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Application of the Direct Strength Method to Steel Deck

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Abstract

With the reorganization of the AISI S100 Standard, the Direct Strength Method (DSM) takes a position of equal footing with the Equivalent Width Method (EWM) for calculating the strength of cold-formed steel cross sections. The majority of previous DSM studies focused on C and Z profiles, while little study of panel sections, especially steel deck sections, has been performed. A study was undertaken to determine and compare the behavior and usable strength of existing floor and roof deck sections with both DSM and EWM. The Cornell University – Finite Strip Method (CUFSM) software was used for the elastic buckling analysis, taking into account the wide, continuous nature of installed deck sections. Flexural capacity was analyzed for positive and negative flexure to account for gravity loading as well as uplift of the steel deck sections. Graphical representations of the relationships for DSM strength to the EWM strength ratio vs. material width to thickness ratio were developed and are illustrative as to the trends seen. DSM predicts lower flexural strength versus EWM for sections with relatively wide and thin compression flanges (larger b/t ratios).

Introduction

Research Goals

As the Direct Strength Method (DSM) will be taking equal footing with the Effective Width Method (EWM) in the proposed reorganization of the AISI S100, the following goal was set: To analyze a variety of existing floor and roof deck sections to observe the behavior and compare the usable flexural strengths using both DSM and EWM. DSM has mostly been previously applied to C and

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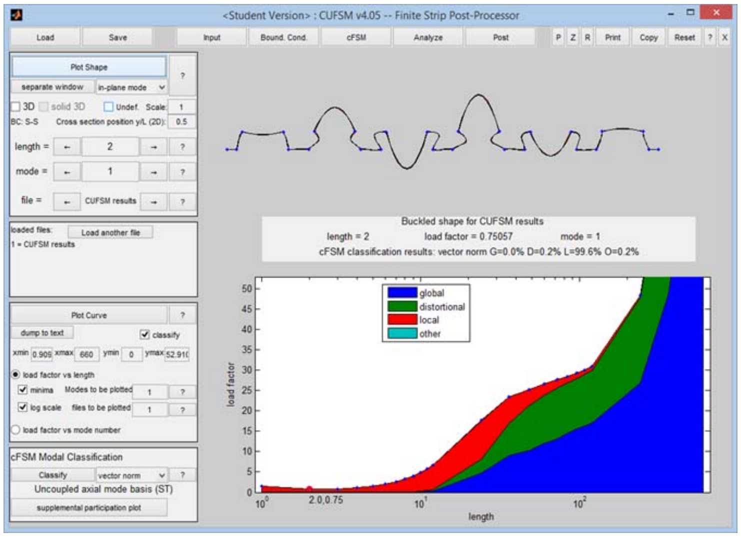
Z profiles so it was necessary to develop a finite strip method (FSM) model that would accurately model and account for multi-web deck sections installed in an adjacent fashion. Once a model that would accurately represent installed floor and roof deck was developed, potential enhancements to existing deck sections were studied that would take advantage of DSM (i.e. DSM predicts higher flexural strength than EWM).

Direct Strength Method

"A new design method: Direct Strength, has been created that aims to alleviate the current complexity, ease calculation, provide a more robust and flexible design procedure, and integrate with available, established, numerical methods" (AISI, 2006).

The Direct Strength Method (DSM) is a method of analyzing cold-formed steel (wide, light gauge) members. In DSM, the elastic buckling capacity is determined over the entire cross section rather than neglecting less "effective" portions of the cross section.

In order to apply DSM, the elastic local, distortional, and global buckling capacities are first computed. Graphical representations of local, distortional, and global buckling are illustrated below in Figures 1, 2, and 3 respectively. The lateral-torsional buckling, local buckling, and distortional buckling flexural strengths are calculated to observe the governing buckling mode per DSM equations 1.2.2.1, 1.2.2.2, and 1.2.2.3. (AISI, 2012) In this study, the Cornell University Finite Strip Method was used to find the elastic local, distortional, and global buckling capacities.



