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Structural Engineering and Materials

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Submitted to

The Steel Deck Institute
P.O. Box 25
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Research Report

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1. Introduction

Cellular decks are formed by attaching cold-formed "hat-shaped" deck sections on top of cold-formed steel sheets. The attachment is typically made using resistance spot welds spaced at a specific interval. The void left underneath the deck flutes and above the steel sheet provides a convenient means for the distribution of wiring and data cables throughout building systems.

The section properties of cellular decks subjected to positive bending can be determined using the provisions of Chapter B of the 2001 AISI Specification (AISI, 2001). However, the provisions of Chapter B do not apply to cellular decks subjected to negative bending unless a specific weld spacing requirement is met. This requirement, set by Section D1.2 *Spacing of Connections in Compression Elements* (AISI, 2001), limits weld spacing so as to completely prevent column-like buckling between welds and provide adequate resistance to horizontal shear forces. Using section D1.2 limits weld spacing to a range of 1 in. to 2 in. for most cellular decks.

It is standard industry practice to space cellular deck welds at 4 in. to 8 in. on center, exceeding the limits of Section D1.2. If the spacing limits of Section D1.2 are exceeded, the 2001 AISI Specification requires that the steel sheet be neglected when determining the section properties of cellular deck in negative bending. This is done because column-like buckling is likely to occur in the sheet when it is subjected to compression forces. Although the 2001 AISI Specification has provisions in place to account for the effects of local buckling, it has no provisions in place to account for the post column-like buckling strength of the steel sheet. However, a procedure for determining the post-buckling strength of cellular decks was developed by Luttrell and Balaji (1992), and is based on the results of 82 negative bending tests performed on six cellular deck profiles.

The procedure developed by Luttrell and Balaji (1992) utilizes a dimensional reduction factor, ρ_m, which is used to determine the effective width of the steel sheet when column-like buckling is an issue. The factors having the greatest influence on ρ_m include steel sheet thickness, steel sheet yield strength, weld spacing, and the depth of the deck. Although the method correlated well with the 82 bending tests performed, a ballot containing his method was not passed by AISI. The principal reason for its rejection was that the reduction factor, ρ_m, was dimensional, which violates an AISI directive that all equations be non-dimensional so they apply to both US Standard and SI units.

The primary objective of this research was to modify the method developed by Luttrell and Balaji such that the dimensional reduction factor is non-dimensional. Using Luttrell's method, section properties for 49 of the 82 cellular decks tested in negative bending were determined. Section properties were not determined for the remaining 33 ECP266 and EPC3 cellular decks due to a lack of information with regard to the deck dimensions. However, a dimensionless reduction factor was developed based on the section properties of the EP-type cellular deck. The equation used to predict the reduction factor was optimized so as to reduce the error between observed and theoretical bending strength to a minimum.

2. Test Program

2.1 Negative Bending Tests

As part of their research, Luttrell and Balaji reported results for 82 negative bending tests on six different cellular deck profiles. Figure 2-1 illustrates the different deck profiles that were part of the testing. Detailed dimension for each type of deck are contained in Appendix A of this report. Connecting welds were spaced in 4 in., 6 in., and 8 in. intervals along the length of each specimen at the contact lines between the upper and lower elements. The thicknesses of the top and bottom elements were varied between 20 gauge, 18 gauge, and 16 gauge. Varying the thickness combinations, weld spacing and cellular deck depth in this manor ensured that the results of the testing would be applicable to a wide variety of cellular deck profiles.

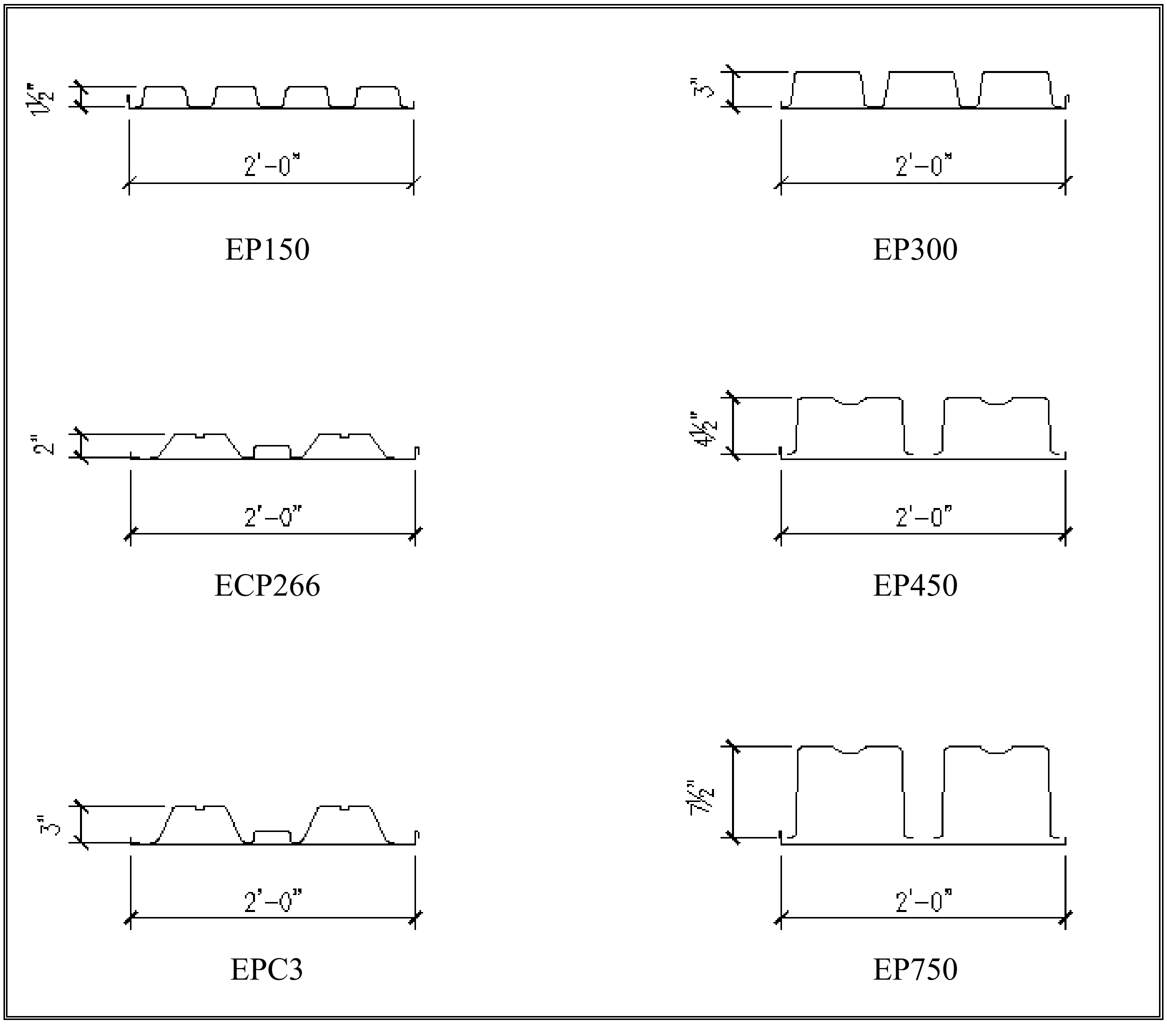


Figure 2-1: Cellular Deck Profiles

The specimens were tested using simple span conditions with the cellular deck flipped upside down, such that the bottom steel sheet was facing upward. Loads were applied downward using cross-panel line loads at the specimen's third points, forcing the steel sheet into compression. Typical bearing widths used were 4 in., though for deeper deck profiles where web crippling was an issue, this was often insufficient. The web crippling problem was solved by bringing the spreader beams closer to the midspan and providing wooden blocks below the spreader beam so as to distribute the load over a wider area (Balaji, 1991).

2.2 Theoretical Development by Luttrell and Balaji

When cellular decks are subjected to negative bending their bottom steel sheet element will be in compression. If the compressive stress in the steel sheet is great enough and the welds connecting it to the ribbed deck are spaced far enough apart, "column-like" buckling of the steel sheet will occur between the welds. The stress at which this type of buckling occurs is known as the critical buckling stress. The critical buckling stress can be estimated using Eq 2-1, which is derived from the classic Euler buckling equation.

$$F_c = \frac{\pi^2 E}{\left(\frac{K \cdot S_w}{r}\right)^2} \qquad \text{Eq 2-1}$$

Where:

t = Steel sheet thickness

K = Effective length factor (0.5)

S_w = Weld spacing

E = Modulus of elasticity

r^2 = Radius of gyration squared ($t^2/12$)

If the compressive stress in the steel sheet, f, is less than the critical buckling stress, then plate local buckling will be the controlling mode of failure, which can be adequately predicted using the effective width procedures given in Chapter B of the 2001 AISI Specification. If f is equal to the critical buckling stress then it is in a transition region, between "column-like" buckling and plate local buckling. If f is in this transition region, then the same procedures of Chapter B are followed with the exception that a transition reduction factor, ρ_t, must be used in place of the normal reduction factor, ρ. The transition reduction factor is calculated using Eq's 2-2 through 2-4 below.

$$\lambda_t = \left(\frac{1.052}{\sqrt{k}}\right)\left(\frac{w}{t}\right)\sqrt{\frac{F_c}{E}} \qquad \text{Eq 2-2}$$

$$\rho_t = 1.0 \quad when\ \lambda_t \leq 0.673 \qquad \text{Eq 2-3}$$

$$\rho_t = \frac{\left(1.0 - 0.22/\lambda_t\right)}{\lambda_t} \quad when\ \lambda_t \geq 0.673 \qquad \text{Eq 2-4}$$

Where:

t = Steel sheet thickness

k = Plate buckling coefficient (4.0)

w = Width of the compression element between connection lines

F_c = Critical column buckling stress (see Eq 1)

E = Modulus of elasticity

ρ_t = Transition reduction factor

If the moment in the cellular deck is great enough to cause the compressive stress in the bottom steel sheet, f, to exceed the critical buckling stress, then "column-like" buckling of the steel sheet will occur. To accurately estimate the reduced bending capacity of cellular deck when the bottom steel sheet undergoes "column-like" buckling, a different reduction factor must be used. The factor developed by Luttrell and Balaji (1992) is a function of the overall depth of the cellular deck section as well as the steel sheet critical buckling stress, yield stress and compressive stress. The bending strength properties estimated using this reduction factor were found to coincide reasonably well with observed bending strengths obtained during testing. The equations developed by Luttrell and Balaji for determining the reduction factor for cellular deck steel sheets that have compressive stresses exceeding their critical buckling stresses are shown below as Eq 2-5 and 2-6.

$$\rho_m = \left(\frac{F_y}{f}\right)\sqrt{\frac{F_c}{d \cdot f}} \qquad \text{Eq 2-5}$$

$$\rho = \rho_m \cdot \rho_t \qquad \text{Eq 2-6}$$

Where:

F_y = Steel sheet yield stress

F_c = Steel sheet critical buckling stress (Eq 2-1)

f = Steel sheet compressive stress

d = Overall depth of the cellular deck

ρ_t = Transition reduction factor (Eq 2-3 and 2-4)

ρ = Reduction factor (to be used with Chapter B of 2001 AISI Specification)

At a critical buckling stress, F_c, the plate buckles away from the hat but it is not free to buckle as a "simple column" (Luttrell and Balaji, 1992). It is most common for waves to form at alternate positions as indicated by Figure 2-2. Observations made during testing indicate that the first buckle allows a local relaxation to develop in the steel sheet, thereby relieving the adjacent span, s. This alternate-wave pattern extended through the entire length of the maximum bending moment region.

