8	1.04
	95	50	10	1.8	1.9	4.61	4680	150	68	73	1.43	63.5	1.07	1.31	0.66	63.5	1.07
	95	50	10	1.8	1.9	4.61	4680	300	92	73	2.03	64.1	1.44	1.31	0.66	78.9	1.17
	95	50	10	1.8	1.9	4.61	4680	450	110	73	2.48	64.1	1.72	1.31	0.66	90.7	1.21
	95	50	10	1.8	1.9	4.61	4680	600	120	73	2.86	64.1	1.87	1.31	0.66	100.1	1.20
H8_L5	75	60	10	1	1.3	2.21	5460	75	31	33	1.51	28.7	1.07	1.07	0.60	28.9	1.06
	75	60	10	1	1.3	2.21	5460	150	46	33	2.14	28.7	1.61	1.07	0.60	39.9	1.16
	75	60	10	1	1.3	2.21	5460	300	69	33	3.03	28.7	2.42	1.07	0.60	55.1	1.26
	75	60	10	1	1.3	2.21	5460	450	80	33	3.71	28.7	2.78	1.07	0.60	66.6	1.20
	75	60	10	1	1.3	2.21	5460	600	87	33	4.28	28.7	3.03	1.07	0.60	76.1	1.14
H9_L5	80	45	11	1.6	1.8	4.01	3640	75	53	80	0.97	50.7	1.04	1.25	0.65	50.7	1.04
	80	45	11	1.6	1.8	4.01	3640	150	72	80	1.37	68.5	1.06	1.25	0.65	68.5	1.06
	80	45	11	1.6	1.8	4.01	3640	300	99	80	1.94	70.2	1.41	1.25	0.65	85.1	1.16
	80	45	11	1.6	1.8	4.01	3640	450	123	80	2.37	70.2	1.75	1.25	0.65	99.0	1.24
	80	45	11	1.6	1.8	4.01	3640	600	140	80	2.74	70.2	1.99	1.25	0.65	110.3	1.27
H1_L6	60	55	11	1.2	1.1	1.72	3000	75	47	65	1.07	46.2	1.01	1.02	0.59	46.2	1.01
	60	55	11	1.2	1.1	1.72	3000	150	63	65	1.52	56.9	1.10	1.02	0.59	57.7	1.09
	60	55	11	1.2	1.1	1.72	3000	300	94	65	2.15	56.9	1.65	1.02	0.59	81.0	1.16
	60	55	11	1.2	1.1	1.72	3000	450	125	65	2.63	56.9	2.20	1.02	0.59	98.7	1.27
	60	55	11	1.2	1.1	1.72	3000	600	146	65	3.04	56.9	2.57	1.02	0.59	113.6	1.29
H2_L6	100	60	10	2	1.7	3.70	6000	75	45	58	1.14	43.7	1.02	1.22	0.64	43.7	1.02
	100	60	10	2	1.7	3.70	6000	150	59	58	1.61	51.0	1.16	1.22	0.64	53.8	1.10
	100	60	10	2	1.7	3.70	6000	300	82	58	2.27	51.0	1.60	1.22	0.64	70.5	1.16
	100	60	10	2	1.7	3.70	6000	450	96	58	2.78	51.0	1.89	1.22	0.64	82.6	1.17
	100	60	10	2	1.7	3.70	6000	600	104	58	3.21	51.0	2.04	1.22	0.64	92.4	1.13
H3_L6	120	80	15	3	1.5	3.02	5700	75	55	87	0.93	52.3	1.06	1.15	0.62	52.3	1.06
	120	80	15	3	1.5	3.02	5700	150	77	87	1.31	72.8	1.05	1.15	0.62	72.8	1.05
	120	80	15	3	1.5	3.02	5700	300	102	87	1.86	76.2	1.34	1.15	0.62	91.4	1.12
	120	80	15	3	1.5	3.02	5700	450	128	87	2.28	76.2	1.68	1.15	0.62	108.6	1.18
	120	80	15	3	1.5	3.02	5700	600	149	87	2.63	76.2	1.96	1.15	0.62	122.6	1.21
H4_L6	140	70	10	3	3.0	5.28	7800	75	51	73	1.02	48.7	1.05	1.38	0.68	48.7	1.05
	140	70	10	3	2.0	5.28	7800	150	68	73	1.44	63.2	1.07	1.38	0.68	63.2	1.07
	140	70	10	3	2.0	5.28	7800	300	85	73	2.03	63.8	1.33	1.38	0.68	77.0	1.10
	140	70	10	3	2.0	5.28	7800	450	93	73	2.49	63.8	1.45	1.38	0.68	87.4	1.06
	140	70	10	3	2.0	5.28	7800	600	95	73	2.87	63.8	1.49	1.38	0.68	95.5	1.00
H5_L6	150	100	10	4	1.5	3.21	9900	75	49	66	1.06	46.7	1.05	1.17	0.63	46.7	1.05
	150	100	10	4	1.5	3.21	9900	150	64	66	1.51	58.1	1.10	1.17	0.63	58.3	1.10
	150	100	10	4	1.5	3.21	9900	300	83	66	2.13	58.1	1.42	1.17	0.63	77.6	1.06
	150	100	10	4	1.5	3.21	9900	450	95	66	2.61	58.1	1.63	1.17	0.63	91.8	1.03
	150	100	10	4	1.5	3.21	9900	600	101	66	3.01	58.1	1.74	1.17	0.63	103.5	0.98
H6_L6	80	65	15	1.2	1.2	2.11	5700	75	31	33	1.51	28.8	1.08	1.06	0.60	29.0	1.07
	80	65	15	1.2	1.2	2.11	5700	150	48	33	2.14	28.8	1.65	1.06	0.60	40.1	1.18
	80	65	15	1.2	1.2	2.11	5700	300	75	33	3.02	28.8	2.60	1.06	0.60	55.6	1.35
	80	65	15	1.2	1.2	2.11	5700	450	87	33	3.70	28.8	3.03	1.06	0.60	67.2	1.30
	80	65	15	1.2	1.2	2.11	5700	600	96	33	4.28	28.8	3.32	1.06	0.60	77.0	1.24
H7_L6	95	50	10	1.8	1.9	4.61	5400	75	46	60	1.11	44.6	1.02	1.31	0.66	44.6	1.02
	95	50	10	1.8	1.9	4.61	5400	150	61	60	1.58	53.0	1.14	1.31	0.66	54.8	1.11
	95	50	10	1.8	1.9	4.61	5400	300	82	60	2.23	53.0	1.54	1.31	0.66	69.6	1.17
	95	50	10	1.8	1.9	4.61	5400	450	94	60	2.73	53.0	1.77	1.31	0.66	80.0	1.17
	95	50	10	1.8	1.9	4.61	5400	600	99	60	3.15	53.0	1.86	1.31	0.66	88.4	1.11
H8_L6	75	60	10	1	1.3	2.21	6300	75	27	26	1.70	22.8	1.20	1.07	0.60	25.6	1.07
	75	60	10	1	1.3	2.21	6300	150	43	26	2.40	22.8	1.89	1.07	0.60	35.3	1.22
	75	60	10	1	1.3	2.21	6300	300	63	26	3.40	22.8	2.74	1.07	0.60	48.8	1.28
	75	60	10	1	1.3	2.21	6300	450	70	26	4.16	22.8	3.08	1.07	0.60	58.9	1.19
	75	60	10	1	1.3	2.21	6300	600	75	26	4.80	22.8	3.29	1.07	0.60	67.3	1.11
H9_L6	80	45	11	1.6	1.8	4.01	4200	75	48	66	1.07	46.5	1.02	1.25	0.65	46.5	1.02
	80	45	11	1.6	1.8	4.01	4200	150	64	66	1.51	57.5	1.11	1.25	0.65	57.9	1.10
	80	45	11	1.6	1.8	4.01	4200	300	90	66	2.14	57.5	1.56	1.25	0.65	75.1	1.19
	80	45	11	1.6	1.8	4.01	4200	450	109	66	2.62	57.5	1.89	1.25	0.65	87.4	1.25
	80	45	11	1.6	1.8	4.01	4200	600	120	66	3.02	57.5	2.09	1.25	0.65	97.3	1.23
											Mean		1.36		Mean		1.11
											Sd. Dev.		0.46		Sd. Dev.		0.07
											Max		3.32		Max		1.35
											Min		0.99		Min		0.92

ANNEX D: R COLUMN DATA

Table D1: Columns failing in F_MT modes: (i) geometries, (ii) buckling stresses and ultimate strengths, (iii) ultimate strength predictions by current and proposed DSM design curves, and (iv) numerical-to-predicted ultimate strength ratios (mm and MPa)