<Student Version> : CUFSM v4.05 -- Finite Strip Post-Processor

☐ 3D ☐ solid 3D ☐ Undef. Scale: 1

BC: S-S Cross section position y/L (2D): 0.5

length = 2

mode = 1

file = CUFSM results

loaded files:

1 = CUFSM results

Buckled shape for CUFSM results

length = 2 load factor = 0.75057 mode = 1

cFSM classification results: vector norm G=0.0% D=0.2% L=99.6% O=0.2%

☑ classify

xmin 0.909 xmax 660 ymin 0 ymax 52.910

● load factor vs length

☑ minima Modes to be plotted 1

☑ log scale files to be plotted 1

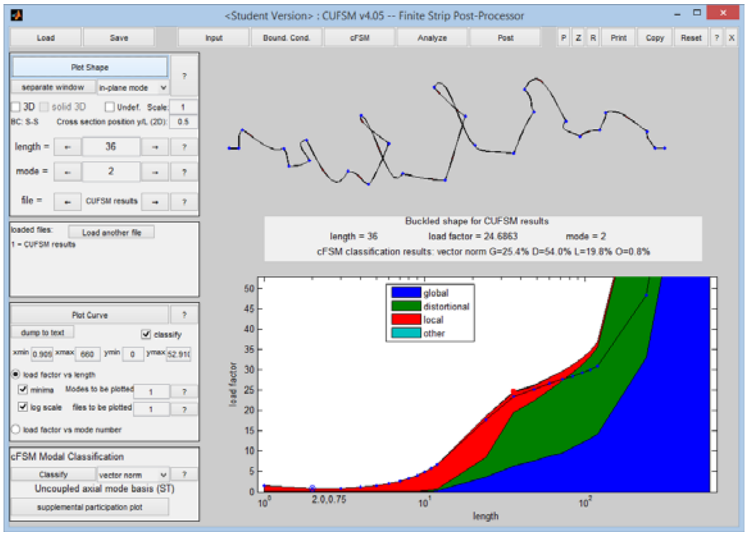
○ load factor vs mode number

cFSM Modal Classification

Classify: vector norm

Uncoupled axial mode basis (ST)

Figure 1 – 1.5B 22GA Deck 33KSI Local Buckling (CUFSM Output)



<Student Version> : CUFSM v4.05 -- Finite Strip Post-Processor

☐ 3D ☐ solid 3D ☐ Undef. Scale: 1

BC: S-S Cross section position y/L (2D): 0.5

length = 36

mode = 2

file = CUFSM results

loaded files:

1 = CUFSM results

Buckled shape for CUFSM results

length = 36 load factor = 24.6863 mode = 2

cFSM classification results: vector norm G=25.4% D=54.0% L=19.8% O=0.8%

☑ classify

xmin 0.909 xmax 660 ymin 0 ymax 52.910

● load factor vs length

☑ minima Modes to be plotted 1

☑ log scale files to be plotted 1

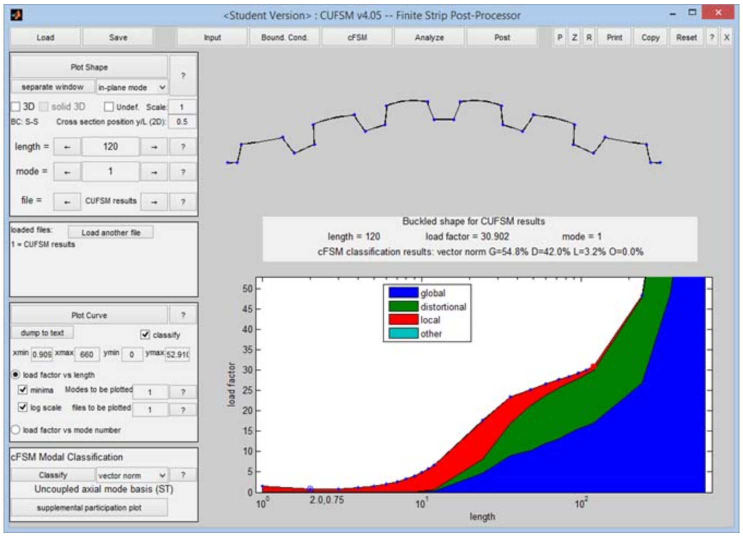
○ load factor vs mode number

cFSM Modal Classification

Classify: vector norm

Uncoupled axial mode basis (ST)

Figure 2 – 1.5B 22GA Deck 33KSI Distortional Buckling (CUFSM Output)



in-plane mode

☐ 3D ☐ solid 3D ☐ Undef. Scale: 1

BC: S-S Cross section position y/L (2D): 0.5

length = 120

mode = 1

file = CUFSM results

loaded files:

1 = CUFSM results

☑ classify

xmin 0.909 xmax 660 ymin 0 ymax 52.91

● load factor vs length

☑ minima Modes to be plotted 1

☑ log scale files to be plotted 1

○ load factor vs mode number

cFSM Modal Classification

vector norm

Uncoupled axial mode basis (ST)

Buckled shape for CUFSM results

length = 120 load factor = 30.902 mode = 1

cFSM classification results: vector norm G=54.8% D=42.0% L=3.2% O=0.0%

Figure 3 – 1.5B 22GA Deck 33KSI Global Buckling (CUFSM Output)

Effective Width Method

The Effective Width Method (EWM) is another method for analyzing cold-formed steel members. In the EWM, an effective width of compression elements is computed and used as the lightly stressed areas, near the center of an element, are neglected. The regions near junctions or stiffeners are considered to be fully effective, as these areas are most effective in resisting the applied stress. Figure 4 shows the actual compression element and the effective width, b, of the element when subjected to compressive stress.

Figure 4 – Flange Under Compressive Stress, Effective Element Width, b

Cornell University Finite Strip Method

The Cornell University Finite Strip Method (CUFSM) (Li and Schafer, 2010) is a tool that provides cross-section elastic buckling solutions. This program allows the user to define a cross-section based on nodal coordinates, member end designations, fixities, etc. The user can then apply axial and flexure stresses and observe the elastic buckling solutions over a variety of specified unbraced lengths.

The analysis procedure is "specialized to apply to plate deformations beyond conventional beam theory. The semi-analytical finite strip method is a variant of the more common finite element method. A thin-walled cross-section is discretized into a series of longitudinal strips, or elements. Based on these strips elastic and geometric stiffness matrices can be formulated" (Li and Schafer, 2010).

Deck Sections

This study compared the behavior of DSM and EWM for both stiffened and unstiffened deck sections. The unstiffened deck sections are 1F and 1.5B. The stiffened deck sections are 1.5B, 2C, and 3C. The deck sections included in this study are shown in Figure 5 below. The stiffened 1.5B Deck section is a non-standard shape. As a point of reference, the 2C compression flange stiffener was added to the compression flange of the 1.5B Deck section and performed the analysis to observe the benefits. The 1.5B and 2C Deck both include flange stiffeners 0.37 inches deep and 1.25 inches wide. The 3C Deck includes flange stiffeners 0.37 inches deep and 1 inch wide. Each deck section was checked in both positive and negative flexure. Each deck section was checked for yield stresses of 33, 40, 50, and 60 KSI at gage thicknesses ranging from 0.0598 inches (16 gage) to 0.0239 inches (24 gage). No cold working of forming was considered.

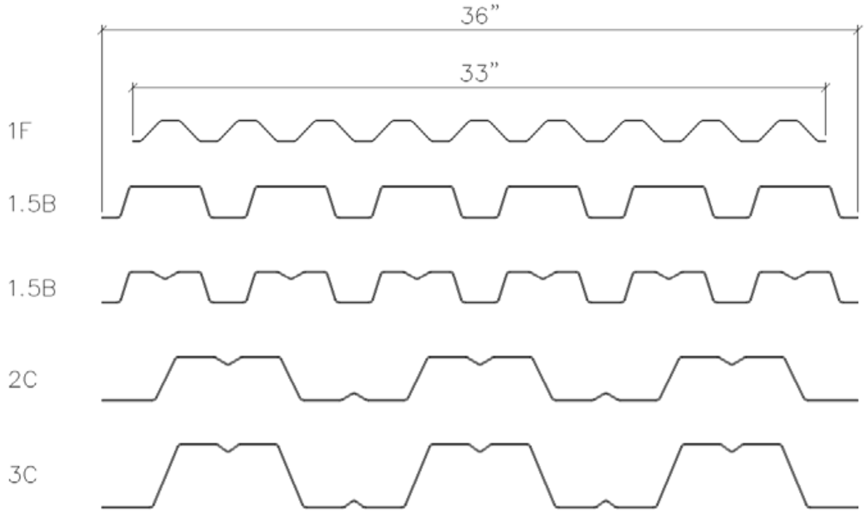


Figure 5 – Deck Sections Included in Study

Process of Modeling and Analysis

DSM Analysis Procedure

For the DSM analysis, a preprocessor was developed to process input files for the elastic buckling analysis done with CUFSM. CUFSM output (load factors) were then applied to the DSM equations to predict strength.