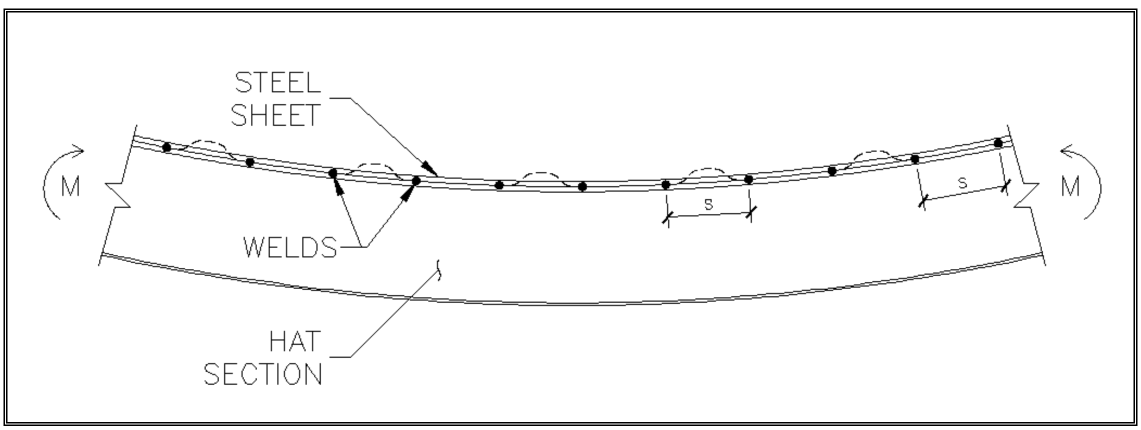


Figure 2-2: Elevation of Cellular Deck Section in Negative Bending (Luttrell and Balaji, 1992)

Figure 2-3 illustrates the relationship that the reduction factor, ρ, has with the compressive stress, *f*, applied to the steel sheet of a 3 in. deep cellular deck with a weld spacing of 4 in and a critical stress, F_c, equal to 14 ksi. From the graph, line ρo represents the reduction factor taken from Section B2.1 of the 2001 AISI Specification and line ρ represents the reduction factor developed by Luttrell and Balaji. Both reduction factors are the same for values of *f* less than or equal to the critical buckling stress. However, there is a substantial decrease in the reduction factor developed by Luttrell and Balaji after the critical buckling stress is exceeded, which accounts for the sudden relaxation in the cellular deck stiffness as the sheet begins to buckle. Still, this buckling is not free. It instead is controlled by the attached cellular hat and, with increasing applied bending moments, the buckled plate will continue to maintain a rather constant stress level (Luttrell and Balaji, 1992).

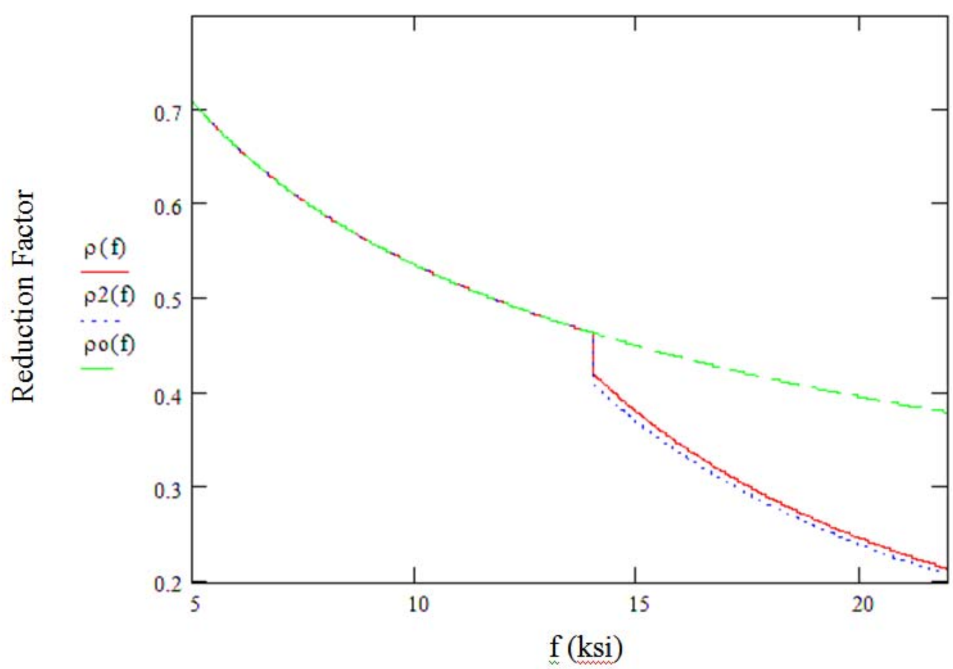


Figure 2-3: Reduction Factors vs. Compressive Stress

The reduction factor, ρ_m, developed by Luttrell and Balaji is dependent on the overall depth of the cellular deck. From Eq 2-5 it is apparent that ρ_m will be greater for shallow decks with a smaller d value than it will be for deep decks with a larger d value. This variation accounts for the fact that shallow cellular deck sections are more flexible and better able to develop compressive strains in the flat sheet. The ρ_m term will be close to unity for shallow cellular decks with thick steel sheets.

2.3 Non-Dimensional Reduction Factor

Although the theoretical bending strengths determined using Luttrell and Balaji's method adequately coincided with the 82 negative bending tests performed, a ballot containing the method was not passed by AISI. The primary reason for the rejection was the fact that the ρ_m factor used in the method was dimensional. In an effort to see that the method be accepted by AISI, the Steel Deck Institute sponsored a research program at Virginia Polytechnic Institute and State University in which a non-dimensional equation for the ρ_m factor was developed.

The first step taken was to determine the section properties of all EP-type cellular deck tested using the procedures form Chapter B of the 2001 AISI Specification and the effective width method developed by Luttrell and Balaji. As part of this process, the reduction factors ρ_m and ρ_t and the theoretical bending moment capacity were also determined. Knowing the ρ_m values for each cellular deck profile and the observed bending moments observed during testing, a new non-dimensional ρ_m equation was developed. This equation originally took the form shown as below as Eq 2-7. It is similar to the one developed by Luttrell and Balaji, but with two major exceptions. First, it has an addition thickness term, t, in the numerator under the square root sign. This t term leaves the ρ_m equation non-dimensional and increases the effective sheet width for cellular decks with thicker steel sheets.

$$\rho_m = C \cdot \left(\frac{F_y}{f}\right)\sqrt{\frac{t \cdot F_c}{d \cdot f}} \qquad \text{Eq 2-7}$$

Where:

F_y = Steel sheet yield stress

F_c = Steel sheet critical buckling stress (Eq 2-1)

f = Steel sheet compressive stress

d = Overall depth of the cellular deck

t = Steel sheet thickness

ρ_m = Reduction factor for column-like buckling of the sheet

C = Constant (8.0)

The second difference between the new equation (Eq 2-7) and the previous equation developed by Luttrell and Balaji (Eq 2-5) is a constant term, C. To solve for the value of C, a solver function was developed that minimized the error between the estimated bending strengths and the tested bending strengths observed in Luttrell and Balaji's research. Tests in which the specimen failed in a manner other than bending, such as web crippling, were neglected when solving for the appropriate C value.

Initially, different C values were selected for each cellular deck profile. However, after solving for these individual C values, it was observed that each of them were nearly identical. The smallest C value, 7.5, was observed in EP300 deck while the largest C value, 9.0, was observed in EP450 deck. Because the values were all so close, it was decided to develop a single constant that would minimize the error between the estimated and observed bending strengths for all four cellular deck profiles. This value for C was found to be 8.0.

The difference between the dimensional ρ_m equation developed by Luttrell and Balaji and the non-dimensional equation developed in this research is quite small. Figure 2-3 illustrates how the two differ with respect to the compressive stress in the steel sheet of a 3 in. deep cellular deck. In the figure, ρ represents the dimensional equation and $\rho 2$ represent the non-dimensional equation.

2.4 Limiting ρ Factor

In reviewing the previous report written by Luttrell and Balaji (1992), it was discovered that the ρ values for cellular decks with compressive stresses barely exceeding the critical buckling stress of the steel sheet were excessively high. These high values are caused by the F_y/f ratio seen at the front of the ρ_m equation (Eq 2-7 and 2-5). An example of how the ρ value might vary with respect to the compressive stress, f, is given in Figure 2-4.

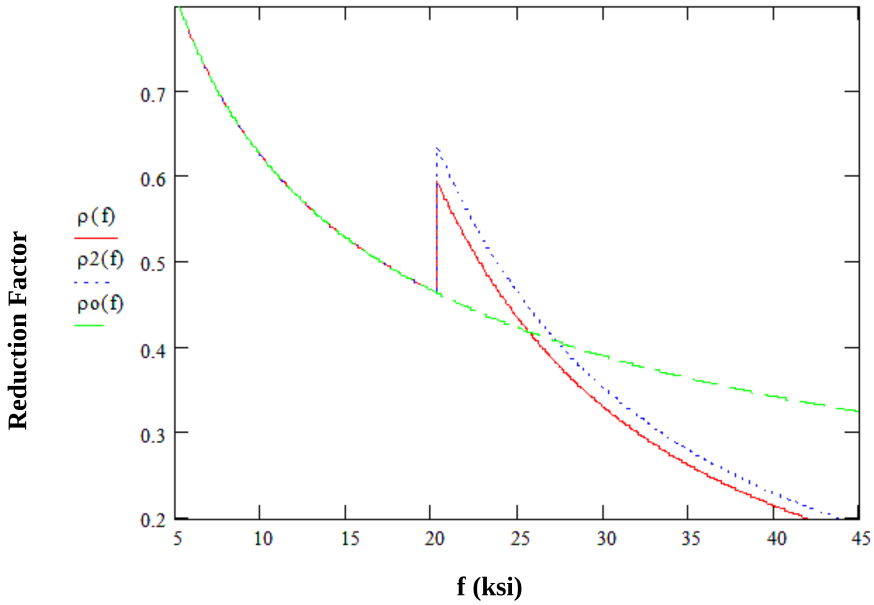


Figure 2-4: Reduction Factors vs. Compressive Stress

The type of deck used in Figure 2-4 is a 3 in. deep deck with a 4 in. spot weld spacing. The thickness and yield strength of the steel sheet used were 16 gauge (0.06 in.) and 45 ksi, resulting in a critical buckling stress of approximately 20 ksi. The dashed green line, ρ_o, is equivalent to the ρ term calculated using Section B2.1 of the 2001 AISI Specification, and should not be exceeded. The red and blue lines represent the dimensional and non-dimensional reduction factors respectively. It is apparent from the figure that both the dimensional and non-dimensional reduction factors exceed the one given in Section B2.1. This type of situation will only occur when the critical buckling stress is slightly less than the compressive stress in the bottom steel sheet and the yield stress is significantly higher than both the critical buckling stress and the compressive stress. To prevent this excessively high ρ value from being used, the equation given in Section B2.1 must be utilized as a limiting equation. Therefore Eqs 2-8 through 2-10 are proposed for determining the value of ρ.