	Geometry								SFEA		DSM Design							
Column	b_w	b_f	b_s	b_l	t	b_w/b_t	$\beta=I_I/I_{II}$	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	b	a	f_{nFT}	f_u/f_{nFT}
R1_L1	80	50	15	20	1	1.6	1.65	3500	75	64	143	0.72	60.2	1.06	1.02	0.59	60.2	1.06
	80	50	15	20	1	1.6	1.65	3500	150	105	143	1.02	96.8	1.09	1.02	0.59	96.8	1.09
	80	50	15	20	1	1.6	1.65	3500	300	125	143	1.45	124.8	1.00	1.02	0.59	124.8	1.00
	80	50	15	20	1	1.6	1.65	3500	450	131	143	1.77	125.6	1.04	1.02	0.59	148.1	0.88
	80	50	15	20	1	1.6	1.65	3500	600	137	143	2.05	125.6	1.09	1.02	0.59	170.6	0.80
R2_L1	100	70	20	30	1.2	1.4	1.45	4500	75	64	141	0.73	60.0	1.06	1.00	0.58	60.0	1.06
	100	70	20	30	1.2	1.4	1.45	4500	150	104	141	1.03	96.0	1.08	1.00	0.58	96.0	1.08
	100	70	20	30	1.2	1.4	1.45	4500	300	121	141	1.46	123.0	0.98	1.00	0.58	123.0	0.98
	100	70	20	30	1.2	1.4	1.45	4500	450	127	141	1.79	123.5	1.03	1.00	0.58	147.4	0.86
	100	70	20	30	1.2	1.4	1.45	4500	600	133	141	2.06	123.5	1.08	1.00	0.58	170.3	0.78
R3_L1	67	35	10	20	0.8	1.9	2.19	2700	75	64	148	0.71	60.7	1.06	1.07	0.60	60.7	1.06
	67	35	10	20	0.8	1.9	2.19	2700	150	107	148	1.01	98.2	1.09	1.07	0.60	98.2	1.09
	67	35	10	20	0.8	1.9	2.19	2700	300	128	148	1.42	128.6	0.99	1.07	0.60	128.6	0.99
	67	35	10	20	0.8	1.9	2.19	2700	450	134	148	1.74	130.1	1.03	1.07	0.60	149.6	0.90
	67	35	10	20	0.8	1.9	2.19	2700	600	140	148	2.01	130.1	1.08	1.07	0.60	171.0	0.82
R4_L1	150	110	22.5	20	2.4	1.4	1.89	4600	75	69	250	0.55	66.1	1.04	1.04	0.59	66.1	1.04
	150	110	22.5	20	2.4	1.4	1.89	4600	150	127	250	0.78	116.7	1.09	1.04	0.59	116.7	1.09
	150	110	22.5	20	2.4	1.4	1.89	4600	300	195	250	1.10	181.4	1.07	1.04	0.59	181.4	1.07
	150	110	22.5	20	2.4	1.4	1.89	4600	450	212	250	1.34	211.7	1.00	1.04	0.59	211.7	1.00
	150	110	22.5	20	2.4	1.4	1.89	4600	600	219	250	1.55	219.0	1.00	1.04	0.59	226.1	0.97
R1_L2	80	50	15	20	1	1.6	1.65	4200	75	58	102	0.86	55.1	1.06	1.02	0.59	55.1	1.06
	80	50	15	20	1	1.6	1.65	4200	150	84	102	1.21	81.0	1.03	1.02	0.59	81.0	1.03
	80	50	15	20	1	1.6	1.65	4200	300	98	102	1.72	89.4	1.10	1.02	0.59	102.1	0.96
	80	50	15	20	1	1.6	1.65	4200	450	106	102	2.10	89.4	1.19	1.02	0.59	124.6	0.85
	80	50	15	20	1	1.6	1.65	4200	600	113	102	2.43	89.4	1.26	1.02	0.59	143.6	0.79
R2_L2	100	70	20	30	1.2	1.4	1.45	5400	75	58	100	0.86	54.9	1.06	1.00	0.58	54.9	1.06
	100	70	20	30	1.2	1.4	1.45	5400	150	83	100	1.22	80.3	1.03	1.00	0.58	80.3	1.03
	100	70	20	30	1.2	1.4	1.45	5400	300	97	100	1.73	88.1	1.10	1.00	0.58	101.6	0.96
	100	70	20	30	1.2	1.4	1.45	5400	450	104	100	2.12	88.1	1.18	1.00	0.58	124.5	0.84
	100	70	20	30	1.2	1.4	1.45	5400	600	110	100	2.44	88.1	1.25	1.00	0.58	143.9	0.76
R3_L2	67	35	10	20	0.8	1.9	2.19	3500	75	56	92	0.91	53.2	1.05	1.07	0.60	53.2	1.05
	67	35	10	20	0.8	1.9	2.19	3500	150	78	92	1.28	75.5	1.03	1.07	0.60	75.5	1.03
	67	35	10	20	0.8	1.9	2.19	3500	300	92	92	1.81	80.2	1.15	1.07	0.60	95.7	0.96
	67	35	10	20	0.8	1.9	2.19	3500	450	101	92	2.22	80.2	1.26	1.07	0.60	115.5	0.87
	67	35	10	20	0.8	1.9	2.19	3500	600	109	92	2.56	80.2	1.36	1.07	0.60	132.1	0.83
R4_L2	150	110	22.5	20	2.4	1.4	1.89	5500	75	66	181	0.64	63.1	1.04	1.04	0.59	63.1	1.04
	150	110	22.5	20	2.4	1.4	1.89	5500	150	116	181	0.91	106.0	1.09	1.04	0.59	106.0	1.09
	150	110	22.5	20	2.4	1.4	1.89	5500	300	157	181	1.29	149.9	1.05	1.04	0.59	149.9	1.05
	150	110	22.5	20	2.4	1.4	1.89	5500	450	170	181	1.58	158.6	1.07	1.04	0.59	166.6	1.02
	150	110	22.5	20	2.4	1.4	1.89	5500	600	183	181	1.82	158.6	1.15	1.04	0.59	191.3	0.96
R1_L3	80	50	15	20	1	1.6	1.65	5200	75	48	68	1.05	47.3	1.02	1.02	0.59	47.3	1.02
	80	50	15	20	1	1.6	1.65	5200	150	62	68	1.48	59.7	1.04	1.02	0.59	59.7	1.04
	80	50	15	20	1	1.6	1.65	5200	300	76	68	2.10	59.7	1.28	1.02	0.59	83.2	0.92
	80	50	15	20	1	1.6	1.65	5200	450	85	68	2.57	59.7	1.42	1.02	0.59	101.6	0.84
	80	50	15	20	1	1.6	1.65	5200	600	91	68	2.97	59.7	1.53	1.02	0.59	117.0	0.78
R2_L3	100	70	20	30	1.2	1.4	1.45	6700	75	48	67	1.06	46.8	1.02	1.00	0.58	46.8	1.02
	100	70	20	30	1.2	1.4	1.45	6700	150	61	67	1.50	58.5	1.04	1.00	0.58	58.5	1.04
	100	70	20	30	1.2	1.4	1.45	6700	300	76	67	2.12	58.5	1.29	1.00	0.58	82.9	0.91
	100	70	20	30	1.2	1.4	1.45	6700	450	84	67	2.60	58.5	1.43	1.00	0.58	101.6	0.82
	100	70	20	30	1.2	1.4	1.45	6700	600	90	67	3.00	58.5	1.54	1.00	0.58	117.4	0.76
R3_L3	67	35	10	20	0.8	1.9	2.19	4500	75	44	57	1.15	43.3	1.01	1.07	0.60	43.3	1.01
	67	35	10	20	0.8	1.9	2.19	4500	150	55	57	1.62	50.2	1.09	1.07	0.60	53.9	1.01
	67	35	10	20	0.8	1.9	2.19	4500	300	70	57	2.29	50.2	1.39	1.07	0.60	74.4	0.94
	67	35	10	20	0.8	1.9	2.19	4500	450	77	57	2.80	50.2	1.54	1.07	0.60	89.9	0.86
	67	35	10	20	0.8	1.9	2.19	4500	600	85	57	3.24	50.2	1.70	1.07	0.60	102.8	0.83
R4_L3	150	110	22.5	20	2.4	1.4	1.89	7000	75	60	116	0.81	57.2	1.05	1.04	0.59	57.2	1.05
	150	110	22.5	20	2.4	1.4	1.89	7000	150	92	116	1.14	87.1	1.05	1.04	0.59	87.1	1.05
	150	110	22.5	20	2.4	1.4	1.89	7000	300	113	116	1.61	101.4	1.11	1.04	0.59	108.6	1.04
	150	110	22.5	20	2.4	1.4	1.89	7000	450	129	116	1.97	101.4	1.27	1.04	0.59	132.0	0.98
	150	110	22.5	20	2.4	1.4	1.89	7000	600	144	116	2.28	101.4	1.42	1.04	0.59	151.6	0.95
R1_L4	80	50	15	20	1	1.6	1.65	7000	75	33	39	1.38	33.6	0.99	1.02	0.59	33.6	0.99
	80	50	15	20	1	1.6	1.65	7000	150	42	39	1.96	34.3	1.22	1.02	0.59	44.6	0.94
	80	50	15	20	1	1.6	1.65	7000	300	56	39	2.77	34.3	1.64	1.02	0.59	62.8	0.89
	80	50	15	20	1	1.6	1.65	7000	450	62	39	3.39	34.3	1.81	1.02	0.59	76.6	0.81
	80	50	15	20	1	1.6	1.65	7000	600	66	39	3.92	34.3	1.93	1.02	0.59	88.3	0.75

	Geometry								SFEA		DSM Design							
Column	b_w	b_f	b_s	b_l	t	b_w/b_t	$\beta=I_I/I_{II}$	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	b	a	f_{nFT}	f_u/f_{nFT}
R2_L4	100	70	20	30	1.2	1.4	1.45	9000	75	33	38	1.40	33.0	0.99	1.00	0.58	33.0	0.99
	100	70	20	30	1.2	1.4	1.45	9000	150	41	38	1.98	33.5	1.24	1.00	0.58	44.3	0.93
	100	70	20	30	1.2	1.4	1.45	9000	300	56	38	2.80	33.5	1.68	1.00	0.58	62.8	0.90
	100	70	20	30	1.2	1.4	1.45	9000	450	64	38	3.43	33.5	1.90	1.00	0.58	77.0	0.83
	100	70	20	30	1.2	1.4	1.45	9000	600	68	38	3.96	33.5	2.04	1.00	0.58	89.0	0.77
R3_L4	67	35	10	20	0.8	1.9	2.19	5500	75	34	40	1.37	34.0	0.99	1.07	0.60	34.0	0.99
	67	35	10	20	0.8	1.9	2.19	5500	150	43	40	1.94	34.8	1.22	1.07	0.60	44.3	0.96
	67	35	10	20	0.8	1.9	2.19	5500	300	57	40	2.75	34.8	1.63	1.07	0.60	61.2	0.93
	67	35	10	20	0.8	1.9	2.19	5500	450	64	40	3.37	34.8	1.85	1.07	0.60	74.0	0.87
	67	35	10	20	0.8	1.9	2.19	5500	600	68	40	3.89	34.8	1.96	1.07	0.60	84.6	0.81
R4_L4	150	110	22.5	20	2.4	1.4	1.89	9500	75	48	66	1.07	46.6	1.02	1.04	0.59	46.6	1.02
	150	110	22.5	20	2.4	1.4	1.89	9500	150	62	66	1.51	57.8	1.07	1.04	0.59	58.1	1.06
	150	110	22.5	20	2.4	1.4	1.89	9500	300	80	66	2.13	57.8	1.39	1.04	0.59	81.1	0.99
	150	110	22.5	20	2.4	1.4	1.89	9500	450	98	66	2.61	57.8	1.70	1.04	0.59	98.6	1.00
	150	110	22.5	20	2.4	1.4	1.89	9500	600	108	66	3.02	57.8	1.87	1.04	0.59	113.2	0.95
												Mean		1.24		Mean		0.95
												Sd. Dev.		0.28		Sd. Dev.		0.10
												Max		2.04		Max		1.09
												Min		0.98		Min		0.75

ANNEX E: WSC Column Data

Table E1: Columns failing in F_MT modes: (i) geometries, (ii) buckling stresses and ultimate strengths, (iii) ultimate strength predictions by current and proposed DSM design curves, and (iv) numerical-to-predicted ultimate strength ratios (mm and MPa)