DSM Preprocessor

In order to run CUFSM to obtain the elastic buckling solutions, the user must define the cross-section parameters. CUFSM takes in information such as the material properties, nodes, elements, and boundary conditions. As it can be very tedious to calculate nodal locations, assign member end designations, and enter other parameters manually, a preprocessor was created to expedite the process.

A preprocessor processes its input data to produce output that is used as input for another program. In this case, a MATLAB code was written to preprocess the information required to run CUFSM. This eased the process of segmenting and refining members to obtain more accurate results (i.e. the curved corners at joints could be segmented into many line elements that adequately represent a curve).

The preprocessor used in this study produced the input data for the Nodes, Members, and Lengths input areas for CUFSM. Once the information was entered, program files for each deck section and each gage thickness were retained for convenience for analyzing the deck sections at a variety of thicknesses and yield stresses.

DSM Deck Model

Based upon advice from Schafer (personal communication), two sets of models were run for each deck section: Curved Corner models (Figure 6) and Straight Corner models (Figure 7). Although the curved corner models provided more representative elastic buckling solutions, straight corner models, where no curvature appears at the element joints, were modeled to accurately capture the buckling classification. The straight corner models were not used to evaluate strength as the models would have been overly penalized in DSM by misrepresenting the actual flat length of the compression flange. The end nodal locations of the deck profile were restrained to account for adjacent deck sections and represent the wide and continuous nature of installed floor and roof deck (Figure 8).

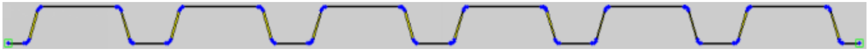


Figure 6 – Curved Corner Model for Determining Elastic Strength

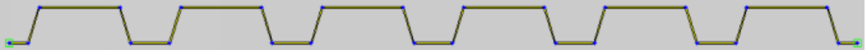
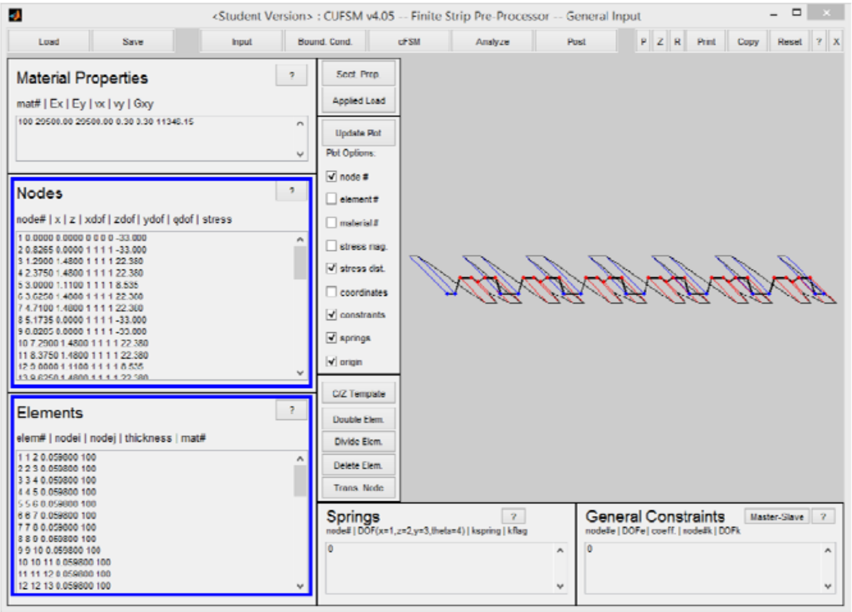


Figure 7 – Straight Corner Model for Determining Buckling Modes



Material Properties

mat# | Ex | Ey | vx | vy | Gxy

```
100 29500.00 29500.00 0.30 0.30 11346.15
```

Nodes

node# | x | z | xdof | zdof | ydof | qdof | stress

```
1 0.0000 0.0000 0 0 0 0 -33.000
2 0.8265 0.0000 1 1 1 1 -33.000
3 1.2900 1.4800 1 1 1 1 22.380
4 2.3750 1.4800 1 1 1 1 22.380
5 3.0000 1.1100 1 1 1 1 8.535
6 3.6250 1.4800 1 1 1 1 22.380
7 4.7100 1.4800 1 1 1 1 22.380
8 5.1735 0.0000 1 1 1 1 -33.000
9 6.0265 0.0000 1 1 1 1 -33.000
10 7.2900 1.4800 1 1 1 1 22.380
11 8.3750 1.4800 1 1 1 1 22.380
12 9.0000 1.1100 1 1 1 1 8.535
13 9.6250 1.4800 1 1 1 1 22.380
```