$$\rho = \left(1 - \frac{0.22}{\lambda}\right) / \lambda \quad if \;\; f < F_c \qquad \text{Eq 2-8}$$

$$\rho = \rho_t \quad if \;\; f = F \qquad \text{Eq 2-9}$$

$$\rho = \rho_m \cdot \rho_t \leq \left(1 - \frac{0.22}{\lambda}\right) / \lambda \quad if \;\; f > F_c \qquad \text{Eq 2-10}$$

Where:

F_c	=	Steel sheet critical buckling stress (Eq 2-1)
f	=	Steel sheet compressive stress
ρ	=	Reduction factor
ρ_t	=	Transition reduction factor (Eq 2-4)
ρ_m	=	Reduction factor for column-like buckling of the sheet (Eq 2-7)
λ	=	$(f/Fcr)^{0.5}$ per Section B2.1 of the 2001 AISI Specification

2.5 Development of Resistance Factor

In addition to modifying the reduction factor, a resistance factor, φ, was also determined for each type of cellular deck. The resistance factor is a factor that accounts for the unavoidable deviations of the actual strength from the nominal value (Yu, 2000). The procedure used to calculate this factor was taken from the method suggested in Section F1.1 of the 2001 AISI Specification. The equation recommended by the Specification is given as Eq 2-11 below.

$$\varphi = C_\phi (M_m F_m P_m) e^{-\beta_o \sqrt{V_M{}^2 + V_F{}^2 + C_P V_P{}^2 + V_Q{}^2}} \qquad \text{Eq 2-11}$$

Where:

C_φ	=	Calibration Coefficient (1.52)
M_m	=	Mean material factor (1.1)
F_m	=	Mean value of fabrication (1.0)
P_m	=	Mean value of professional factor (1.0)
e	=	Natural logarithmic base (2.7183)

β_o	=	Reliability index (2.5)
V_M	=	Coefficient of variance for material (0.10)
V_F	=	Coefficient of variance for fabrication (0.05)
C_P	=	Correction factor
	=	$(1+1/n)m/(m-2)$ for $n \geq 4$
V_P	=	Coefficient of variance for observed-to-theoretical strength ratio ≥ 0.065
n	=	number of tests
m	=	Degrees of freedom
	=	n-1
V_Q	=	Coefficient of variation of load effect
	=	0.21

The β value of 2.5 is recommended by AISI for determining the bending strengths of structural members. Given the average material strengths observed during testing, the recommended M_m value of 1.10 would correspond to a nominal cold-formed steel yield strength of 40 ksi. This value is assumed to be correct, as no nominal yield strengths were given in the original research reported by Luttrell and Balaji (1992). The values used for M_m, V_m, F_m, and V_F are those required by the Bending Strength section of Table F1 of the 2001 AISI Specification

3. Results

3.1 Section Property Comparisons with Luttrell and Balaji Data

Prior to the development of the non-dimensional equation, section properties were computed for each of the deck profiles using the same method used by Luttrell and Balaji (1992). Many of the section properties are similar to those calculated by Luttrell and Balaji. However, some section properties are significantly different. Upon further reviewing the 1992 “Cellular Decks in Negative Bending Effective Width Formulations” report and the procedure used, several small arithmetic errors were discovered. These small errors most likely led to the discrepancies observed between the section properties calculated during this research and the section properties calculated by Luttrell and Balaji

(1992). The values calculated by Luttrell and Balaji and those calculated as part of this research are displayed below in Tables 3-1 through 3-4. Mt and Mo represent the theoretical and observed bending moments, respectively. An Mo/Mt ratio value greater than 1 means that the equation used to estimate the bending strength was conservative, while a value less than 1 means it overestimated the bending strength. Sw represents the weld spacing, t represents the thickness of the ribbed deck, tb represents the thickness of the steel sheet, and Fy represents the yield strength of the steel sheet.

Table 3-1: Section Properties of EP150 Cellular Deck

	Test No.	F_y (ksi)	t (in)	t_b (in)	S_w	Luttrell and Balaji			Snow		
						Mo	M_t	M_o/M_t	ρ_m	M_t	M_o/M_t
EP150 Deck	1	44	0.046	0.045	8	23.16	23.39	0.99	0.205	21.87	1.06
	2	44	0.045	0.046	8	23.33	23.33	1.00	0.208	21.91	1.07
	75	45	0.036	0.046	4	22.72	21.04	1.08	0.483	20.21	1.12
	76	45	0.036	0.046	6	21.23	20.41	1.04	0.278	19.89	1.07
	77	45	0.035	0.046	8	21.48	19.53	1.10	0.205	17.97	1.20
	78	44	0.049	0.058	4	30.78	26.31	1.17	0.822	27.86	1.11
	79	44	0.046	0.057	6	29.89	25.33	1.18	0.467	25.95	1.15
	80	44	0.046	0.058	8	28.37	24.89	1.14	0.277	25.33	1.12
	81	44	0.046	0.046	4	27.10	24.64	1.10	0.423	24.91	1.09
	82	44	0.046	0.046	6	26.90	24.02	1.12	0.279	23.70	1.14
							Averages:	1.09			1.11

Table 3-2: Section Properties of EP300 Cellular Deck

	Test No.	F_y (ksi)	t (in)	t_b (in)	S_w	Luttrell and Balaji			Snow		
						Mo	M_t	Mo/Mt	ρ_m	M_t	M_o/M_t
EP300 Deck	37	43	0.046	0.046	8	40.72	42.86	0.95	0.155	43.42	0.94
	38	43	0.046	0.046	8	41.86	41.86	1.00	0.153	42.75	0.98
	39	43	0.045	0.045	6	41.61	44.74	0.93	0.200	42.56	0.98
	40	43	0.045	0.045	6	43.18	44.52	0.97	0.200	42.44	1.02
	41	43	0.045	0.045	4	46.67	53.03	0.88	0.299	43.25	1.08
	42	43	0.046	0.045	4	46.66	53.63	0.87	0.299	43.48	1.07
	43	42	0.035	0.045	8	34.09	35.14	0.97	0.154	35.54	0.96
	44	42	0.036	0.046	8	33.73	35.51	0.95	0.155	35.86	0.94
	45	42	0.035	0.046	6	37.26	38.02	0.98	0.209	36.40	1.02
	46	42	0.035	0.046	6	36.62	38.15	0.96	0.207	36.40	1.01
	47	42	0.035	0.045	4	38.17	43.37	0.88	0.308	36.79	1.04
	48	42	0.036	0.046	4	37.35	44.47	0.84	0.310	37.32	1.00
	49	43	0.046	0.057	8	49.25	52.96	0.93	0.191	50.53	0.98
	50	43	0.045	0.057	8	49.40	52.55	0.94	0.191	50.36	0.98
	51	43	0.045	0.057	6	49.13	55.83	0.88	0.255	51.40	0.96
	52	43	0.045	0.057	6	50.95	55.99	0.91	0.255	51.52	0.99
							Average:	0.93			1.00

Table 3-3: Section Properties of EP450 Cellular Deck

	Test No.	F_y (ksi)	t (in)	t_b (in)	S_w	Luttrell and Balaji			Snow		
						Mo	M_t	M_o/M_t	ρ_m	M_t	M_o/M_t
EP450 Deck	53	43	0.035	0.057	4	43.80	74.24	0.59	0.310	54.02	0.81
	54	43	0.034	0.046	4	41.58	58.56	0.71	0.251	43.91	0.95
	55	43	0.035	0.046	6	39.20	52.97	0.74	0.167	42.98	0.91
	56	43	0.045	0.046	6	40.07	52.73	0.76	0.167	51.52	0.78
	57	43	0.035	0.046	8	37.28	49.70	0.75	0.125	42.03	0.89
	58	43	0.035	0.046	8	36.62	49.49	0.74	0.125	41.94	0.87
	59	43	0.048	0.057	8	62.36	76.99	0.81	0.155	60.70	1.03
	60	43	0.048	0.057	8	64.37	76.63	0.84	0.155	60.56	1.06
	61	43	0.048	0.057	6	77.46	87.03	0.89	0.208	61.98	1.25
	62	43	0.048	0.057	4	81.61	94.89	0.86	0.313	64.00	1.28
	63	43	0.048	0.046	8	65.28	62.77	1.04	0.125	52.86	1.24
	64	43	0.048	0.046	6	66.01	68.05	0.97	0.167	53.68	1.23
	65	43	0.048	0.046	4	70.05	79.60	0.88	0.250	54.93	1.28
							Averages:	0.81			1.04

Table 3-4: Section Properties of EP750 Cellular Deck

	Test No.	F_y (ksi)	t (in)	t_b (in)	S_w	Luttrell and Balaji			Snow		
						Mo	M_t	M_o/M_t	ρ_m	M_t	M_o/M_t
EP 750 Deck	66	44	0.046	0.058	8	99.16	135.83	0.73	0.122	104.92	0.95
	67	44	0.045	0.058	6	115.25	144.06	0.80	0.163	105.82	1.09
	68	44	0.046	0.057	4	134.93	166.58	0.81	0.242	109.25	1.24
	69	44	0.034	0.046	6	78.93	86.74	0.91	0.130	70.01	1.13
	70	44	0.034	0.046	4	86.94	96.60	0.90	0.194	71.90	1.21
	71	44	0.034	0.046	8	72.64	82.55	0.88	0.096	68.54	1.06
	72	44	0.046	0.046	6	108.38	117.80	0.92	0.129	91.97	1.18
	73	44	0.046	0.046	8	103.38	108.82	0.95	0.097	89.63	1.15
	74	44	0.046	0.046	4	113.82	130.83	0.87	0.193	92.01	1.24
							Averages:	0.86			1.14

3.2 Results Using Non-Dimensional Reduction Factor

New section properties were determined for four of the six cellular deck profiles tested in Luttrell and Balaji's research using the newly developed non-dimensional equation discussed in section 2.3 of this report. These section properties were then used to estimate the bending strength for each of the four cellular deck profiles tested by Luttrell and Balaji. Appendix B of this report contains example calculations that demonstrate how the section properties and estimated bending strengths were determined. The following four sections highlight comparisons made between these estimated bending strengths and the bending strengths observed during testing for each cellular deck profile.