	Geometry							SFEA		DSM Design							
Column	b_w	b_f	b_s	t	b_w/b_t	$\beta=I_I/I_{II}$	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	b	a	f_{nFT}	f_u/f_{nFT}
WSC1_L1	170	130	12	3.5	1.3	2.46	5500	75	67	181	0.64	63.0	1.06	1.10	0.61	63.0	1.06
	170	130	12	3.5	1.3	2.46	5500	150	117	181	0.91	105.9	1.10	1.10	0.61	105.9	1.10
	170	130	12	3.5	1.3	2.46	5500	300	154	181	1.29	149.6	1.03	1.10	0.61	149.6	1.03
	170	130	12	3.5	1.3	2.46	5500	450	165	181	1.58	158.3	1.04	1.10	0.61	165.9	0.99
	170	130	12	3.5	1.3	2.46	5500	600	167	181	1.82	158.3	1.05	1.10	0.61	188.9	0.88
WSC2_L1	150	110	10	2.4	1.4	2.67	5500	75	63	138	0.74	59.7	1.06	1.12	0.61	59.7	1.06
	150	110	10	2.4	1.4	2.67	5500	150	100	138	1.04	95.0	1.05	1.12	0.61	95.0	1.05
	150	110	10	2.4	1.4	2.67	5500	300	124	138	1.48	120.4	1.03	1.12	0.61	120.4	1.03
	150	110	10	2.4	1.4	2.67	5500	450	125	138	1.81	120.6	1.04	1.12	0.61	142.4	0.88
	150	110	10	2.4	1.4	2.67	5500	600	175	138	2.09	120.6	1.45	1.12	0.61	161.6	1.08
WSC3_L1	120	90	10	2.4	1.3	2.50	4000	75	66	176	0.65	62.7	1.06	1.10	0.61	62.7	1.06
	120	90	10	2.4	1.3	2.50	4000	150	115	176	0.92	104.9	1.10	1.10	0.61	104.9	1.10
	120	90	10	2.4	1.3	2.50	4000	300	154	176	1.31	146.7	1.05	1.10	0.61	146.7	1.05
	120	90	10	2.4	1.3	2.50	4000	450	171	176	1.60	153.9	1.11	1.10	0.61	163.3	1.05
	120	90	10	2.4	1.3	2.50	4000	600	196	176	1.85	153.9	1.27	1.10	0.61	185.9	1.05
WSC4_L1	160	100	12.5	2.4	1.6	3.44	5000	75	66	181	0.64	63.0	1.05	1.19	0.63	63.0	1.05
	160	100	12.5	2.4	1.6	3.44	5000	150	115	181	0.91	106.0	1.09	1.19	0.63	106.0	1.09
	160	100	12.5	2.4	1.6	3.44	5000	300	150	181	1.29	149.7	1.00	1.19	0.63	149.7	1.00
	160	100	12.5	2.4	1.6	3.44	5000	450	165	181	1.58	158.5	1.04	1.19	0.63	165.2	1.00
	160	100	12.5	2.4	1.6	3.44	5000	600	168	181	1.82	158.5	1.06	1.19	0.63	185.5	0.91
WSC1_L2	170	130	12	3.5	1.3	2.46	7000	75	61	119	0.79	57.6	1.06	1.10	0.61	57.6	1.06
	170	130	12	3.5	1.3	2.46	7000	150	94	119	1.12	88.4	1.06	1.10	0.61	88.4	1.06
	170	130	12	3.5	1.3	2.46	7000	300	119	119	1.59	104.2	1.14	1.10	0.61	109.8	1.08
	170	130	12	3.5	1.3	2.46	7000	450	143	119	1.95	104.2	1.37	1.10	0.61	131.9	1.08
	170	130	12	3.5	1.3	2.46	7000	600	166	119	2.25	104.2	1.59	1.10	0.61	150.2	1.10
WSC2_L2	150	110	10	2.4	1.4	2.67	7000	75	55	90	0.91	52.9	1.05	1.12	0.61	52.9	1.05
	150	110	10	2.4	1.4	2.67	7000	150	78	90	1.29	74.6	1.04	1.12	0.61	74.6	1.04
	150	110	10	2.4	1.4	2.67	7000	300	101	90	1.83	78.8	1.28	1.12	0.61	93.8	1.08
	150	110	10	2.4	1.4	2.67	7000	450	124	90	2.24	78.8	1.57	1.12	0.61	112.2	1.10
	150	110	10	2.4	1.4	2.67	7000	600	144	90	2.58	78.8	1.83	1.12	0.61	127.4	1.13
WSC3_L2	120	90	10	2.4	1.3	2.50	5500	75	58	101	0.86	55.0	1.06	1.10	0.61	55.0	1.06
	120	90	10	2.4	1.3	2.50	5500	150	85	101	1.22	80.6	1.05	1.10	0.61	80.6	1.05
	120	90	10	2.4	1.3	2.50	5500	300	108	101	1.72	88.7	1.22	1.10	0.61	100.5	1.07
	120	90	10	2.4	1.3	2.50	5500	450	131	101	2.11	88.7	1.48	1.10	0.61	120.6	1.09
	120	90	10	2.4	1.3	2.50	5500	600	152	101	2.44	88.7	1.71	1.10	0.61	137.3	1.11
WSC4_L2	160	100	12.5	2.4	1.6	3.44	6500	75	60	113	0.81	56.8	1.05	1.19	0.63	56.8	1.05
	160	100	12.5	2.4	1.6	3.44	6500	150	90	113	1.15	86.1	1.05	1.19	0.63	86.1	1.05
	160	100	12.5	2.4	1.6	3.44	6500	300	114	113	1.63	99.1	1.15	1.19	0.63	106.0	1.08
	160	100	12.5	2.4	1.6	3.44	6500	450	134	113	2.00	99.1	1.35	1.19	0.63	124.8	1.07
	160	100	12.5	2.4	1.6	3.44	6500	600	151	113	2.30	99.1	1.52	1.19	0.63	140.1	1.08
WSC1_L3	170	130	12	3.5	1.3	2.46	8000	75	57	95	0.89	53.9	1.06	1.10	0.61	53.9	1.06
	170	130	12	3.5	1.3	2.46	8000	150	81	95	1.26	77.4	1.05	1.10	0.61	77.4	1.05
	170	130	12	3.5	1.3	2.46	8000	300	105	95	1.78	83.2	1.26	1.10	0.61	97.1	1.08
	170	130	12	3.5	1.3	2.46	8000	450	129	95	2.18	83.2	1.55	1.10	0.61	116.6	1.11
	170	130	12	3.5	1.3	2.46	8000	600	150	95	2.51	83.2	1.80	1.10	0.61	132.8	1.13
WSC2_L3	150	110	10	2.4	1.4	2.67	8000	75	50	71	1.03	48.3	1.03	1.12	0.61	48.3	1.03
	150	110	10	2.4	1.4	2.67	8000	150	67	71	1.45	62.2	1.07	1.12	0.61	62.2	1.07
	150	110	10	2.4	1.4	2.67	8000	300	91	71	2.05	62.5	1.45	1.12	0.61	82.5	1.10
	150	110	10	2.4	1.4	2.67	8000	450	112	71	2.51	62.5	1.79	1.12	0.61	98.7	1.14
	150	110	10	2.4	1.4	2.67	8000	600	128	71	2.90	62.5	2.05	1.12	0.61	112.0	1.14
WSC3_L3	120	90	10	2.4	1.3	2.50	7000	75	49	68	1.05	47.3	1.03	1.10	0.61	47.3	1.03
	120	90	10	2.4	1.3	2.50	7000	150	65	68	1.48	59.7	1.08	1.10	0.61	59.7	1.08
	120	90	10	2.4	1.3	2.50	7000	300	88	68	2.10	59.8	1.47	1.10	0.61	80.9	1.09
	120	90	10	2.4	1.3	2.50	7000	450	108	68	2.57	59.8	1.81	1.10	0.61	97.1	1.11
	120	90	10	2.4	1.3	2.50	7000	600	123	68	2.97	59.8	2.06	1.10	0.61	110.6	1.11
WSC4_L3	160	100	12.5	2.4	1.6	3.44	8000	75	52	79	0.98	50.3	1.04	1.19	0.63	50.3	1.04
	160	100	12.5	2.4	1.6	3.44	8000	150	71	79	1.38	67.6	1.05	1.19	0.63	67.6	1.05
	160	100	12.5	2.4	1.6	3.44	8000	300	93	79	1.95	69.0	1.34	1.19	0.63	85.4	1.09
	160	100	12.5	2.4	1.6	3.44	8000	450	111	79	2.39	69.0	1.61	1.19	0.63	100.6	1.10
	160	100	12.5	2.4	1.6	3.44	8000	600	124	79	2.76	69.0	1.80	1.19	0.63	112.9	1.10
WSC1_L4	170	130	12	3.5	1.3	2.46	9500	75	50	72	1.02	48.5	1.04	1.10	0.61	48.5	1.04
	170	130	12	3.5	1.3	2.46	9500	150	67	72	1.44	62.6	1.07	1.10	0.61	62.6	1.07
	170	130	12	3.5	1.3	2.46	9500	300	91	72	2.04	63.1	1.45	1.10	0.61	83.4	1.09
	170	130	12	3.5	1.3	2.46	9500	450	113	72	2.50	63.1	1.79	1.10	0.61	100.2	1.13
	170	130	12	3.5	1.3	2.46	9500	600	130	72	2.89	63.1	2.06	1.10	0.61	114.1	1.14

WSC2_L4	150	110	10	2.4	1.4	2.67	9500	75	42	54	1.18	41.8	1.01	1.12	0.61	41.8	1.01
	150	110	10	2.4	1.4	2.67	9500	150	56	54	1.67	47.0	1.19	1.12	0.61	51.8	1.08
	150	110	10	2.4	1.4	2.67	9500	300	79	54	2.37	47.0	1.69	1.12	0.61	70.3	1.13
	150	110	10	2.4	1.4	2.67	9500	450	96	54	2.90	47.0	2.05	1.12	0.61	84.1	1.14
	150	110	10	2.4	1.4	2.67	9500	600	106	54	3.35	47.0	2.25	1.12	0.61	95.5	1.11
WSC3_L4	120	90	10	2.4	1.3	2.50	9500	75	41	44	1.31	36.5	1.13	1.10	0.61	36.5	1.13
	120	90	10	2.4	1.3	2.50	9500	150	54	44	1.85	38.2	1.41	1.10	0.61	46.3	1.16
	120	90	10	2.4	1.3	2.50	9500	300	75	44	2.62	38.2	1.97	1.10	0.61	63.3	1.19
	120	90	10	2.4	1.3	2.50	9500	450	90	44	3.21	38.2	2.34	1.10	0.61	76.0	1.18
	120	90	10	2.4	1.3	2.50	9500	600	98	44	3.71	38.2	2.56	1.10	0.61	86.5	1.13
WSC4_L4	160	100	12.5	2.4	1.6	3.44	9500	75	45	59	1.13	44.1	1.02	1.19	0.63	44.1	1.02
	160	100	12.5	2.4	1.6	3.44	9500	150	59	59	1.59	51.9	1.13	1.19	0.63	54.5	1.08
	160	100	12.5	2.4	1.6	3.44	9500	300	80	59	2.25	51.9	1.53	1.19	0.63	72.1	1.10
	160	100	12.5	2.4	1.6	3.44	9500	450	93	59	2.76	51.9	1.80	1.19	0.63	84.8	1.10
	160	100	12.5	2.4	1.6	3.44	9500	600	100		3.18	51.9	1.93	1.19	0.63	95.3	1.05
											Mean		1.35		Mean		1.07
											Sd. Dev.		0.38		Sd. Dev.		0.05
											Max		2.56		Max		1.19
											Min		1.00		Min		0.88