Elements

elem# | nodei | nodej | thickness | mat#

```
1 1 2 0.059800 100
2 2 3 0.059800 100
3 3 4 0.059800 100
4 4 5 0.059800 100
5 5 6 0.059800 100
6 6 7 0.059800 100
7 7 8 0.059800 100
8 8 9 0.059800 100
9 9 10 0.059800 100
10 10 11 0.059800 100
11 11 12 0.059800 100
12 12 13 0.059800 100
```

Springs

node# | DOF(x=1,z=2,y=3,theta=4) | kspring | kflag

```
0
```

General Constraints

nodee | DOFe | coeff. | nodek | DOFk

```
0
```

Figure 8 – CUFSM General Input

DSM Deck Analysis

The deck profile models were analyzed at stresses of 33, 40, 50, and 60 KSI for positive flexure and likewise at stresses of -33, -40, -50, and -60 KSI for negative flexure for a variety of unbraced lengths ranging from 1 inch to 50 feet. The CUFSM output supplies load factors (nominal buckling moment to yield moment) which are used as input for the strength prediction for the deck profile, Mn_{DSM}.

EWM Deck Analysis

For EWM, an effective width of compression elements is computed and used as the lightly stressed areas, near the center of an element, are neglected. For each deck section, the parallel axis theorem was used in a tabular format to provide the effective section properties to obtain the effective nominal flexural strength using EWM, Mn_{EWM}. The deck sections bend about their neutral axis for positive and negative flexure. The compression elements of the cross-section consist of the compression flange as well as a portion of the web element. For each deck section at each variety of thickness and stress, the webs were found to be fully effective. Only the compression flange then needed to be computed for its effective width before iterating to convergence to obtain the nominal flexural capacity of the effective section, Mn_{EWM}.

Observations

Comparison of Data

After running the DSM and EWM analyses, comparisons were made on a couple of sets of data to observe trends between the various deck sections. Charts which show the comparison of DSM versus EWM for each section are found in the Appendix at the end of this paper. What is most insightful are the charts which add the width to thickness ration (b/t) of the compression flange into the consideration. The first data comparison plots, Figures 9 and 10, show the nominal moment capacity ratio of DSM to EWM, Mn_{DSM} / Mn_{EWM}, vs. the flat width of the compression flange over the thickness, b/t. The second data comparison plots, Figures 11 and 12, show the same relationship but now normalizing the nominal moment capacity ratio by the yield stress, (Mn_{DSM} / Mn_{EWM}) / F_y.