3.2.1 EP150 Cellular Deck

At a total depth of no more than 1.72 in., the EP150 profile was the shallowest cellular deck profile tested. While column-like buckling of the sheet was still observed, it had a far less significant impact on bending strength due to the shallowness of the deck. This trend is accounted for in the ρ_m equation and can be observed in Table 3-5, where the values of ρ_m are close to or at unity for cellular decks with thick steel sheets and more closely spaced welds. For many of the specimens the limiting ρ factor discussed in Section 2.4 of this report controlled the effective width of the steel sheet. Note that values of ρ_m were only this high for EP150 deck. Other cellular deck profiles were much deeper, and therefore had much smaller ρ_m values.

Table 3-5: EP150 Bending Strength Comparisons using Non-Dimensional ρ_m

	Test No.	F_y (ksi)	t (in)	t_b (in)	S_w	ρ_m	M_t	M_o	M_o/M_t
EP150 Deck	1	44	0.046	0.045	8	0.363	24.85	23.16	0.93
	2	44	0.046	0.046	8	0.379	24.83	23.33	0.94
	75	45	0.036	0.046	4	1.000	20.63	22.72	1.10
	76	45	0.036	0.046	6	0.666	20.68	21.23	1.03
	77	45	0.035	0.046	8	0.495	20.34	21.48	1.06
	78	44	0.049	0.058	4	1.000	27.90	30.78	1.10
	79	44	0.046	0.057	6	1.000	26.52	29.89	1.13
	80	44	0.046	0.058	8	0.856	26.74	28.37	1.06
	81	44	0.046	0.046	4	0.894	25.55	27.10	1.06
	82	44	0.046	0.046	6	0.595	25.33	26.90	1.06
							Average:		1.05

In all, the non-dimensional ρ_m equation adequately estimated the bending strength of each EP150 specimen with an average observed-to-theoretical bending moment capacity ratio of 1.05. This average ratio held relatively constant regardless of weld spacing, as illustrated by Figure 3-1.

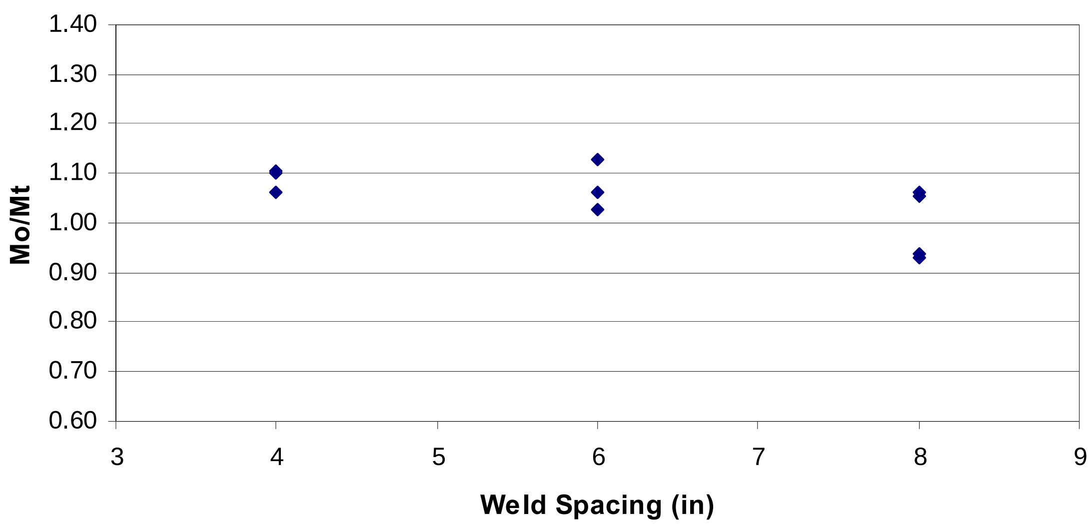


Figure 3-1: EP150 Cellular Deck Bending Moment Comparisons

3.2.2 EP300 Cellular Deck

With a depth of just over 3 in., all of the ρ_m values for EP300 cellular deck varied between 0.261 and 0.682. These values are notably higher than those seen in Table 3-2, where the values ranged from 0.153 to 0.31. The difference between the two can be attributed to the way in which the new ρ_m equations were modified to better match the bending strength results observed during testing. Table 3-6 lists the theoretical bending strength results for EP300 cellular deck obtained using the non-dimensional ρ_m, and compares the results to the strength results determined experimentally by Luttrell and Balaji (1992).

Table 3-6: EP300 Bending Strength Comparisons using Non-Dimensional ρ_m

	Test No.	F_y (ksi)	t (in)	t_b (in)	S_w	ρ_m	M_t	M_o	M_o/M_t	Note*
EP300 Deck	37	43	0.046	0.046	8	0.267	48.64	40.72	0.84	w
	38	43	0.046	0.046	8	0.261	47.76	41.86	0.88	w
	39	43	0.045	0.045	6	0.338	47.70	41.61	0.87	w
	40	43	0.045	0.045	6	0.338	47.59	43.18	0.91	
	41	43	0.045	0.045	4	0.506	48.81	46.67	0.96	
	42	43	0.046	0.045	4	0.506	49.04	46.66	0.95	
	43	42	0.035	0.045	8	0.281	39.50	34.09	0.86	w
	44	42	0.036	0.046	8	0.286	39.79	33.73	0.85	w
	45	42	0.035	0.046	6	0.444	39.66	37.26	0.94	
	46	42	0.035	0.046	6	0.419	39.91	36.62	0.92	
	47	42	0.035	0.045	4	0.642	39.95	38.17	0.96	
	48	42	0.036	0.046	4	0.642	40.60	37.35	0.92	
	49	43	0.046	0.057	8	0.506	53.99	49.25	0.91	
	50	43	0.045	0.057	8	0.510	53.67	49.40	0.92	w
	51	43	0.045	0.057	6	0.679	53.67	49.13	0.92	
	52	43	0.045	0.057	6	0.682	53.79	50.95	0.95	
							Average:		0.91	
							Average2:		0.93	

***w = web crippling failure at ultimate**

The ratio of observed to theoretical bending strength for the 16 EP300 cellular decks tested averaged 0.91 including the specimens that failed due to web crippling, and averaged 0.93 when these specimens were not included. The ratio also varied little with respect to weld spacing, as illustrated by Figure 3-2. It should be noted that the specimens that failed by means other than bending were not included in the development of the non-dimensional reduction factor or the resistance factors.

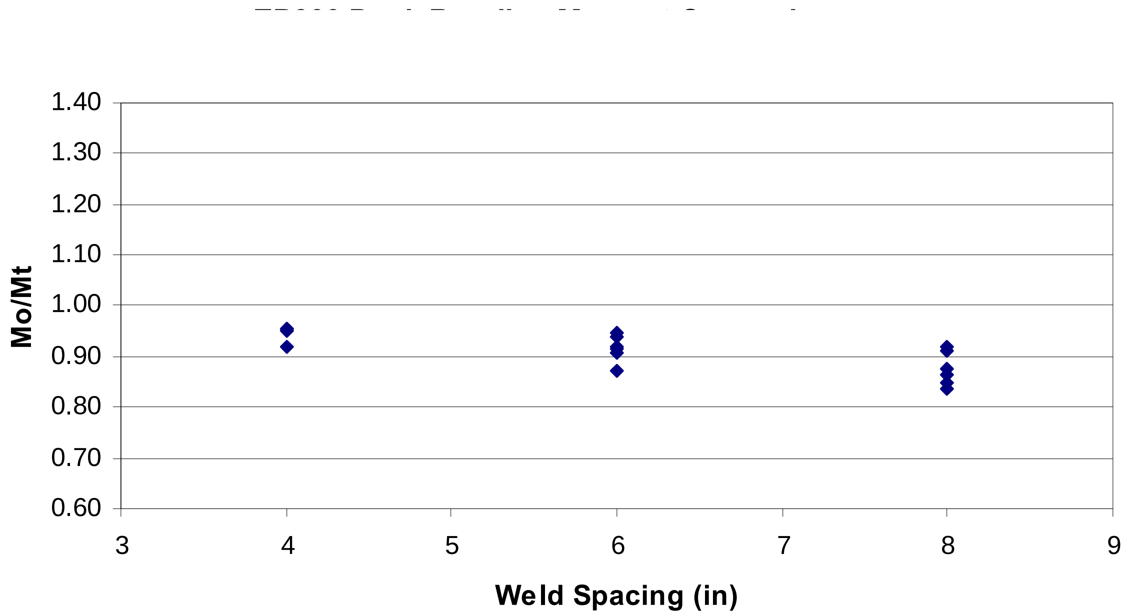


Figure 3-2: EP300 Cellular Deck Bending Moment Comparisons

3.2.3 EP450 Cellular Deck

In all, thirteen EP450 cellular decks were tested. Each deck had non-dimensional ρ_m values that ranged from 0.215 for decks with an 18 gauge steel sheet spot welded at 8 in. o.c. to 0.599 for decks with a 16 gauge steel sheet spot welded at 4 in. o.c. These ρ_m values are slightly different from those calculated using Luttrell and Balaji's method, where values ranged from 0.12 to 0.31. Table 3-7 lists all non-dimensional ρ_m values used for the EP450 type cellular deck.

Table 3-7: EP450 Bending Strength Comparisons using Non-Dimensional ρ_m

	Test No.	F_y (ksi)	t (in)	t_b (in)	S_w	ρ_m	M_t	M_o	M_o/M_t	Note*
EP450 Deck	53	43	0.035	0.057	4	0.592	67.97	43.80	0.64	w
	54	43	0.034	0.046	4	0.431	52.41	41.58	0.79	w
	55	43	0.035	0.046	6	0.287	50.45	39.20	0.78	w
	56	43	0.045	0.046	6	0.286	57.84	40.07	0.69	w
	57	43	0.035	0.046	8	0.215	48.76	37.28	0.76	w
	58	43	0.035	0.046	8	0.215	48.67	36.62	0.75	w
	59	43	0.048	0.057	8	0.296	71.92	62.36	0.87	w
	60	43	0.048	0.057	8	0.296	71.79	64.37	0.90	w
	61	43	0.048	0.057	6	0.398	74.54	77.46	1.04	
	62	43	0.048	0.057	4	0.599	78.40	81.61	1.04	
	63	43	0.048	0.046	8	0.215	58.65	65.28	1.11	
	64	43	0.048	0.046	6	0.285	59.97	66.01	1.10	
	65	43	0.048	0.046	4	0.428	62.10	70.05	1.13	
							Average:		0.89	
							Average2:		1.08	

***w = web crippling failure at ultimate**

Overall, the non-dimensional ρ_m values adequately estimated the bending strength of the EP450 cellular deck. Neglecting specimens that failed due to web crippling, the average observed-to-theoretical bending strength ratio averaged 1.08. Figure 3-3 illustrates the scatter seen in the observed to theoretical bending strength ratios, which was significantly more than the scatter observed from other types of cellular deck. The amount of scatter can be largely attributed to the manor in which the EP450 cellular deck failed. Many of the specimens having observed to theoretical bending strength ratios below 1.0 failed due to web crippling, as noted in Table 3-7. To prevent this type of failure, wooden blocks were placed beneath the spreader beams, so as to distribute the load over a wider area (Balaji, 1991). Placement of the wooden blocks, however, only occurred after many of the EP450 specimens had been tested. The specimens without blocks failed due to web crippling and as a result had observed to theoretical bending strengths below 1.0. Conversely, specimens with wooden blocks did not fail in web crippling and had observed to theoretical bending strength ratios above 1.0.