ANNEX F: WFSC COLUMN DATA

Table F1: Columns failing in F_MT modes: (i) geometries, (ii) buckling stresses and ultimate strengths, (iii) ultimate strength predictions by current and proposed DSM design curves, and (iv) numerical-to-predicted ultimate strength ratios (mm and MPa)

	Geometry							SFEA		DSM Design							
Column	b_w	b_f	b_s	t	b_w/b_t	$\beta=I_I/I_{II}$	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	b	a	f_{nFT}	f_u/f_{nFT}
WFSC1_L1	170	130	12.5	3.5	1.3	2.51	5000	75	67	200	0.61	64.1	1.05	1.10	0.61	64.1	1.05
	170	130	12.5	3.5	1.3	2.51	5000	150	121	200	0.87	109.5	1.10	1.10	0.61	109.5	1.10
	170	130	12.5	3.5	1.3	2.51	5000	300	168	200	1.23	160.0	1.05	1.10	0.61	160.0	1.05
	170	130	12.5	3.5	1.3	2.51	5000	450	180	200	1.50	175.1	1.03	1.10	0.61	175.3	1.03
	170	130	12.5	3.5	1.3	2.51	5000	600	211	200	1.73	175.1	1.20	1.10	0.61	199.5	1.06
WFSC2_L1	150	110	12.5	2.4	1.4	2.66	5000	75	64	153	0.70	61.1	1.05	1.12	0.61	61.1	1.05
	150	110	12.5	2.4	1.4	2.66	5000	150	107	153	0.99	99.5	1.07	1.12	0.61	99.5	1.07
	150	110	12.5	2.4	1.4	2.66	5000	300	136	153	1.40	132.1	1.03	1.12	0.61	132.1	1.03
	150	110	12.5	2.4	1.4	2.66	5000	450	146	153	1.71	134.3	1.09	1.12	0.61	151.2	0.97
	150	110	12.5	2.4	1.4	2.66	5000	600	180	153	1.98	134.3	1.34	1.12	0.61	171.7	1.05
WFSC3_L1	120	90	12.5	1.2	1.3	2.48	4600	75	59	112	0.82	56.6	1.04	1.10	0.61	56.6	1.04
	120	90	12.5	1.2	1.3	2.48	4600	150	85	112	1.16	85.5	1.00	1.10	0.61	85.5	1.00
	120	90	12.5	1.2	1.3	2.48	4600	300	108	112	1.64	98.0	1.10	1.10	0.61	106.2	1.02
	120	90	12.5	1.2	1.3	2.48	4600	450	133	112	2.01	98.0	1.36	1.10	0.61	127.5	1.04
	120	90	12.5	1.2	1.3	2.48	4600	600	152	112	2.32	98.0	1.55	1.10	0.61	145.2	1.05
WFSC4_L1	160	100	12.5	3	1.6	3.53	4600	75	67	201	0.61	64.2	1.05	1.20	0.64	64.2	1.05
	160	100	12.5	3	1.6	3.53	4600	150	121	201	0.86	109.8	1.10	1.20	0.64	109.8	1.10
	160	100	12.5	3	1.6	3.53	4600	300	172	201	1.22	160.8	1.07	1.20	0.64	160.8	1.07
	160	100	12.5	3	1.6	3.53	4600	450	190	201	1.49	176.6	1.08	1.20	0.64	176.6	1.08
	160	100	12.5	3	1.6	3.53	4600	600	207	201	1.73	176.6	1.17	1.20	0.64	197.6	1.05
WFSC1_L2	170	130	12.5	3.5	1.3	2.51	6500	75	62	127	0.77	58.6	1.06	1.10	0.61	58.6	1.06
	170	130	12.5	3.5	1.3	2.51	6500	150	98	127	1.09	91.5	1.07	1.10	0.61	91.5	1.07
	170	130	12.5	3.5	1.3	2.51	6500	300	124	127	1.54	111.4	1.11	1.10	0.61	113.9	1.09
	170	130	12.5	3.5	1.3	2.51	6500	450	146	127	1.88	111.4	1.31	1.10	0.61	136.7	1.07
	170	130	12.5	3.5	1.3	2.51	6500	600	169	127	2.17	111.4	1.52	1.10	0.61	155.5	1.09
WFSC2_L2	150	110	12.5	2.4	1.4	2.66	6500	75	57	96	0.88	54.2	1.05	1.12	0.61	54.2	1.05
	150	110	12.5	2.4	1.4	2.66	6500	150	81	96	1.25	78.2	1.04	1.12	0.61	78.2	1.04
	150	110	12.5	2.4	1.4	2.66	6500	300	103	96	1.76	84.5	1.22	1.12	0.61	97.6	1.06
	150	110	12.5	2.4	1.4	2.66	6500	450	126	96	2.16	84.5	1.49	1.12	0.61	116.8	1.08
	150	110	12.5	2.4	1.4	2.66	6500	600	147	96	2.49	84.5	1.74	1.12	0.61	132.6	1.11
WFSC3_L2	120	90	12.5	1.2	1.3	2.48	6000	75	48	70	1.04	47.7	1.01	1.10	0.61	47.7	1.01
	120	90	12.5	1.2	1.3	2.48	6000	150	64	70	1.47	60.8	1.05	1.10	0.61	60.8	1.05
	120	90	12.5	1.2	1.3	2.48	6000	300	86	70	2.08	61.0	1.41	1.10	0.61	81.8	1.05
	120	90	12.5	1.2	1.3	2.48	6000	450	106	70	2.54	61.0	1.74	1.10	0.61	98.2	1.08
	120	90	12.5	1.2	1.3	2.48	6000	600	121	70	2.94	61.0	1.99	1.10	0.61	111.8	1.08
WFSC4_L2	160	100	12.5	3	1.6	3.53	6000	75	62	127	0.77	58.6	1.06	1.20	0.64	58.6	1.06
	160	100	12.5	3	1.6	3.53	6000	150	97	127	1.09	91.5	1.06	1.20	0.64	91.5	1.06
	160	100	12.5	3	1.6	3.53	6000	300	124	127	1.54	111.5	1.11	1.20	0.64	113.7	1.09
	160	100	12.5	3	1.6	3.53	6000	450	143	127	1.88	111.5	1.28	1.20	0.64	133.6	1.07
	160	100	12.5	3	1.6	3.53	6000	600	162	127	2.17	111.5	1.45	1.20	0.64	149.8	1.08
WFSC1_L3	170	130	12.5	3.5	1.3	2.51	8000	75	56	90	0.91	52.8	1.05	1.10	0.61	52.8	1.05
	170	130	12.5	3.5	1.3	2.51	8000	150	78	90	1.29	74.4	1.04	1.10	0.61	74.4	1.04
	170	130	12.5	3.5	1.3	2.51	8000	300	101	90	1.83	78.6	1.29	1.10	0.61	94.0	1.07
	170	130	12.5	3.5	1.3	2.51	8000	450	124	90	2.24	78.6	1.58	1.10	0.61	112.8	1.10
	170	130	12.5	3.5	1.3	2.51	8000	600	145	90	2.59	78.6	1.85	1.10	0.61	128.3	1.13
WFSC2_L3	150	110	12.5	2.4	1.4	2.66	8000	75	48	67	1.06	47.0	1.02	1.12	0.61	47.0	1.02
0	150	110	12.5	2.4	1.4	2.66	8000	150	64	67	1.49	59.0	1.08	1.12	0.61	59.0	1.08
0	150	110	12.5	2.4	1.4	2.66	8000	300	87	67	2.11	59.0	1.47	1.12	0.61	79.9	1.09
0	150	110	12.5	2.4	1.4	2.66	8000	450	108	67	2.59	59.0	1.83	1.12	0.61	95.6	1.13
0	150	110	12.5	2.4	1.4	2.66	8000	600	123	67	2.99	59.0	2.08	1.12	0.61	108.5	1.13
WFSC3_L3	120	90	12.5	1.2	1.3	2.48	7500	75	38	46	1.27	38.0	0.99	1.10	0.61	38.0	0.99
	120	90	12.5	1.2	1.3	2.48	7500	150	50	46	1.80	40.5	1.23	1.10	0.61	47.8	1.04
	120	90	12.5	1.2	1.3	2.48	7500	300	73	46	2.55	40.5	1.80	1.10	0.61	65.4	1.11
	120	90	12.5	1.2	1.3	2.48	7500	450	89	46	3.12	40.5	2.19	1.10	0.61	78.5	1.13
	120	90	12.5	1.2	1.3	2.48	7500	600	97	46	3.60	40.5	2.40	1.10	0.61	89.4	1.09
WFSC4_L3	160	100	12.5	3	1.6	3.53	7500	75	55	88	0.92	52.5	1.05	1.20	0.64	52.5	1.05
	160	100	12.5	3	1.6	3.53	7500	150	77	88	1.31	73.5	1.04	1.20	0.64	73.5	1.04
	160	100	12.5	3	1.6	3.53	7500	300	98	88	1.85	77.2	1.27	1.20	0.64	91.1	1.08
	160	100	12.5	3	1.6	3.53	7500	450	117	88	2.26	77.2	1.52	1.20	0.64	107.1	1.09
	160	100	12.5	3	1.6	3.53	7500	600	132	88	2.61	77.2	1.71	1.20	0.64	120.1	1.10
WFSC1_L4	170	130	12.5	3.5	1.3	2.51	9500	75	49	68	1.05	47.3	1.03	1.10	0.61	47.3	1.03
	170	130	12.5	3.5	1.3	2.51	9500	150	65	68	1.48	59.7	1.08	1.10	0.61	59.7	1.08
	170	130	12.5	3.5	1.3	2.51	9500	300	88	68	2.10	59.7	1.48	1.10	0.61	80.8	1.09
	170	130	12.5	3.5	1.3	2.51	9500	450	110	68	2.57	59.7	1.84	1.10	0.61	97.0	1.13
	170	130	12.5	3.5	1.3	2.51	9500	600	126	68	2.97	59.7	2.11	1.10	0.61	110.3	1.14