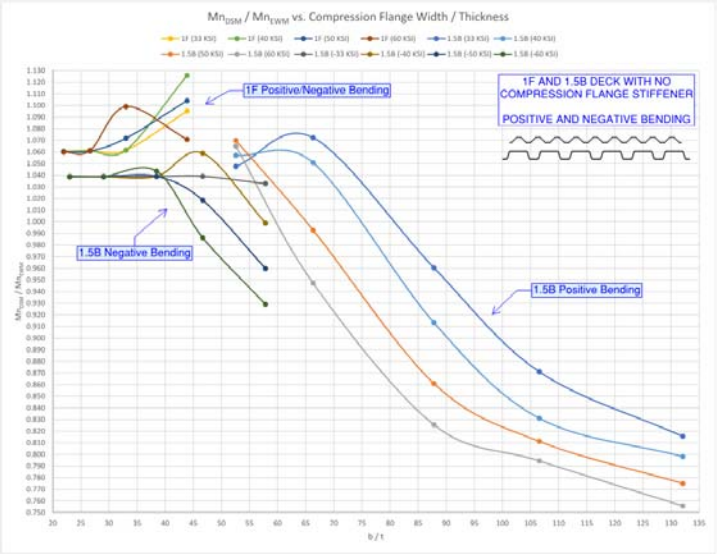


Figure 9 – Unstiffened Deck – Mn_{DSM} / Mn_{EWM} vs. b/t

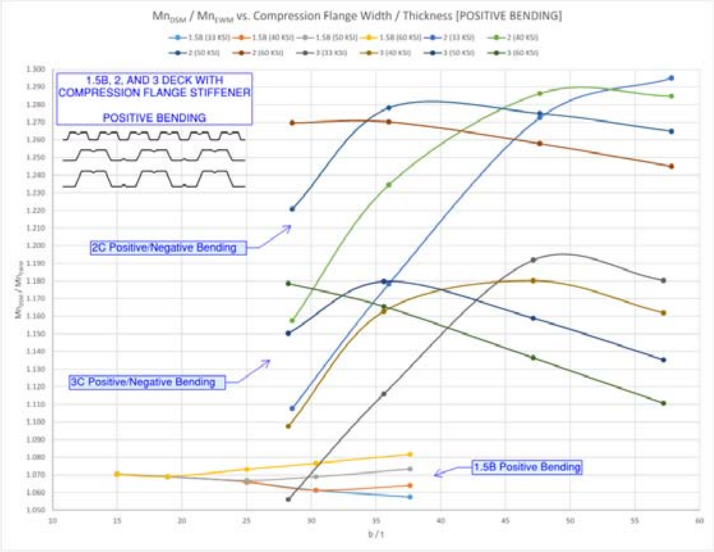


Figure 10 – Stiffened Deck – Mn$_{DSM}$ / Mn$_{EWM}$ vs. b/t

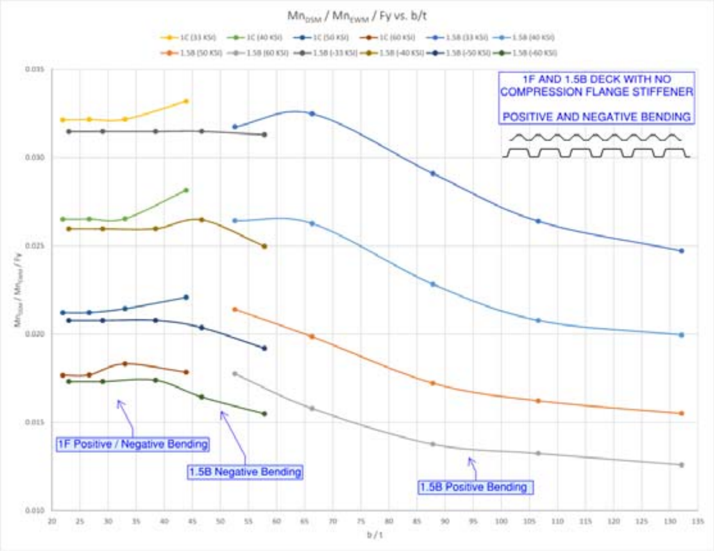


Figure 11 – Unstiffened Deck – (Mn$_{DSM}$ / Mn$_{EWM}$) / Fy vs. b/t

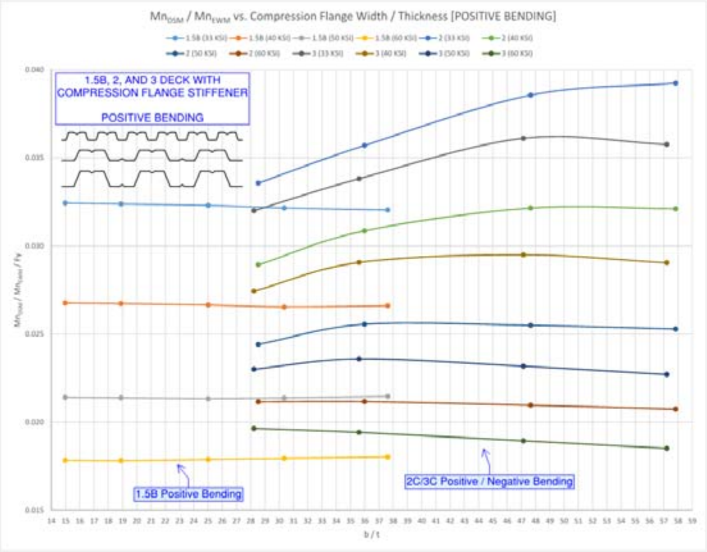


Figure 12 – Stiffened Deck – (Mn_{DSM} / Mn_{EWM}) / F_y vs. b/t

Comments on Results

From Figure 9, it is seen that DSM starts to predict lower strengths than EWM when b/t ratios exceed 40-70 for unstiffened deck sections. From Figure 10, for the stiffened deck sections, b/t tops out around 55. DSM is able to take advantage of the lower b/t and predicts higher strengths than EWM. In the second data comparison, Figures 11 and 12, with the normalized nominal moment capacity ratio, the same decrease in DSM strength is observed around the 40-70 b/t range. DSM performs well for lower b/t ratios. DSM also predicted fully effective sections where the EWM did not.