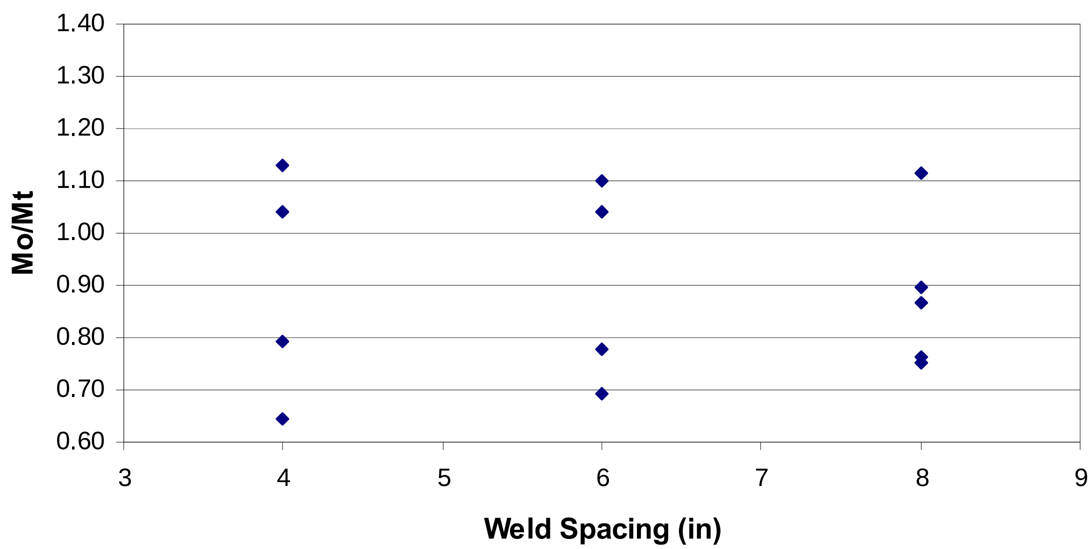


Figure 3-3: EP450 Cellular Deck Bending Moment Comparisons

3.2.4 EP750 Cellular Deck

A total of nine EP750 cellular deck specimens were tested. Non-dimensional ρ_m values varied between 0.165 and 0.463, for 18 gauge and 16 gauge deck, respectively. These values are slightly greater than those calculated using Luttrell and Balaji's method, which were found to be 0.10 and 0.24. Table 3-8 lists the non-dimensional ρ_m values for all nine EP750 specimens.

Table 3-8: EP750 Bending Strength Comparisons using Non-Dimensional ρ_m

	Test No.	F_y (ksi)	t (in)	t_b (in)	S_w	ρ_m	M_t	M_o	M_o/M_t	Note*
EP 750 Deck	66	44	0.046	0.056	8	0.234	123.38	99.16	0.80	ws
	67	44	0.045	0.058	6	0.313	126.77	115.25	0.91	ws
	68	44	0.046	0.057	4	0.463	132.24	134.93	1.02	bcb
	69	44	0.034	0.046	6	0.222	79.95	78.93	0.99	bcb
	70	44	0.034	0.046	4	0.333	83.08	86.94	1.05	bcb
	71	44	0.034	0.046	8	0.165	77.30	72.64	0.94	bcb
	72	44	0.046	0.046	6	0.221	102.13	108.38	1.06	bcb
	73	44	0.046	0.046	8	0.167	98.88	103.38	1.05	bcb
	74	44	0.046	0.046	4	0.331	103.41	113.82	1.10	bcb
							Average:		0.99	

***ws = web crippling at support**

***bcb = buckling in hat flange at ultimate**

The average ratio of observed to theoretical bending strength for the nine EP750 cellular deck specimens tested was 0.99, indicating that the non-dimensional ρ_m equation slightly underestimated the bending strength of the deck. Upon closer inspection of the failure modes, however, it is apparent that each of the EP750 specimens failed in some manner other than bending. Because of the specimens' premature failure, it is assumed that the reduction factor adequately estimated the effective width of the steel sheet. As Figure 3-4 indicates, the scatter observed between ratios was relatively small. Only specimen number 66 deviated substantially from unity. The cause for the difference is probably the web crippling failure mode, which likely failed before the full bending strength capacity of the deck was reached.

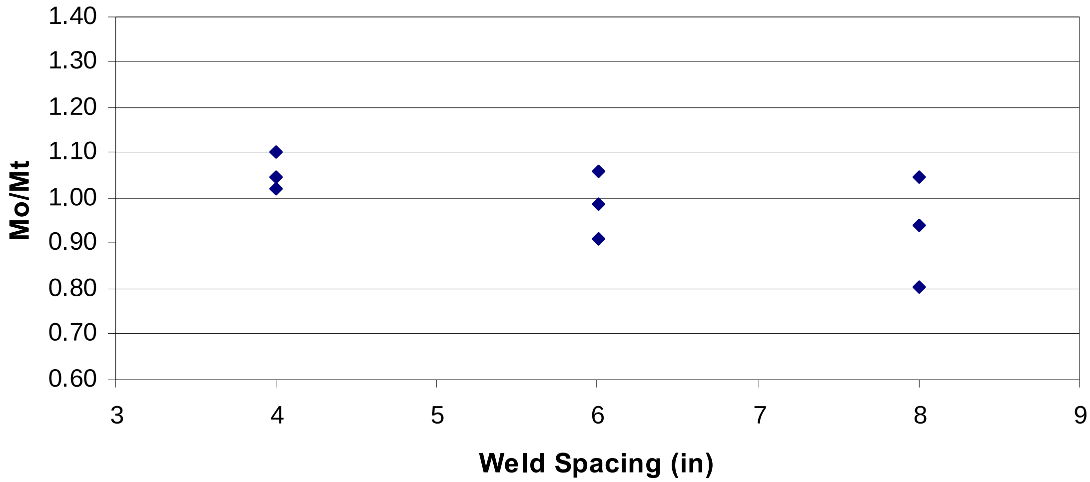


Figure 3-4: EP750 Cellular Deck Bending Moment Comparisons

3.3 Resistance Factor

A resistance factor was determined for each type of cellular deck based on the procedure outlined in Section 2.5 of this report. Many of the specimens that were tested prematurely failed in a manner other bending, such as web crippling and buckling of the compression flange. When a specimen prematurely failed, the ratio of its observed-to-theoretical bending strength was not utilized in the development of resistance factor.

The resistance factors together with the C_p, V_p, m and n values developed in this research are presented in Table 3-9 below. Due to the low variance observed in the observed-to-theoretical bending strengths, resistance factors were near 0.90 for each type of cellular deck. Resistance values of this magnitude are common in cold-formed steel sections subjected to bending.

Table 3-9: Resistance Factors

Deck Type	Cp	Vp	m	n	φ
EP150	1.4143	0.0624	9	10	0.895
EP300	1.4143	0.0209	9	10	0.895
EP450	2.4000	0.0384	4	5	0.876
EP750	1.4815	0.0933	8	9	0.865

4. Summary & Conclusions

4.1 Research Summary

When cellular deck is subjected to positive bending, its strength and section properties are well understood and can be determined with the use of the Chapter B of the 2001 AISI Specification. However, when cellular deck is subjected to negative bending, the bottom steel sheet is forced into compression. If the spacing of the resistance spot welds that connect the steel sheet element to the hat section element is less than the required limits of Section D1.2 of the 2001 AISI Specification, then plate buckling of the steel sheet will occur at maximum load. The effective width of a steel sheet undergoing plate buckling at maximum load can be adequately determined using Chapter B of the Specification.

If the limits of Section D1.2 are exceeded, column-like buckling of the bottom steel sheet is likely to occur in decks subjected to negative bending. There are no provisions in the 2001 AISI Specification in place to account for the additional bending strength that a steel sheet with column-like buckling would provide. However, a procedure was developed by Luttrell and Balaji (1992), which, based on the results of 82 cellular deck bending tests, sufficiently estimated the additional strength provided by a steel sheet undergoing column-like buckling.

Although the method developed by Luttrell and Balaji adequately estimated the bending strength of the 82 cellular decks tested, it contained a reduction factor, ρ_m, which was dimensional. And because AISI requires that equations used in the Specification be non-dimensional, a ballot containing Luttrell and Balaji's method was not passed. It was the objective of this research study to modify the ρ_m equation such that it is non-dimensional yet continued to adequately estimate the effective width of the bottom steel sheet when it was subjected to column-like buckling.

To achieve this objective, section properties of 49 of the 82 cellular decks tested were determined using the method originally developed by Luttrell and Balaji (1992). Small errors were discovered in the original report, which led to significant differences in the calculated section properties for deeper cellular decks. Based on the newly determined section properties, two modifications were made to the original ρ_m equation. The first modification was to place a thickness variable, t, in the numerator under the square root sign, thereby making the equation non-dimensional and decreasing its effect on thicker steel sheets. The second modification was a constant, C. The optimum value of this constant was determined through the use of a solver function, which minimized the error between observed and theoretical bending strength for the cellular decks investigated that failed in bending.

4.2 Conclusions

- With mean observed-to-theoretical ratios of 1.05, 0.93, 1.08 and 0.99 for EP150, EP300, EP450 and EP750 decks, it is apparent that the non-dimensional reduction factor proposed in this research adequately estimated the effective width for the bottom steel sheets of cellular decks.
- Many specimens prematurely failed by means other than bending during the testing portion of this research. When the data from these specimens are neglected, the scatter observed in each type of cellular deck was relatively low. Low scatter indicates that the proposed procedure applies to a variety of cellular deck profiles, regardless of the spot weld spacing, the material thickness or the depth of the section.
- Due to the observed-to-theoretical bending strength ratios being near unity with relatively low scatter, the resistance factors, φ, that were developed neared 0.90. Having φ factors of this magnitude indicates that the accuracy of the proposed procedure is consistent with other procedures used to determine bending strength of other types of structural members.

References

1. American Iron and Steel Institute, AISI (2001). “North American Specification for the Design of Cold-Formed Steel Structural Members,” 2001 Edition, With 2004 Supplement, Washington D.C.