	Geometry							SFEA		DSM Design							
Column	b_w	b_f	b_s	t	b_w/b_t	$\beta = I_I/I_{II}$	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	b	a	f_{nFT}	f_u/f_{nFT}
WFSC2_L4	150	110	12.5	2.4	1.4	2.66	9500	75	41	51	1.22	40.4	1.00	1.12	0.61	40.4	1.00
	150	110	12.5	2.4	1.4	2.66	9500	150	53	51	1.72	44.5	1.20	1.12	0.61	50.2	1.06
	150	110	12.5	2.4	1.4	2.66	9500	300	76	51	2.43	44.5	1.72	1.12	0.61	68.2	1.12
	150	110	12.5	2.4	1.4	2.66	9500	450	93	51	2.98	44.5	2.09	1.12	0.61	81.6	1.14
	150	110	12.5	2.4	1.4	2.66	9500	600	103	51	3.44	44.5	2.32	1.12	0.61	92.7	1.11
WFSC3_L4	120	90	12.5	1.2	1.3	2.48	9000	75	29	33	1.50	29.2	0.99	1.10	0.61	29.2	0.99
	120	90	12.5	1.2	1.3	2.48	9000	150	41	33	2.12	29.2	1.41	1.10	0.61	40.0	1.03
	120	90	12.5	1.2	1.3	2.48	9000	300	60	33	3.00	29.2	2.06	1.10	0.61	54.6	1.10
	120	90	12.5	1.2	1.3	2.48	9000	450	69	33	3.68	29.2	2.38	1.10	0.61	65.6	1.06
	120	90	12.5	1.2	1.3	2.48	9000	600	73	33	4.24	29.2	2.50	1.10	0.61	74.7	0.98
WFSC4_L4	160	100	12.5	3	1.6	3.53	9000	75	48	67	1.06	46.8	1.03	1.20	0.64	46.8	1.03
	160	100	12.5	3	1.6	3.53	9000	150	63	67	1.50	58.4	1.08	1.20	0.64	58.5	1.08
	160	100	12.5	3	1.6	3.53	9000	300	84	67	2.12	58.4	1.43	1.20	0.64	77.0	1.09
	160	100	12.5	3	1.6	3.53	9000	450	99	67	2.60	58.4	1.69	1.20	0.64	90.6	1.09
	160	100	12.5	3	1.6	3.53	9000	600	108	67	3.00	58.4	1.85	1.20	0.64	101.6	1.06
											Mean		1.38		Mean		1.07
											Sd. Dev.		0.41		Sd. Dev.		0.04
											Max		2.50		Max		1.14
											Min		0.99		Min		0.97

ANNEX G: Z COLUMN DATA

Table G1: Columns failing in F_m modes: (i) geometries, (ii) buckling stresses and ultimate strengths, (iii) ultimate strength predictions by current and proposed DSM design curves, and (iv) numerical-to-predicted ultimate strength ratios (mm and MPa)

	Geometry						SFEA		DSM Design					
Column	b_w	b_f	b_s	t	b_w/b_t	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	f_{nF}	f_u/f_{nF}
Z1_L1	60	55	11	1.2	1.1	2200	75	66	266	0.53	66.7	0.99	70.3	0.94
	60	55	11	1.2	1.1	2200	150	122	266	0.75	118.5	1.03	115.3	1.06
	60	55	11	1.2	1.1	2200	300	192	266	1.06	187.1	1.03	163.8	1.17
	60	55	11	1.2	1.1	2200	450	218	266	1.30	221.7	0.98	188.9	1.15
	60	55	11	1.2	1.1	2200	600	226	266	1.50	233.3	0.97	204.1	1.11
Z2_L1	100	60	10	2	1.7	2600	75	67	326	0.48	68.1	0.98	72.8	0.92
	100	60	10	2	1.7	2600	150	127	326	0.68	123.7	1.03	123.9	1.03
	100	60	10	2	1.7	2600	300	210	326	0.96	204.0	1.03	183.6	1.14
	100	60	10	2	1.7	2600	450	249	326	1.18	252.3	0.99	216.4	1.15
	100	60	10	2	1.7	2600	600	265	326	1.36	277.4	0.96	237.0	1.12
Z3_L1	120	80	15	3	1.5	2900	75	68	442	0.41	69.9	0.98	75.0	0.91
	120	80	15	3	1.5	2900	150	132	442	0.58	130.1	1.01	135.1	0.98
	120	80	15	3	1.5	2900	300	240	442	0.82	225.8	1.06	213.4	1.12
	120	80	15	3	1.5	2900	450	309	442	1.01	293.9	1.05	260.7	1.19
	120	80	15	3	1.5	2900	600	345	442	1.17	339.9	1.01	292.0	1.18
Z4_L1	140	70	10	3	3.0	3100	75	67	327	0.48	68.1	0.99	72.8	0.93
	140	70	10	3	2.0	3100	150	128	327	0.68	123.8	1.03	124.1	1.03
	140	70	10	3	2.0	3100	300	217	327	0.96	204.4	1.06	184.1	1.18
	140	70	10	3	2.0	3100	450	257	327	1.17	253.1	1.02	217.2	1.18
	140	70	10	3	2.0	3100	600	279	327	1.35	278.6	1.00	237.9	1.17
Z5_L1	150	100	10	4	1.5	4100	75	67	318	0.49	68.0	0.98	72.5	0.92
	150	100	10	4	1.5	4100	150	126	318	0.69	123.2	1.02	123.0	1.02
	150	100	10	4	1.5	4100	300	211	318	0.97	202.2	1.04	181.4	1.16
	150	100	10	4	1.5	4100	450	246	318	1.19	249.1	0.99	213.3	1.15
	150	100	10	4	1.5	4100	600	259	318	1.37	272.7	0.95	233.3	1.11
Z6_L1	80	65	15	1.2	1.2	3200	75	63	210	0.60	64.6	0.98	66.7	0.94
	80	65	15	1.2	1.2	3200	150	111	210	0.85	111.2	1.00	104.2	1.06
	80	65	15	1.2	1.2	3200	300	160	210	1.20	164.9	0.97	141.2	1.13
	80	65	15	1.2	1.2	3200	450	175	210	1.46	183.4	0.95	159.1	1.10
	80	65	15	1.2	1.2	3200	600	179	210	1.69	184.1	0.97	169.6	1.06
Z7_L1	95	50	10	1.8	1.9	2200	75	68	347	0.47	68.5	0.99	73.4	0.92
	95	50	10	1.8	1.9	2200	150	129	347	0.66	125.2	1.03	126.4	1.02
	95	50	10	1.8	1.9	2200	300	221	347	0.93	208.8	1.06	189.8	1.16
	95	50	10	1.8	1.9	2200	450	268	347	1.14	261.4	1.03	225.3	1.19
	95	50	10	1.8	1.9	2200	600	292	347	1.32	290.8	1.00	247.9	1.18
Z8_L1	75	60	10	1	1.3	3300	75	59	162	0.68	61.8	0.95	61.8	0.95
	75	60	10	1	1.3	3300	150	96	162	0.96	101.7	0.94	91.5	1.05
	75	60	10	1	1.3	3300	300	127	162	1.36	138.0	0.92	117.9	1.08
	75	60	10	1	1.3	3300	450	131	162	1.67	141.8	0.92	130.0	1.01
	75	60	10	1	1.3	3300	600	132	162	1.93	141.8	0.93	136.8	0.96
Z9_L1	80	45	11	1.6	1.8	1900	75	68	383	0.44	69.1	0.98	74.3	0.91
	80	45	11	1.6	1.8	1900	150	130	383	0.63	127.3	1.02	130.1	1.00
	80	45	11	1.6	1.8	1900	300	230	383	0.89	216.1	1.06	199.5	1.15
	80	45	11	1.6	1.8	1900	450	287	383	1.08	275.1	1.04	239.6	1.20
	80	45	11	1.6	1.8	1900	600	317	383	1.25	311.3	1.02	265.4	1.19
Z1_L2	60	55	11	1.2	1.1	3000	75	58	149	0.71	60.7	0.96	60.0	0.97
	60	55	11	1.2	1.1	3000	150	95	149	1.01	98.3	0.97	87.3	1.09
	60	55	11	1.2	1.1	3000	300	124	149	1.42	128.8	0.96	110.8	1.12
	60	55	11	1.2	1.1	3000	450	132	149	1.74	130.2	1.01	121.4	1.09
	60	55	11	1.2	1.1	3000	600	134	149	2.01	130.2	1.03	127.3	1.05
Z2_L2	100	60	10	2	1.7	3500	75	61	180	0.65	63.0	0.97	63.9	0.96
	100	60	10	2	1.7	3500	150	106	180	0.91	105.9	1.00	96.8	1.09
	100	60	10	2	1.7	3500	300	146	180	1.29	149.5	0.98	127.3	1.15
	100	60	10	2	1.7	3500	450	158	180	1.58	158.0	1.00	141.6	1.12
	100	60	10	2	1.7	3500	600	163	180	1.82	158.0	1.03	149.8	1.09
Z3_L2	120	80	15	3	1.5	4000	75	64	235	0.57	65.6	0.97	68.5	0.93
	120	80	15	3	1.5	4000	150	116	235	0.80	114.8	1.01	109.6	1.06
	120	80	15	3	1.5	4000	300	176	235	1.13	175.7	1.00	151.7	1.16
	120	80	15	3	1.5	4000	450	199	235	1.38	201.8	0.99	172.8	1.15
	120	80	15	3	1.5	4000	600	209	235	1.60	205.9	1.01	185.4	1.13
Z4_L2	140	70	10	3	3.0	4500	75	60	156	0.69	61.3	0.98	61.0	0.98
	140	70	10	3	2.0	4500	150	100	156	0.98	100.2	1.00	89.6	1.11
	140	70	10	3	2.0	4500	300	131	156	1.39	133.9	0.98	114.7	1.14
	140	70	10	3	2.0	4500	450	140	156	1.70	136.5	1.03	126.0	1.11
	140	70	10	3	2.0	4500	600	144	156	1.96	136.5	1.06	132.4	1.09