Recommendation

To take advantage of the slight increase in strength with DSM, consider using compression element stiffeners. By adding stiffeners to compression elements, b/t is reduced and as determined in this study, DSM predicts higher strengths than EWM for lower b/t ratios.

Future Work

The next step is to conduct laboratory testing to verify DSM strength results. Once the results are backed up with physical testing, potential enhancements to new deck profiles that may take advantage of DSM can be developed.

Acknowledgements

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References

AISI (2013) AISI Manual of Cold-Formed Steel Design. *American Iron and Steel Institute*, Washington, D.C.

AISI (2006) Direct Strength Design Guide. *American Iron and Steel Institute*, Washington, D.C.

AISI S100 (2012) North American Specification for the Design of Cold-Formed Steel Structural Members. *American Iron and Steel Institute*, Washington, D.C.

Li, Z., Schafer, B.W. (2010) "Buckling analysis of cold-formed steel members with general boundary conditions using CUFSM: conventional and constrained finite strip methods." Proceedings of the 20th International Specialty Conference on Cold-Formed Steel Structures, St. Louis, MO. November, 2010.

Schafer, B.W., personal communication, July 25, 2014.

Appendix

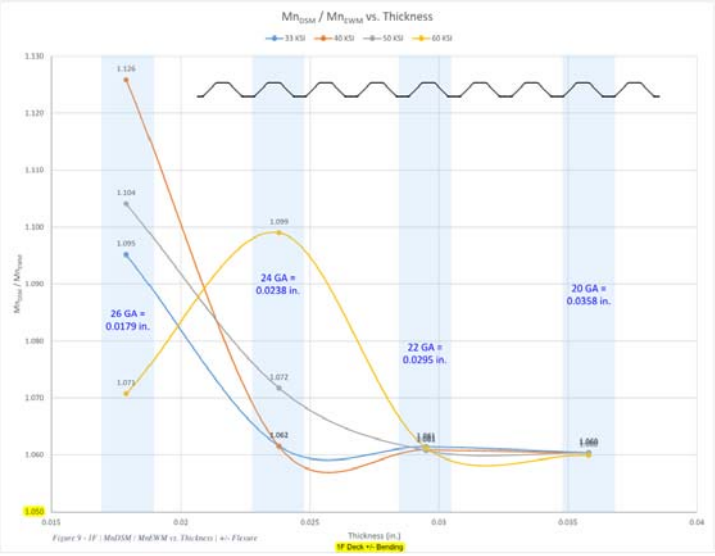

Figure 13 – 1F – MnDSM / MnEWM vs. Thickness

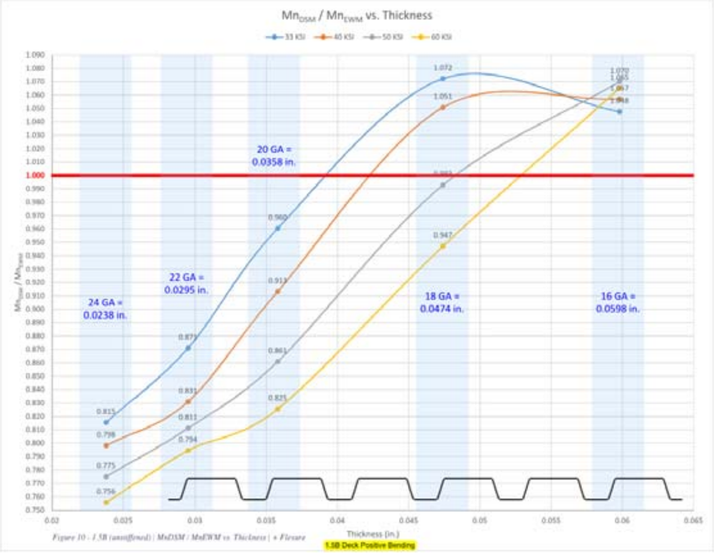

Figure 14 – 1.5B – MnDSM / MnEWM vs. Thickness

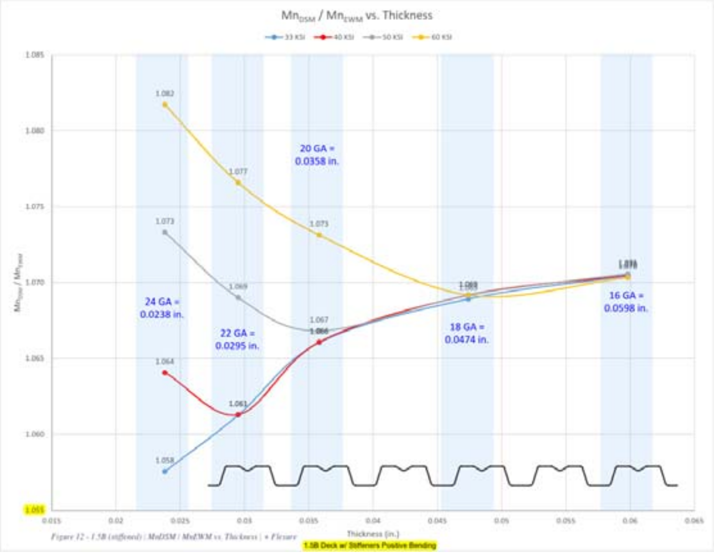

Figure 15 – 1.5B (stiffeners) – MnDSM / MnEWM vs. Thickness

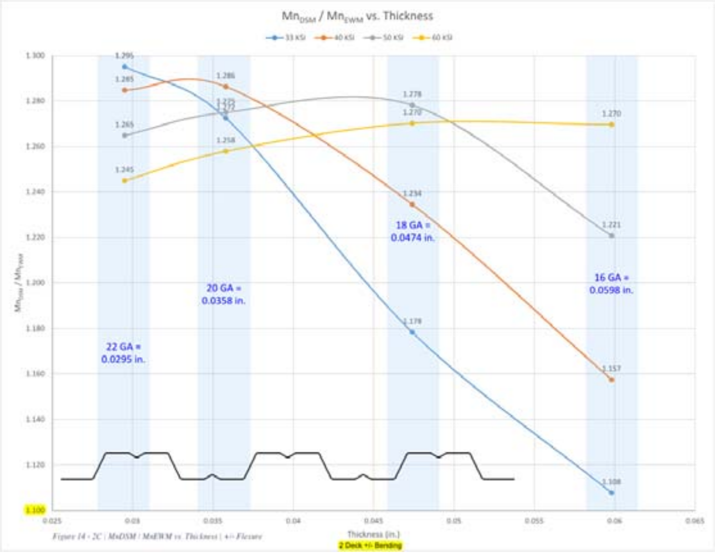

Figure 16 – 2C – MnDSM / MnEWM vs. Thickness

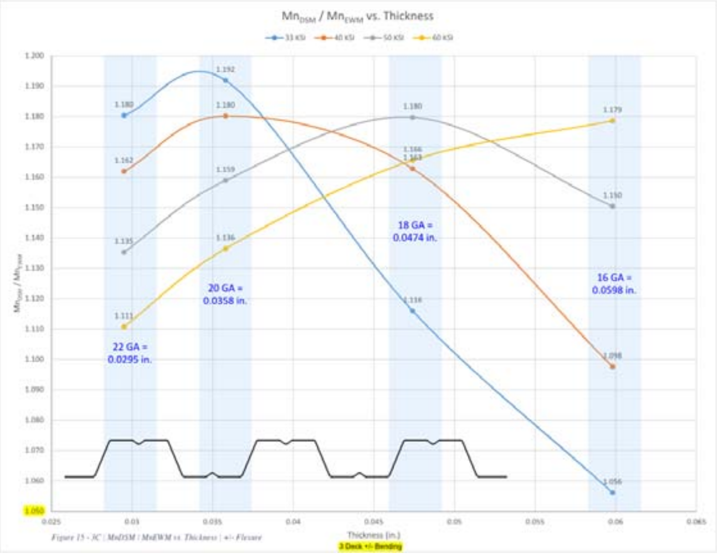

Figure 17 – 3C – MnDSM / MnEWM vs. Thickness