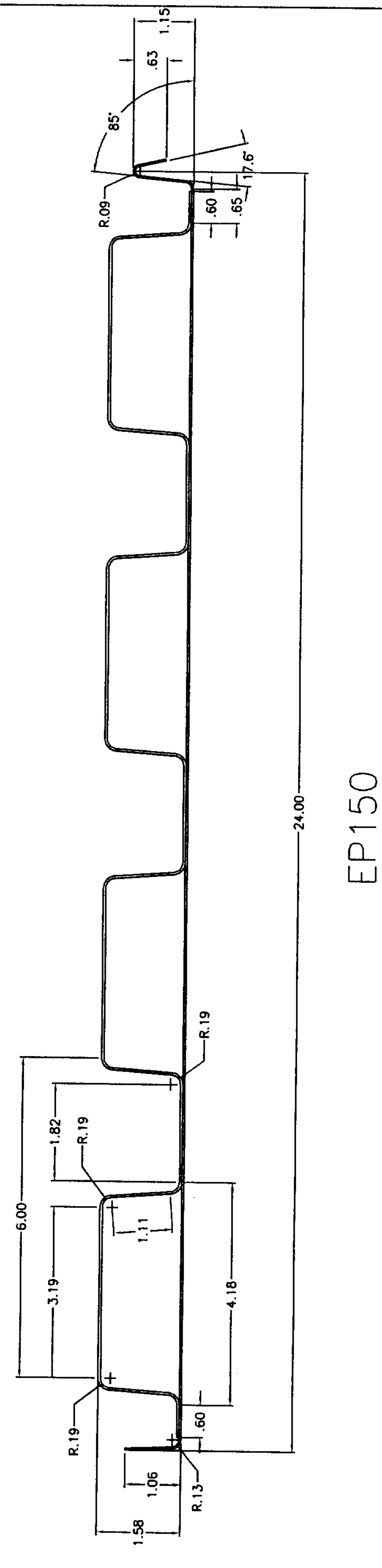
2. Balaji, K. (1991). “Evaluation of Section Properties for Cellular Decks in Negative Bending,” Master’s Report, West Virginia University. Morgantown, West Virginia.

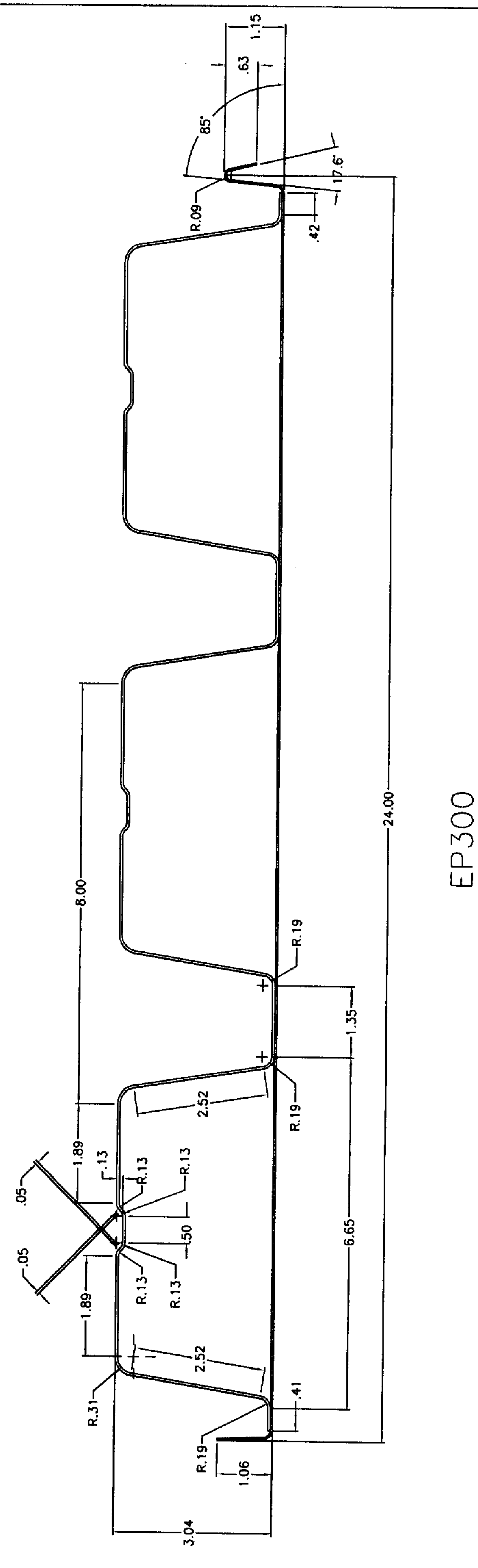
3. Luttrell, L.D. and Balaji, K. (1992). “Properties of Cellular Decks in Negative Bending, “ Proceedings of the 11^{th} International Specialty Conference on Cold-Formed Steel Structures, University of Missouri – Rolla, Rolla, MO.

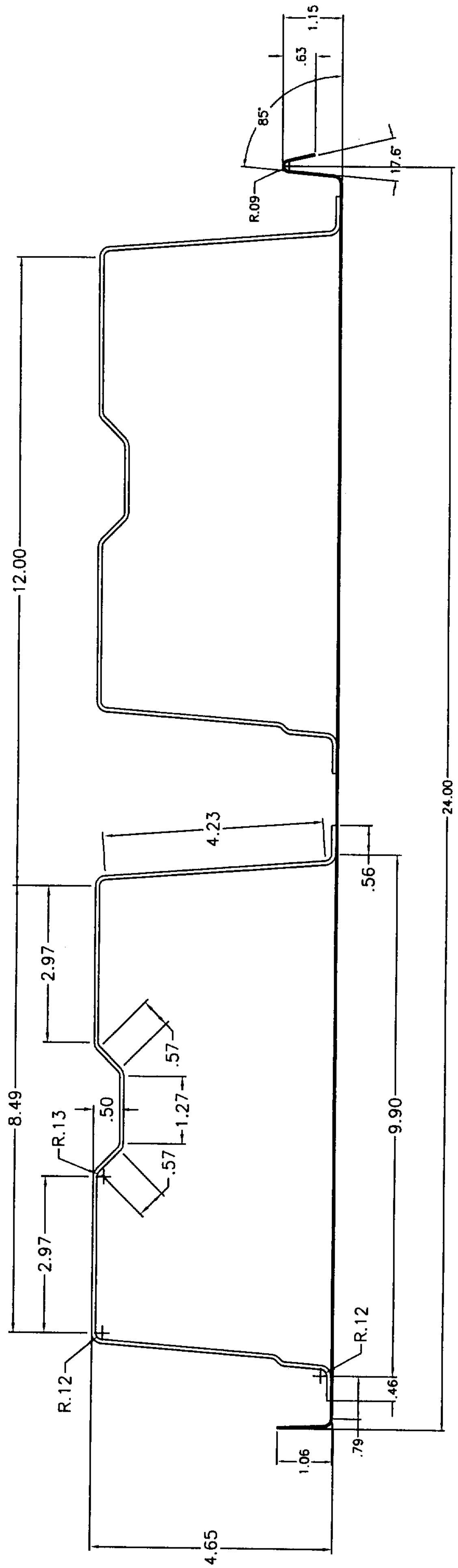
4. Yu, W. W. (2000). Cold-Formed Steel Design. Third Edition. New York, New York: John Wiley and Sons, Inc.

Appendix A: Deck Profile Dimensions

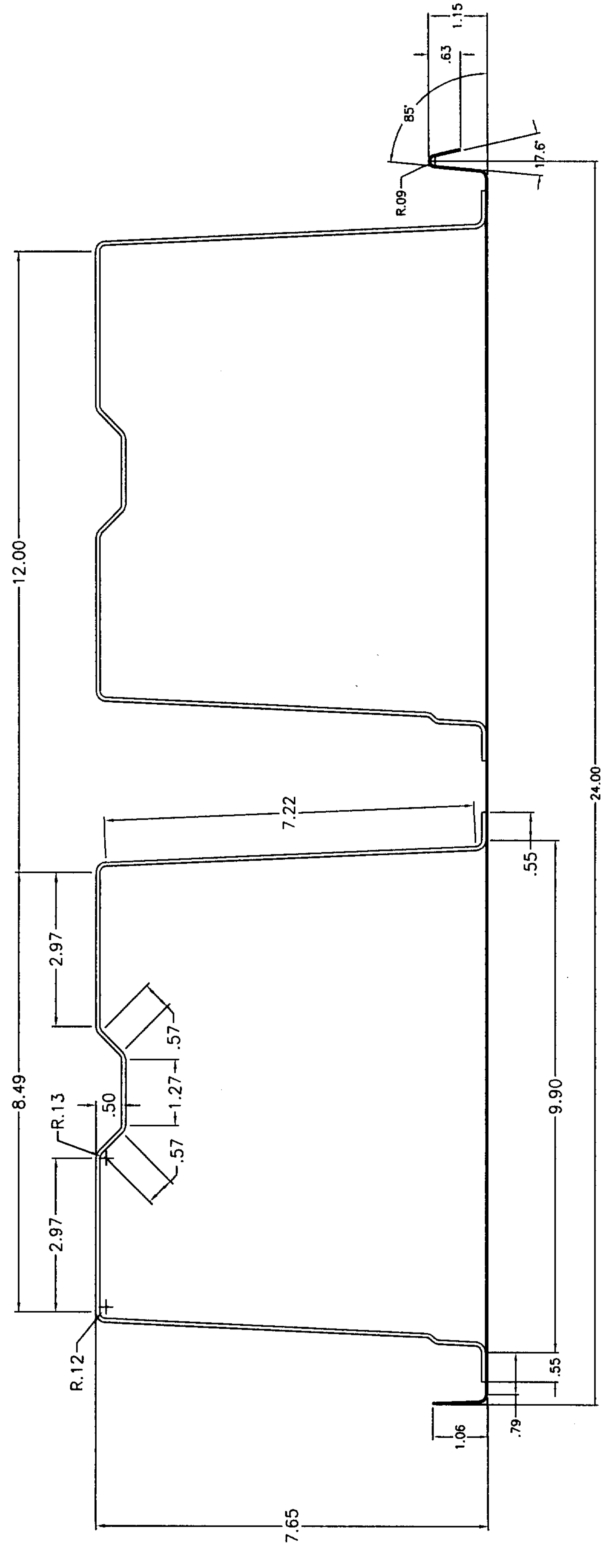
The following section contains the dimensions of the EP150, EPC266, ECP3, EP300, EP450, and EP750 cellular deck profiles used during this study. All dimensions and figures were provided by Epic Metals Corporation.


EP150
24.00
1.15
.63
85°
17.6°
R.09
.60
.65
R.19
1.82
R.19
6.00
1.11
3.19
4.18
R.19
.60
1.06
R.13
1.58


EP300
24.00
8.00
6.65
3.04
2.52
2.52
1.89
1.89
1.35
1.15
1.06
.63
.50
.42
.41
.13
.05
.05
85°
17.6°
R.09
R.19
R.19
R.19
R.31
R.13
R.13
R.13
R.13


1.15
.63
85°
17.6°
R.09
12.00
4.23
.56
2.97
.57
.50
1.27
R.13
8.49
2.97
9.90
24.00
R.12
R.12
.46
.79
1.06
4.65

EP450


1.15
.63
85°
17.6°
R.09
12.00
24.00
7.22
.55
9.90
2.97
.57
1.27
.50
R.13
.57
8.49
2.97
R.12
.55
.79
1.06
7.65

EP750

Appendix B: Sample Calculations of Cellular Deck Section Properties

The theoretical bending strengths of the cellular deck profiles used in this study were calculated based on the non-dimensional procedure proposed by this report and the deck dimensions provided by Epic Metals Corporation. The following section contains one example section property calculation for each type of cellular deck profile used in this study. See Appendix A of this report for an explanation of the input variables used in the following examples.