	Geometry						SFEA		DSM Design					
Column	b_w	b_f	b_s	t	b_w/b_t	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	f_{nF}	f_u/f_{nF}
Z5_L2	150	100	10	4	1.5	5500	75	61	178	0.65	62.9	0.97	63.7	0.96
	150	100	10	4	1.5	5500	150	105	178	0.92	105.4	1.00	96.1	1.09
	150	100	10	4	1.5	5500	300	145	178	1.30	148.0	0.98	126.1	1.15
	150	100	10	4	1.5	5500	450	156	178	1.59	155.8	1.00	140.0	1.11
	150	100	10	4	1.5	5500	600	161	178	1.84	155.8	1.03	148.1	1.09
Z6_L2	80	65	15	1.2	1.2	4500	75	52	108	0.83	56.1	0.92	52.8	0.98
	80	65	15	1.2	1.2	4500	150	77	108	1.18	83.9	0.92	71.9	1.07
	80	65	15	1.2	1.2	4500	300	93	108	1.67	94.7	0.98	86.8	1.07
	80	65	15	1.2	1.2	4500	450	97	108	2.04	94.7	1.03	93.0	1.04
	80	65	15	1.2	1.2	4500	600	98	108	2.36	94.7	1.03	96.4	1.02
Z7_L2	95	50	10	1.8	1.9	3000	75	62	187	0.63	63.4	0.98	64.6	0.96
	95	50	10	1.8	1.9	3000	150	108	187	0.90	107.2	1.01	98.6	1.10
	95	50	10	1.8	1.9	3000	300	151	187	1.27	153.2	0.99	130.5	1.16
	95	50	10	1.8	1.9	3000	450	164	187	1.55	163.8	1.00	145.6	1.13
	95	50	10	1.8	1.9	3000	600	170	187	1.79	163.8	1.04	154.3	1.10
Z8_L2	75	60	10	1	1.3	4500	75	47	88	0.92	52.5	0.89	47.9	0.98
	75	60	10	1	1.3	4500	150	66	88	1.30	73.6	0.89	62.7	1.05
	75	60	10	1	1.3	4500	300	77	88	1.84	77.4	0.99	73.6	1.04
	75	60	10	1	1.3	4500	450	78	88	2.26	77.4	1.01	77.9	1.00
	75	60	10	1	1.3	4500	600	78	88	2.61	77.4	1.01	80.3	0.98
Z9_L2	80	45	11	1.6	1.8	2500	75	64	221	0.58	65.1	0.98	67.6	0.94
	80	45	11	1.6	1.8	2500	150	115	221	0.82	113.0	1.02	106.8	1.08
	80	45	11	1.6	1.8	2500	300	171	221	1.16	170.1	1.01	146.2	1.17
	80	45	11	1.6	1.8	2500	450	191	221	1.43	192.2	0.99	165.5	1.15
	80	45	11	1.6	1.8	2500	600	199	221	1.65	194.2	1.02	177.0	1.12
Z1_L3	60	55	11	1.2	1.1	4000	75	49	84	0.94	51.6	0.94	46.7	1.04
	60	55	11	1.2	1.1	4000	150	65	84	1.34	71.1	0.91	60.7	1.07
	60	55	11	1.2	1.1	4000	300	75	84	1.89	73.8	1.01	70.7	1.06
	60	55	11	1.2	1.1	4000	450	78	84	2.31	73.8	1.05	74.7	1.04
	60	55	11	1.2	1.1	4000	600	78	84	2.67	73.8	1.06	76.9	1.02
Z2_L3	100	60	10	2	1.7	4500	75	53	109	0.83	56.2	0.95	53.0	1.00
	100	60	10	2	1.7	4500	150	80	109	1.17	84.4	0.95	72.4	1.10
	100	60	10	2	1.7	4500	300	96	109	1.66	95.7	1.00	87.5	1.09
	100	60	10	2	1.7	4500	450	100	109	2.03	95.7	1.05	93.8	1.07
	100	60	10	2	1.7	4500	600	101	109	2.35	95.7	1.06	97.2	1.04
Z3_L3	120	80	15	3	1.5	5500	75	55	124	0.78	58.3	0.95	56.1	0.98
	120	80	15	3	1.5	5500	150	86	124	1.10	90.6	0.95	78.6	1.09
	120	80	15	3	1.5	5500	300	107	124	1.55	109.1	0.98	97.0	1.10
	120	80	15	3	1.5	5500	450	113	124	1.90	109.1	1.04	104.8	1.08
	120	80	15	3	1.5	5500	600	116	124	2.20	109.1	1.06	109.2	1.06
Z4_L3	140	70	10	3	3.0	5500	75	53	104	0.85	55.5	0.96	51.9	1.02
	140	70	10	3	2.0	5500	150	78	104	1.20	82.1	0.95	70.3	1.11
	140	70	10	3	2.0	5500	300	92	104	1.70	91.4	1.01	84.3	1.09
	140	70	10	3	2.0	5500	450	96	104	2.08	91.4	1.05	90.2	1.07
	140	70	10	3	2.0	5500	600	98	104	2.40	91.4	1.07	93.3	1.05
Z5_L3	150	100	10	4	1.5	6500	75	56	127	0.77	58.6	0.96	56.7	0.99
	150	100	10	4	1.5	6500	150	88	127	1.09	91.6	0.96	79.8	1.10
	150	100	10	4	1.5	6500	300	110	127	1.53	111.7	0.98	98.8	1.11
	150	100	10	4	1.5	6500	450	116	127	1.88	111.7	1.04	106.9	1.08
	150	100	10	4	1.5	6500	600	118	127	2.17	111.7	1.06	111.5	1.06
Z6_L3	80	65	15	1.2	1.2	5500	75	43	73	1.02	48.6	0.88	43.1	0.99
	80	65	15	1.2	1.2	5500	150	57	73	1.44	63.1	0.90	54.5	1.05
	80	65	15	1.2	1.2	5500	300	65	73	2.03	63.6	1.02	62.4	1.04
	80	65	15	1.2	1.2	5500	450	67	73	2.49	63.6	1.05	65.4	1.02
	80	65	15	1.2	1.2	5500	600	67	73	2.88	63.6	1.05	67.1	1.00
Z7_L3	95	50	10	1.8	1.9	4000	75	53	105	0.84	55.7	0.95	52.2	1.02
	95	50	10	1.8	1.9	4000	150	78	105	1.19	82.6	0.95	70.7	1.11
	95	50	10	1.8	1.9	4000	300	93	105	1.69	92.3	1.01	85.0	1.09
	95	50	10	1.8	1.9	4000	450	97	105	2.07	92.3	1.05	90.9	1.07
	95	50	10	1.8	1.9	4000	600	99	105	2.39	92.3	1.07	94.1	1.05
Z8_L3	75	60	10	1	1.3	5500	75	38	59	1.13	44.1	0.85	38.1	0.99
	75	60	10	1	1.3	5500	150	48	59	1.59	51.9	0.92	46.7	1.03
	75	60	10	1	1.3	5500	300	53	59	2.25	51.9	1.02	52.3	1.02
	75	60	10	1	1.3	5500	450	54	59	2.76	51.9	1.04	54.4	0.99
	75	60	10	1	1.3	5500	600	54	59	3.18	51.9	1.04	55.6	0.97
Z9_L3	80	45	11	1.6	1.8	3500	75	54	113	0.81	56.8	0.95	53.9	1.00
	80	45	11	1.6	1.8	3500	150	82	113	1.15	86.1	0.95	74.1	1.11
	80	45	11	1.6	1.8	3500	300	99	113	1.63	99.1	1.00	90.0	1.10
	80	45	11	1.6	1.8	3500	450	104	113	2.00	99.1	1.05	96.6	1.08
	80	45	11	1.6	1.8	3500	600	106	113	2.30	99.1	1.07	100.3	1.06