EP150 Cellular Deck

(Test No. 78)

Inputs

Deck Dimensions:

$D := 1.58$

$R := .19$

$H := .6$

$\phi := \frac{85 \cdot \pi}{180}$

$Wt := 3.19$

$Wb := 1.82$

$t := .0455$

$E := 29500$

$\mu := 0.3$

$r := R + \frac{t}{2}$

$Dt := D + t + tb$

$y\_ := .90$

$AV := r \cdot (1 - \cos(\phi)) + \frac{t}{2}$

$AV = 0.217$

Plate Dimensions:

$GP\_L := 1.06$

$HL := 0.6$

$HA := 4.18$

$HM := 4.18$

$HB := 4.18$

$HR := 0.65$

$GP\_R := 1.15$

$HP := 0.63$

$tb := .0461$

$Fy := 44$

$CW := 24$

$s := 6$

$\theta\_stiff := 90$

$$f(y) := \left| \begin{array}{l} \text{if } y\_ > \frac{Dt}{2} \\ \quad \left| \begin{array}{l} f \leftarrow Fy \cdot \left(\frac{y\_ - y}{y\_} \right) \ \text{ if } y < y\_ \\ f \leftarrow \left[Fy \cdot \left(\frac{Dt - y\_}{y\_} \right) \cdot \left(\frac{y - y\_}{Dt - y\_} \right) \right] \ \text{ if } y > y\_ \end{array} \right. \\ \text{if } y\_ < \frac{Dt}{2} \\ \quad \left| \begin{array}{l} f \leftarrow Fy \cdot \left(\frac{y\_}{Dt - y\_} \right) \cdot \left(\frac{y\_ - y}{y\_} \right) \ \text{ if } y < y\_ \\ f \leftarrow Fy \cdot \left(\frac{y - y\_}{Dt - y\_} \right) \ \text{ if } y > y\_ \end{array} \right. \\ f \end{array} \right.$$

EP150 Cellular Deck

(Test No. 78)

1. Top:

$L_1 := 4 \cdot Wt$ $\quad L_1 = 12.76$

$y_1 := \frac{t}{2}$ $\quad y_1 = 0.023$ $\quad I_1 := 0$

2. Top Arcs:

$L_2 := 8r \cdot \phi$ $\quad L_2 = 2.525$

$y_2 := \frac{t}{2} + \left(r - r \cdot \frac{\sin(\phi)}{\phi}\right)$ $\quad y_2 = 0.093$

$I_2 := \left[\left[\frac{(\phi) + \sin(\phi) \cdot \cos(\phi)}{2} - \frac{\sin(\phi)^2}{(\phi)}\right] \cdot r^3\right] \cdot 8$ $\quad I_2 = 8.954 \times 10^{-3}$

3. Webs:

$f1 := f(D - AV)$ $\quad f1 = 22.638$

$f2 := f(AV)$ $\quad f2 = 33.393$

$\psi := \left|\frac{f2}{f1}\right|$ $\quad \psi = 1.475$

$Ww := \frac{(D + t - 2AV)}{\sin(\phi)}$ $\quad Ww = 1.196$

$k := 4 + 2 \cdot (1 + \psi)^3 + 2(1 + \psi)$ $\quad k = 39.276$

$Fcr := k \cdot \frac{\pi^2 E}{12\left(1 - \mu^2\right)} \left(\frac{t}{Ww}\right)^2$ $\quad Fcr = 1.515 \times 10^3$

$\lambda := \sqrt{\frac{f1}{Fcr}}$ $\quad \lambda = 0.122$

< 0.673 Fully Effective

$be := Ww$ $\quad be = 1.196$

EP150 Cellular Deck

(Test No. 78)

$$comp := \frac{(D + t - AV - y\_)}{\sin(\phi)} \qquad comp = 0.51$$

$$b1 := \frac{be}{(3 + \psi)} \qquad b1 = 0.267$$

$$b2 := \frac{be}{2} \qquad b2 = 0.598$$

$$L_3 := 8 \cdot \min[Ww, (Ww - comp + b1 + b2)] \qquad L_3 = 9.569$$

$$y_3 := \frac{(D + t)}{2} \qquad y_3 = 0.813$$

$$I_3 := \left[\left(\frac{\cos\left(\frac{\pi}{2} - \phi\right)^2}{12}\right) \cdot Ww^3\right] \cdot 8 \qquad I_3 = 1.132$$

4. Bottom Arcs:

$$L_4 := 8 \cdot r \cdot \phi \qquad L_4 = 2.525$$

$$y_4 := D + \frac{t}{2} - \left(r - r \cdot \frac{\sin(\phi)}{\phi}\right) \qquad y_4 = 1.533$$

$$I_4 := \left[\left[\frac{(\phi) + \sin(\phi) \cdot \cos(\phi)}{2} - \frac{\sin(\phi)^2}{(\phi)}\right] \cdot r^3\right] \cdot 8 \qquad I_4 = 8.954 \times 10^{-3}$$

EP150 Cellular Deck

(Test No. 78)

5. Stiffened Hat Bottom:

$\frac{Wb}{t} = 40$ $\qquad$ $k := 4$

$Fcr := k \cdot \frac{\pi^2 E}{12(1-\mu^2)} \left(\frac{t}{Wb}\right)^2$ $\qquad$ $Fcr = 66.656$

$f5 := f(D + t)$ $\qquad$ $f5 = 35.469$

$\lambda := \sqrt{\frac{f5}{Fcr}}$ $\qquad$ $\lambda = 0.729$ $\qquad$ > 0.673

$$\rho := \left| \begin{array}{l} \rho \leftarrow 1.0 \ \text{ if } \lambda \le 0.673 \\ \rho \leftarrow \frac{\left(1 - \frac{0.22}{\lambda}\right)}{\lambda} \ \text{ if } \lambda > 0.673 \\ \rho \end{array} \right.$$

$\rho = 0.957$

$L_5 := 3 \cdot Wb \cdot \rho$ $\qquad$ $L_5 = 5.228$

$y_5 := D + \frac{t}{2}$ $\qquad$ $y_5 = 1.603$

$I_5 := 0$

6. Unstiffened Hat Bottom

$\frac{H}{t} = 13.187$ $\qquad$ $k := 0.43$

$Fcr := k \cdot \frac{\pi^2 E}{12(1-\mu^2)} \left(\frac{t}{H}\right)^2$ $\qquad$ $Fcr = 65.931$

$\lambda := \sqrt{\frac{f5}{Fcr}}$ $\qquad$ $\lambda = 0.733$ $\qquad$ > 0.673

$$\rho := \left| \begin{array}{l} \rho \leftarrow 1.0 \ \text{ if } \lambda \le 0.673 \\ \rho \leftarrow \frac{\left(1 - \frac{0.22}{\lambda}\right)}{\lambda} \ \text{ if } \lambda > 0.673 \\ \rho \end{array} \right.$$

$\rho = 0.954$

$L_6 := 2 \cdot H \cdot \rho$ $\qquad$ $L_6 = 1.145$

$I_5 := 0$ $\qquad$ $I_6 := 0$

$y_6 := D + \frac{t}{2}$ $\qquad$ $y_6 = 1.603$

EP150 Cellular Deck

(Test No. 78)

rho_m :

$$Fc := 3.29 \cdot \frac{E}{\left(\frac{s}{tb}\right)^2}$$ $Fc = 5.73$ < f = Fy = 48.5

$k := 4$

$f7 := f(Dt)$ $f7 = 37.723$

$$\rho m := \min\left(8.0 \frac{Fy}{f7} \cdot \sqrt{\frac{tb \cdot Fc}{Dt \cdot f7}}, 1.0\right)$$ $\rho m = 0.604$

7. HL

$$S := 1.28 \sqrt{\frac{E}{f7}}$$ $0.328S = 11.741$

$$\frac{HL}{tb} = 13.015$$ >0.328*S

$$Is := \left(\frac{1}{12}\right)\left(tb \cdot GP\_L^3\right)$$ $Is = 4.575 \times 10^{-3}$

$$Ia := \left|\min\left[399 \cdot tb^4 \cdot \left(\frac{\frac{HL}{tb}}{S} - 0.328\right)^3, tb^4 \cdot \left(115 \cdot \frac{\frac{HL}{tb}}{S} + 5\right)\right]\right|$$ $Ia = 8.134 \times 10^{-8}$

$$RI\_L := \min\left(1, \frac{Is}{Ia}\right)$$ $RI\_L = 1$

$$n := \max\left(0.582 - \frac{\frac{HL}{t}}{4 \cdot S}, \frac{1}{3}\right)$$ $n = 0.49$

$$k := \left|\begin{array}{l} k \leftarrow \min\left[3.57 \cdot \left(RI\_L^n\right) + 0.43, 4\right] \\ k \leftarrow \min\left[\left[4.82 - \frac{5(GP\_L - tb)}{HL}\right] \cdot \left(RI\_L^n\right) + 0.43, 4\right] \text{ if } 140 \geq \theta\_stiff \geq 40 \wedge 0.25 < (GP\_L - tb) < 0.8 \\ k \end{array}\right.$$

EP150 Cellular Deck

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$k = 4$

$$Fcr(w) := k \cdot \frac{\pi^2 E}{12(1-\mu^2)} \left(\frac{tb}{w}\right)^2$$

$Fcr = \text{function}$

$$\lambda := \sqrt{\frac{f7}{Fcr(HL)}}$$

$\lambda = 0.245$ < 0.673

Fully Effective

$$L_7 := HL \cdot \frac{tb}{t}$$

$L_7 = 0.608$

$$y_7 := Dt - \frac{tb}{2}$$

$y_7 = 1.649$

$I_7 := 0$

8. HA

$$\lambda t := \frac{1.052}{(\sqrt{k})} \left(\frac{HA}{tb}\right) \cdot \sqrt{\frac{Fc}{E}}$$

$\lambda t = 0.665$ <0.673

$$\rho t\_HA := \begin{vmatrix} \rho \leftarrow 1.0 \ \text{ if } \ \lambda t \le 0.673 \\ \rho \leftarrow \dfrac{\left(1 - \dfrac{0.22}{\lambda t}\right)}{\lambda t} \ \text{ if } \ \lambda t > 0.673 \\ \rho \end{vmatrix}$$

$\rho t\_HA = 1$

$$\rho\_HA := \begin{vmatrix} \lambda \leftarrow \sqrt{\dfrac{f7}{Fcr(HA)}} \\ \rho \leftarrow \min\left[1, \rho t\_HA \cdot \rho m, \left[\dfrac{\left(1 - \dfrac{0.22}{\lambda}\right)}{\lambda}\right]\right] \\ \rho \end{vmatrix}$$

$$L_8 := HA \cdot \rho\_HA \cdot \frac{tb}{t}$$

$L_8 = 2.163$

$$y_8 := Dt - \frac{tb}{2}$$

$y_8 = 1.649$

$I_8 := 0$

EP150 Cellular Deck

(Test No. 78)