	Geometry						SFEA		DSM Design					
Column	b_w	b_f	b_s	t	b_w/b_t	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	f_{nF}	f_u/f_{nF}
Z1_L4	60	55	11	1.2	1.1	5000	75	36	54	1.18	41.9	0.86	35.9	1.00
	60	55	11	1.2	1.1	5000	150	45	54	1.67	47.3	0.95	43.3	1.04
	60	55	11	1.2	1.1	5000	300	49	54	2.36	47.3	1.05	48.1	1.03
	60	55	11	1.2	1.1	5000	450	51	54	2.89	47.3	1.07	49.9	1.01
	60	55	11	1.2	1.1	5000	600	51	54	3.34	47.3	1.07	50.9	1.00
Z2_L4	100	60	10	2	1.7	5500	75	44	73	1.01	48.8	0.91	43.2	1.03
	100	60	10	2	1.7	5500	150	59	73	1.43	63.5	0.93	54.7	1.08
	100	60	10	2	1.7	5500	300	66	73	2.03	64.0	1.04	62.7	1.06
	100	60	10	2	1.7	5500	450	68	73	2.48	64.0	1.07	65.9	1.04
	100	60	10	2	1.7	5500	600	69	73	2.87	64.0	1.08	67.5	1.02
Z3_L4	120	80	15	3	1.5	6500	75	49	89	0.92	52.7	0.92	48.1	1.01
	120	80	15	3	1.5	6500	150	68	89	1.30	74.1	0.92	63.2	1.08
	120	80	15	3	1.5	6500	300	79	89	1.83	78.1	1.02	74.2	1.07
	120	80	15	3	1.5	6500	450	83	89	2.25	78.1	1.06	78.7	1.05
	120	80	15	3	1.5	6500	600	84	89	2.59	78.1	1.07	81.1	1.04
Z4_L4	140	70	10	3	3.0	6500	75	45	75	1.00	49.2	0.92	43.8	1.04
	140	70	10	3	2.0	6500	150	60	75	1.42	64.7	0.93	55.6	1.08
	140	70	10	3	2.0	6500	300	68	75	2.01	65.4	1.04	63.9	1.06
	140	70	10	3	2.0	6500	450	70	75	2.46	65.4	1.07	67.1	1.04
	140	70	10	3	2.0	6500	600	71	75	2.84	65.4	1.08	68.9	1.03
Z5_L4	150	100	10	4	1.5	7500	75	50	96	0.89	54.0	0.93	49.9	1.01
	150	100	10	4	1.5	7500	150	72	96	1.25	77.8	0.93	66.4	1.08
	150	100	10	4	1.5	7500	300	85	96	1.77	83.9	1.01	78.7	1.08
	150	100	10	4	1.5	7500	450	89	96	2.17	83.9	1.05	83.7	1.06
	150	100	10	4	1.5	7500	600	90	96	2.50	83.9	1.07	86.5	1.04
Z6_L4	80	65	15	1.2	1.2	6500	75	35	52	1.20	41.0	0.85	35.1	0.99
	80	65	15	1.2	1.2	6500	150	43	52	1.70	45.6	0.95	42.1	1.02
	80	65	15	1.2	1.2	6500	300	47	52	2.40	45.6	1.04	46.6	1.02
	80	65	15	1.2	1.2	6500	450	48	52	2.94	45.6	1.06	48.3	1.00
	80	65	15	1.2	1.2	6500	600	48	52	3.40	45.6	1.06	49.2	0.98
Z7_L4	95	50	10	1.8	1.9	5000	75	43	67	1.06	47.0	0.91	41.2	1.04
	95	50	10	1.8	1.9	5000	150	55	67	1.49	59.0	0.94	51.5	1.07
	95	50	10	1.8	1.9	5000	300	62	67	2.11	59.0	1.04	58.5	1.05
	95	50	10	1.8	1.9	5000	450	63	67	2.59	59.0	1.07	61.2	1.03
	95	50	10	1.8	1.9	5000	600	64	67	2.99	59.0	1.09	62.6	1.02
Z8_L4	75	60	10	1	1.3	6500	75	30	42	1.33	35.8	0.84	30.5	0.98
	75	60	10	1	1.3	6500	150	36	42	1.88	37.2	0.97	35.6	1.01
	75	60	10	1	1.3	6500	300	39	42	2.66	37.2	1.04	38.7	1.00
	75	60	10	1	1.3	6500	450	39	42	3.26	37.2	1.05	39.9	0.98
	75	60	10	1	1.3	6500	600	39	42	3.76	37.2	1.06	40.5	0.97
Z9_L4	80	45	11	1.6	1.8	4500	75	43	68	1.05	47.4	0.91	41.6	1.03
	80	45	11	1.6	1.8	4500	150	56	68	1.48	59.9	0.93	52.1	1.07
	80	45	11	1.6	1.8	4500	300	63	68	2.09	60.0	1.04	59.3	1.05
	80	45	11	1.6	1.8	4500	450	64	68	2.56	60.0	1.07	62.1	1.04
	80	45	11	1.6	1.8	4500	600	65	68	2.96	60.0	1.09	63.6	1.02
Z1_L5	60	55	11	1.2	1.1	6000	75	28	38	1.41	32.5	0.85	27.9	0.99
	60	55	11	1.2	1.1	6000	150	33	38	2.00	32.9	0.99	32.1	1.01
	60	55	11	1.2	1.1	6000	300	35	38	2.83	32.9	1.06	34.6	1.01
	60	55	11	1.2	1.1	6000	450	36	38	3.46	32.9	1.08	35.5	1.00
	60	55	11	1.2	1.1	6000	600	36	38	4.00	32.9	1.08	36.0	0.99
Z2_L5	100	60	10	2	1.7	6500	75	36	52	1.20	41.2	0.88	35.2	1.03
	100	60	10	2	1.7	6500	150	44	52	1.69	45.9	0.97	42.3	1.05
	100	60	10	2	1.7	6500	300	48	52	2.40	45.9	1.06	46.8	1.03
	100	60	10	2	1.7	6500	450	50	52	2.93	45.9	1.08	48.5	1.02
	100	60	10	2	1.7	6500	600	50	52	3.39	45.9	1.09	49.4	1.01
Z3_L5	120	80	15	3	1.5	7500	75	42	67	1.06	46.9	0.89	41.1	1.01
	120	80	15	3	1.5	7500	150	54	67	1.50	58.8	0.93	51.3	1.06
	120	80	15	3	1.5	7500	300	61	67	2.12	58.8	1.04	58.3	1.05
	120	80	15	3	1.5	7500	450	63	67	2.59	58.8	1.07	60.9	1.03
	120	80	15	3	1.5	7500	600	64	67	2.99	58.8	1.08	62.4	1.02
Z4_L5	140	70	10	3	3.0	7500	75	38	56	1.16	42.8	0.89	36.8	1.03
	140	70	10	3	2.0	7500	150	47	56	1.64	49.1	0.96	44.7	1.06
	140	70	10	3	2.0	7500	300	52	56	2.31	49.1	1.05	49.8	1.04
	140	70	10	3	2.0	7500	450	53	56	2.83	49.1	1.08	51.7	1.03
	140	70	10	3	2.0	7500	600	54	56	3.27	49.1	1.09	52.7	1.02
Z5_L5	150	100	10	4	1.5	8500	75	45	75	1.00	49.2	0.91	43.7	1.02
	150	100	10	4	1.5	8500	150	60	75	1.42	64.6	0.93	55.6	1.08
	150	100	10	4	1.5	8500	300	68	75	2.01	65.3	1.03	63.8	1.06
	150	100	10	4	1.5	8500	450	70	75	2.46	65.3	1.07	67.1	1.04
	150	100	10	4	1.5	8500	600	71	75	2.84	65.3	1.08	68.8	1.02

	Geometry						SFEA		DSM Design					
Column	b_w	b_f	b_s	t	b_w/b_t	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	f_{nF}	f_u/f_{nF}
Z6_L5	80	65	15	1.2	1.2	7500	75	28	39	1.38	33.6	0.84	28.8	0.98
	80	65	15	1.2	1.2	7500	150	34	39	1.96	34.3	0.98	33.3	1.01
	80	65	15	1.2	1.2	7500	300	36	39	2.77	34.3	1.05	36.0	1.00
	80	65	15	1.2	1.2	7500	450	37	39	3.39	34.3	1.07	37.0	0.99
	80	65	15	1.2	1.2	7500	600	37	39	3.92	34.3	1.07	37.5	0.98
Z7_L5	95	50	10	1.8	1.9	6000	75	34	47	1.27	38.3	0.88	32.6	1.03
	95	50	10	1.8	1.9	6000	150	40	47	1.79	41.0	0.98	38.6	1.04
	95	50	10	1.8	1.9	6000	300	44	47	2.53	41.0	1.06	42.3	1.03
	95	50	10	1.8	1.9	6000	450	45	47	3.10	41.0	1.09	43.7	1.02
	95	50	10	1.8	1.9	6000	600	45	47	3.58	41.0	1.10	44.4	1.01
Z8_L5	75	60	10	1	1.3	7500	75	24	32	1.53	28.0	0.86	24.7	0.97
	75	60	10	1	1.3	7500	150	28	32	2.17	28.0	0.99	27.9	1.00
	75	60	10	1	1.3	7500	300	30	32	3.07	28.0	1.05	29.8	0.99
	75	60	10	1	1.3	7500	450	30	32	3.76	28.0	1.07	30.5	0.98
	75	60	10	1	1.3	7500	600	30	32	4.34	28.0	1.07	30.8	0.97
Z9_L5	80	45	11	1.6	1.8	5500	75	33	46	1.28	37.8	0.87	32.2	1.02
	80	45	11	1.6	1.8	5500	150	40	46	1.81	40.2	0.98	38.0	1.04
	80	45	11	1.6	1.8	5500	300	43	46	2.56	40.2	1.06	41.6	1.03
	80	45	11	1.6	1.8	5500	450	44	46	3.13	40.2	1.09	42.9	1.02
	80	45	11	1.6	1.8	5500	600	44	46	3.62	40.2	1.10	43.6	1.01
Z1_L6	60	55	11	1.2	1.1	7000	75	22	28	1.65	24.2	0.89	22.1	0.98
	60	55	11	1.2	1.1	7000	150	25	28	2.33	24.2	1.01	24.6	1.00
	60	55	11	1.2	1.1	7000	300	26	28	3.30	24.2	1.07	26.0	1.00
	60	55	11	1.2	1.1	7000	450	26	28	4.04	24.2	1.09	26.5	0.99
	60	55	11	1.2	1.1	7000	600	26	28	4.66	24.2	1.09	26.8	0.98
Z2_L6	100	60	10	2	1.7	7500	75	29	39	1.38	33.7	0.87	28.9	1.01
	100	60	10	2	1.7	7500	150	34	39	1.95	34.5	1.00	33.4	1.03
	100	60	10	2	1.7	7500	300	37	39	2.76	34.5	1.07	36.1	1.02
	100	60	10	2	1.7	7500	450	38	39	3.38	34.5	1.09	37.1	1.01
	100	60	10	2	1.7	7500	600	38	39	3.91	34.5	1.09	37.7	1.00
Z3_L6	120	80	15	3	1.5	8500	75	36	52	1.20	41.1	0.87	35.1	1.01
	120	80	15	3	1.5	8500	150	44	52	1.70	45.7	0.96	42.2	1.04
	120	80	15	3	1.5	8500	300	48	52	2.40	45.7	1.05	46.7	1.03
	120	80	15	3	1.5	8500	450	49	52	2.94	45.7	1.08	48.4	1.02
	120	80	15	3	1.5	8500	600	50	52	3.39	45.7	1.09	49.3	1.01
Z4_L6	140	70	10	3	3.0	8500	75	32	44	1.31	36.5	0.88	31.1	1.03
	140	70	10	3	2.0	8500	150	38	44	1.85	38.2	0.99	36.4	1.04
	140	70	10	3	2.0	8500	300	41	44	2.62	38.2	1.07	39.7	1.03
	140	70	10	3	2.0	8500	450	42	44	3.21	38.2	1.09	41.0	1.02
	140	70	10	3	2.0	8500	600	42	44	3.71	38.2	1.10	41.6	1.01
Z5_L6	150	100	10	4	1.5	9500	75	39	60	1.12	44.3	0.88	38.3	1.02
	150	100	10	4	1.5	9500	150	50	60	1.59	52.4	0.95	47.0	1.05
	150	100	10	4	1.5	9500	300	55	60	2.24	52.4	1.05	52.7	1.04
	150	100	10	4	1.5	9500	450	56	60	2.75	52.4	1.08	54.8	1.03
	150	100	10	4	1.5	9500	600	57	60	3.17	52.4	1.09	56.0	1.02
Z6_L6	80	65	15	1.2	1.2	8500	75	23	30	1.57	26.7	0.87	23.8	0.97
	80	65	15	1.2	1.2	8500	150	27	30	2.22	26.7	1.00	26.8	0.99
	80	65	15	1.2	1.2	8500	300	28	30	3.14	26.7	1.06	28.5	0.99
	80	65	15	1.2	1.2	8500	450	29	30	3.85	26.7	1.08	29.1	0.99
	80	65	15	1.2	1.2	8500	600	29	30	4.44	26.7	1.08	29.4	0.98
Z7_L6	95	50	10	1.8	1.9	7000	75	27	34	1.48	30.0	0.88	26.1	1.01
	95	50	10	1.8	1.9	7000	150	31	34	2.09	30.1	1.01	29.7	1.03
	95	50	10	1.8	1.9	7000	300	32	34	2.96	30.1	1.08	31.9	1.02
	95	50	10	1.8	1.9	7000	450	33	34	3.62	30.1	1.09	32.6	1.01
	95	50	10	1.8	1.9	7000	600	33	34	4.18	30.1	1.10	33.0	1.00
Z8_L6	75	60	10	1	1.3	8500	75	20	25	1.74	21.7	0.90	20.3	0.96
	75	60	10	1	1.3	8500	150	22	25	2.46	21.7	1.01	22.3	0.99
	75	60	10	1	1.3	8500	300	23	25	3.48	21.7	1.07	23.5	0.99
	75	60	10	1	1.3	8500	450	23	25	4.26	21.7	1.07	23.9	0.97
	75	60	10	1	1.3	8500	600	23	25	4.92	21.7	1.08	24.1	0.97
Z9_L6	80	45	11	1.6	1.8	6500	75	25	33	1.51	28.8	0.88	25.3	1.01
	80	45	11	1.6	1.8	6500	150	29	33	2.14	28.8	1.01	28.6	1.02
	80	45	11	1.6	1.8	6500	300	31	33	3.02	28.8	1.08	30.6	1.01
	80	45	11	1.6	1.8	6500	450	32	33	3.70	28.8	1.10	31.3	1.01
	80	45	11	1.6	1.8	6500	600	32	33	4.28	28.8	1.10	31.7	1.00
											Mean	1.00	Mean	1.04
											Sd. Dev.	0.06	Sd. Dev.	0.06
											Max	1.10	Max	1.20
											Min	0.84	Min	0.91

ANNEX H: I COLUMN DATA

Table H1: Columns failing in F_m modes: (i) geometries, (ii) buckling stresses and ultimate strengths, (iii) ultimate strength predictions by current and proposed DSM design curves, and (iv) numerical-to-predicted ultimate strength ratios (mm and MPa)

	Geometry					SFEA		DSM Design					
Column	b_w	b_f	t	b_w/b_t	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	f_{nF}	f_u/f_{nF}
I1_L1	100	40	2	2.5	1000	75	71	322	0.48	68.0	1.04	72.6	0.97
	100	40	2	2.5	1000	150	128	322	0.68	123.4	1.04	123.4	1.04
	100	40	2	2.5	1000	300	200	322	0.97	203.1	0.98	182.5	1.10
	100	40	2	2.5	1000	450	242	322	1.18	250.6	0.97	214.8	1.13
	100	40	2	2.5	1000	600	264	322	1.37	274.9	0.96	235.0	1.12
I2_L1	100	80	2	1.3	2000	75	72	491	0.39	70.4	1.02	75.0	0.95
	100	80	2	1.3	2000	150	139	491	0.55	132.0	1.05	138.4	1.00
	100	80	2	1.3	2000	300	245	491	0.78	232.3	1.05	223.2	1.10
	100	80	2	1.3	2000	450	324	491	0.96	306.6	1.06	276.2	1.17
	100	80	2	1.3	2000	600	369	491	1.11	359.8	1.03	312.0	1.18
I3_L1	100	100	2	1.0	3500	75	69	282	0.52	67.1	1.02	71.1	0.96
	100	100	2	1.0	3500	150	122	282	0.73	120.1	1.02	117.9	1.03
	100	100	2	1.0	3500	300	195	282	1.03	192.3	1.01	169.6	1.15
	100	100	2	1.0	3500	450	221	282	1.26	231.0	0.96	196.9	1.12
	100	100	2	1.0	3500	600	223	282	1.46	246.6	0.90	213.6	1.04
I4_L1	100	120	2	0.8	5000	75	66	217	0.59	64.9	1.01	67.3	0.98
	100	120	2	0.8	5000	150	113	217	0.83	112.4	1.01	105.9	1.07
	100	120	2	0.8	5000	300	161	217	1.17	168.3	0.96	144.4	1.11
	100	120	2	0.8	5000	450	163	217	1.44	189.1	0.86	163.3	1.00
	100	120	2	0.8	5000	600	163	217	1.66	190.6	0.86	174.4	0.93
I1_L2	100	40	2	2.5	2000	75	43	81	0.96	50.9	0.85	45.8	0.95
	100	40	2	2.5	2000	150	59	81	1.36	69.2	0.86	59.1	1.00
	100	40	2	2.5	2000	300	70	81	1.92	71.1	0.98	68.6	1.02
	100	40	2	2.5	2000	450	70	81	2.36	71.1	0.98	72.4	0.97
	100	40	2	2.5	2000	600	70	81	2.72	71.1	0.98	74.4	0.94
I2_L2	100	80	2	1.3	4000	75	55	123	0.78	58.1	0.94	55.9	0.98
	100	80	2	1.3	4000	150	83	123	1.10	90.1	0.92	78.2	1.06
	100	80	2	1.3	4000	300	104	123	1.56	108.1	0.96	96.3	1.08
	100	80	2	1.3	4000	450	111	123	1.91	108.1	1.03	104.1	1.07
	100	80	2	1.3	4000	600	114	123	2.21	108.1	1.05	108.4	1.05
I3_L2	100	100	2	1.0	5000	75	58	138	0.74	59.8	0.96	58.5	0.98
	100	100	2	1.0	5000	150	90	138	1.04	95.3	0.95	83.8	1.07
	100	100	2	1.0	5000	300	116	138	1.47	121.1	0.96	105.2	1.10
	100	100	2	1.0	5000	450	124	138	1.80	121.4	1.02	114.6	1.08
	100	100	2	1.0	5000	600	124	138	2.08	121.4	1.02	119.8	1.03
I4_L2	100	120	2	0.8	6500	75	56	129	0.76	58.8	0.96	56.9	0.99
	100	120	2	0.8	6500	150	87	129	1.08	92.1	0.94	80.2	1.08
	100	120	2	0.8	6500	300	108	129	1.53	112.8	0.96	99.5	1.09
	100	120	2	0.8	6500	450	110	129	1.87	112.8	0.98	107.8	1.02
	100	120	2	0.8	6500	600	110	129	2.16	112.8	0.98	112.4	0.98
I1_L3	100	40	2	2.5	3000	75	25	36	1.44	31.4	0.80	27.1	0.93
	100	40	2	2.5	3000	150	30	36	2.04	31.6	0.95	31.0	0.97
	100	40	2	2.5	3000	300	33	36	2.89	31.6	1.05	33.3	0.99
	100	40	2	2.5	3000	450	34	36	3.54	31.6	1.08	34.2	0.99
	100	40	2	2.5	3000	600	35	36	4.08	31.6	1.10	34.6	1.00
I2_L3	100	80	2	1.3	6000	75	36	55	1.17	42.3	0.84	36.3	0.98
	100	80	2	1.3	6000	150	45	55	1.65	48.0	0.93	43.9	1.02
	100	80	2	1.3	6000	300	50	55	2.34	48.0	1.04	48.8	1.02
	100	80	2	1.3	6000	450	52	55	2.87	48.0	1.07	50.7	1.02
	100	80	2	1.3	6000	600	52	55	3.31	48.0	1.09	51.6	1.01
I3_L3	100	100	2	1.0	6500	75	46	82	0.96	51.1	0.90	46.1	1.00
	100	100	2	1.0	6500	150	63	82	1.35	69.7	0.90	59.5	1.06
	100	100	2	1.0	6500	300	73	82	1.91	71.8	1.01	69.2	1.05
	100	100	2	1.0	6500	450	76	82	2.34	71.8	1.06	73.0	1.04
	100	100	2	1.0	6500	600	76	82	2.71	71.8	1.06	75.1	1.02
I4_L3	100	120	2	0.8	8000	75	47	85	0.94	51.8	0.91	46.9	1.00
	100	120	2	0.8	8000	150	65	85	1.33	71.6	0.91	61.1	1.06
	100	120	2	0.8	8000	300	75	85	1.88	74.5	1.01	71.3	1.06
	100	120	2	0.8	8000	450	76	85	2.30	74.5	1.02	75.4	1.01
	100	120	2	0.8	8000	600	76	85	2.66	74.5	1.02	77.6	0.98
I1_L4	100	40	2	2.5	4000	75	16	20	1.92	17.8	0.89	17.2	0.92
	100	40	2	2.5	4000	150	18	20	2.72	17.8	1.00	18.6	0.96
	100	40	2	2.5	4000	300	19	20	3.84	17.8	1.07	19.4	0.98
	100	40	2	2.5	4000	450	20	20	4.71	17.8	1.10	19.7	0.99
	100	40	2	2.5	4000	600	20	20	5.44	17.8	1.11	19.9	0.99

	Geometry					SFEA		DSM Design					
Column	b_w	b_f	t	b_w/b_t	L	f_y	f_u	f_{crG}	λ_G	f_{nG}	f_u/f_{nG}	f_{nF}	f_u/f_{nF}
I2_L4	100	80	2	1.3	8000	75	23	31	1.56	27.0	0.86	24.1	0.96
	100	80	2	1.3	8000	150	27	31	2.21	27.0	0.99	27.1	0.99
	100	80	2	1.3	8000	300	29	31	3.12	27.0	1.07	28.8	1.00
	100	80	2	1.3	8000	450	30	31	3.82	27.0	1.09	29.5	1.00
	100	80	2	1.3	8000	600	30	31	4.41	27.0	1.11	29.8	1.00
I3_L4	100	100	2	1.0	8000	75	36	54	1.18	42.0	0.85	36.0	0.99
	100	100	2	1.0	8000	150	45	54	1.67	47.4	0.94	43.5	1.03
	100	100	2	1.0	8000	300	49	54	2.35	47.4	1.04	48.3	1.02
	100	100	2	1.0	8000	450	51	54	2.88	47.4	1.07	50.1	1.02
	100	100	2	1.0	8000	600	51	54	3.33	47.4	1.08	51.0	1.01
I4_L4	100	120	2	0.8	9500	75	39	60	1.12	44.5	0.87	38.5	1.00
	100	120	2	0.8	9500	150	49	60	1.58	52.8	0.93	47.3	1.04
	100	120	2	0.8	9500	300	55	60	2.23	52.8	1.04	53.1	1.03
	100	120	2	0.8	9500	450	56	60	2.73	52.8	1.05	55.3	1.00
	100	120	2	0.8	9500	600	56	60	3.16	52.8	1.05	56.4	0.98
										Mean	0.99	Mean	1.02
										Sd. Dev.	0.07	Sd. Dev.	0.06
										Max	1.11	Max	1.18
										Min	0.80	Min	0.92