9. HM

$$\lambda t := \frac{1.052}{\left(\sqrt{k}\right)}\left(\frac{HM}{tb}\right)\cdot\sqrt{\frac{Fc}{E}}$$ $\lambda t = 0.665$ <0.673

$$\rho t\_HM := \left| \begin{array}{l} \rho \leftarrow 1.0 \ \text{ if } \ \lambda t \le 0.673 \\ \rho \leftarrow \dfrac{\left(1 - \dfrac{0.22}{\lambda t}\right)}{\lambda t} \ \text{ if } \ \lambda t > 0.673 \\ \rho \end{array} \right.$$ $\rho t\_HM = 1$

$$\rho\_HM := \left| \begin{array}{l} \lambda \leftarrow \sqrt{\dfrac{f7}{Fcr(HM)}} \\ \rho \leftarrow \min\left[1, \rho t\_HM \cdot \rho m, \left[\dfrac{\left(1 - \dfrac{0.22}{\lambda}\right)}{\lambda}\right]\right] \\ \rho \end{array} \right.$$

$$L_9 := 2HM \cdot \rho\_HM \cdot \frac{tb}{t}$$ $L_9 = 4.326$

$$y_9 := Dt - \frac{tb}{2}$$ $y_9 = 1.649$

$$I_9 := 0$$

EP150 Cellular Deck

(Test No. 78)

10. HB

$$\lambda t := \frac{1.052}{\left(\sqrt{k}\right)}\left(\frac{HB}{tb}\right)\cdot\sqrt{\frac{Fc}{E}}$$ $\lambda t = 0.665$ <0.673

$$\rho t\_HB := \left| \begin{array}{l} \rho \leftarrow 1.0 \ \text{ if } \ \lambda t \le 0.673 \\ \rho \leftarrow \dfrac{\left(1 - \dfrac{0.22}{\lambda t}\right)}{\lambda t} \ \text{ if } \ \lambda t > 0.673 \\ \rho \end{array} \right.$$ $\rho t\_HB = 1$

$$\rho\_HB := \left| \begin{array}{l} \lambda \leftarrow \sqrt{\dfrac{f7}{Fcr(HB)}} \\ \rho \leftarrow \min\left[1, \rho t\_HB\cdot\rho m, \left[\dfrac{\left(1 - \dfrac{0.22}{\lambda}\right)}{\lambda}\right]\right] \\ \rho \end{array} \right.$$

$$L_{10} := HB\cdot\rho\_HB\cdot\frac{tb}{t}$$ $L_{10} = 2.163$

$$y_{10} := Dt - \frac{tb}{2}$$ $y_{10} = 1.649$

$$I_{10} := 0$$

11. HR

$$\frac{HR}{tb} = 14.1$$ >0.328*S $0.328\cdot S = 11.741$

$$Is := \left(\frac{1}{12}\right)\left(tb\cdot GP\_R^3\right)$$ $Is = 5.843\times 10^{-3}$

$$Ia := \left|\min\left[399\cdot tb^4\cdot\left(\frac{\frac{HR}{tb}}{S} - 0.328\right)^3, tb^4\cdot\left(115\cdot\frac{\frac{HR}{tb}}{S} + 5\right)\right]\right|$$ $Ia = 5.159\times 10^{-7}$

$$RI\_R := \min\left(1, \frac{Is}{Ia}\right)$$ $RI\_R = 1$

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$$n := \max\left(0.582 - \frac{\frac{HR}{t}}{4 \cdot S}, \frac{1}{3}\right) \qquad n = 0.482$$

$$k := \begin{array}{|l} k \leftarrow \min\left[3.57 \cdot \left(RI\_R^{n}\right) + 0.43, 4\right] \\ k \leftarrow \min\left[\left[4.82 - \frac{5(GP\_R - tb)}{HR}\right] \cdot \left(RI\_R^{n}\right) + 0.43, 4\right] \text{ if } 140 \ge \theta\_stiff \ge 40 \land 0.25 < (GP\_R - tb) < 0.8 \\ k \end{array}$$

$k = 4$

$$Fcr := k \cdot \frac{\pi^2 E}{12\left(1 - \mu^2\right)} \left(\frac{tb}{HR}\right)^2 \qquad Fcr = 536.456$$

$$\lambda := \sqrt{\frac{f7}{Fcr}} \qquad \lambda = 0.265 \qquad < 0.673$$

$$L_{11} := HR \cdot \frac{tb}{t} \qquad L_{11} = 0.659$$

$$y_{11} := Dt - \frac{tb}{2} \qquad y_{11} = 1.649$$

$$I_{11} := 0$$

EP150 Cellular Deck

(Test No. 78)

12. Right Plate Stiffener:

$f12 := f(D)$

$k := 0.43$

$$Fcr := k \cdot \frac{\pi^2 E}{12\left(1 - \mu^2\right)} \left[\frac{tb}{(GP\_R - tb)}\right]^2$$

$Fcr = 19.994$

$$\lambda := \sqrt{\frac{f12}{Fcr}}$$

$\lambda = 1.289$ > 0.673

$$\rho := \frac{\left(1 - \frac{0.22}{\lambda}\right)}{\lambda}$$

$\rho = 0.643$

$d's := (GP\_R - tb) \cdot \rho$

$d's = 0.71$

$ds := d's \cdot RI\_R$

$ds = 0.71$

$$L_{12} := ds \cdot \frac{tb}{t}$$

$L_{12} = 0.719$

$$y_{12} := D + t - \frac{ds}{2}$$

$y_{12} = 1.27$

$$I_{12} := \left(\frac{1}{12}\right) \cdot \left(ds^3\right) \cdot \frac{tb}{t}$$

$I_{12} = 0.03$

EP150 Cellular Deck

(Test No. 78)

13. Left Plate Stiffener:

$f1 := f(Dt)$ $\qquad f1 = 37.723$

$f2 := f(Dt - GP\_R)$ $\qquad f2 = 18.5$

$$\psi := \left|\frac{f2}{f1}\right| \qquad \psi = 0.49$$

$$k := 4 + 2\cdot(1-\psi)^3 + 2(1-\psi) \qquad k = 5.284$$

$$Fcr := k\cdot\frac{\pi^2 E}{12\left(1-\mu^2\right)}\left[\frac{tb}{(GP\_L - tb)}\right]^2 \qquad Fcr = 291.247$$

$$\lambda := \sqrt{\frac{f1}{Fcr}} \qquad \lambda = 0.36 \qquad < 0.673$$ Fully Effective

$be := GP\_L - tb$ $\qquad be = 1.014$

$$b1 := \frac{be}{(3-\psi)} \qquad b1 = 0.404$$

$b2 := be - b1$ $\qquad b2 = 0.61$

$$L_{13} := (b1 + b2)\cdot\frac{tb}{t} \qquad L_{13} = 1.027$$

$$y_{13} := Dt - tb - \frac{GP\_L - tb}{2} \qquad y_{13} = 1.119$$

$$I_{13} := \left(\frac{1}{12}\right)\left(be^3\right)\frac{tb}{t} \qquad I_{13} = 0.088$$

EP150 Cellular Deck

(Test No. 78)

14. Left Plate Lip:

$k := 0.43$

$f14 := f(Dt - GP\_L + HP)$

$f14 = 16.7$

$$Fcr := k \cdot \frac{\pi^2 E}{12\left(1 - \mu^2\right)} \left(\frac{tb}{HP}\right)^2$$

$Fcr = 61.389$

$$\lambda := \sqrt{\frac{f14}{Fcr}}$$

$\lambda = 0.522$ < 0.673

$$\rho := \left| \begin{array}{l} \rho \leftarrow 1.0 \;\; \text{if} \;\; \lambda \le 0.673 \\ \rho \leftarrow \dfrac{\left(1 - \dfrac{0.22}{\lambda}\right)}{\lambda} \;\; \text{if} \;\; \lambda > 0.673 \\ \rho \end{array} \right.$$

$\rho = 1$

$d's := HP \cdot \rho$

$d's = 0.63$

$ds := d's \cdot RI\_L$

$ds = 0.63$

$$L_{14} := ds \cdot \frac{tb}{t}$$

$L_{14} = 0.638$

$$y_{14} := Dt - GP\_L + \frac{ds}{2}$$

$y_{14} = 0.927$

$$I_{14} := \left(\frac{1}{12}\right)\left(ds^3\right)\frac{tb}{t}$$

$I_{14} = 0.021$

EP150 Cellular Deck

(Test No. 78)

Cumulative:

$$\sum_{i=1}^{14} L_i = 46.056$$

$$\sum_{i=1}^{14} (L_i \cdot y_i) = 41.392$$

$$\sum_{i=1}^{14} I_i = 1.289$$

$$\sum_{i=1}^{14} \left[L_i \cdot (y_i)^2\right] = 58.604$$

$$y\_ := \frac{\sum_{i=1}^{14} (L_i \cdot y_i)}{\sum_{i=1}^{14} L_i}$$

$$y\_ = 0.899$$

$$Ix := t \cdot \left[\sum_{i=1}^{14} \left[L_i \cdot (y_i)^2\right] + \sum_{i=1}^{14} I_i - y\_^2 \cdot \sum_{i=1}^{14} L_i\right]$$

$$Ix = 1.033$$

*The ineria is divided by the width (2 feet) to put it in terms of in^4 per foot width

$$\frac{Ix}{2} = 0.516$$

$$Sx\_bot := \frac{Ix}{2 \cdot (Dt - y\_)}$$

$$Sx\_top := \frac{Ix}{2 \cdot y\_}$$

$$Sx := \min(Sx\_bot, Sx\_top)$$

$$Mx := Sx \cdot Fy$$

$$Mx = 25.274$$

EP300 Cellular Deck
(Test No. 46)

Inputs

Deck Dimensions:

$D := 3.04$

$R := .31$

$H := .41$

$\phi := \frac{80.4 \cdot \pi}{180}$

$Wt := 4.5$

$Wb := 1.35$

$t := .0454$

$E := 29500$

$\mu := 0.3$

$r := R + \frac{t}{2}$

$Dt := D + t + tb$

$y\_ := 1.653$

$AV := r \cdot (1 - \cos(\phi)) + \frac{t}{2}$

$AV = 0.3$

Plate Dimensions:

$GP\_L := 1.06$

$HL := .41$

$HA := 6.65$

$HM := 6.65$

$HB := 6.65$

$HR := .42$

$GP\_R := 1.15$

$HP := .6875$

$tb := .0571$

$Fy := 43$

$CW := 24$

$s := 6$

$\theta\_stiff := 90$

$$
f(y) := \left|
\begin{array}{l}
\text{if } y\_ > \frac{Dt}{2} \\
\quad \left|
\begin{array}{l}
f \leftarrow Fy \cdot \left(\frac{y\_ - y}{y\_} \right) \ \text{ if } y < y\_ \\
f \leftarrow \left[Fy \cdot \left(\frac{Dt - y\_}{y\_} \right) \cdot \left(\frac{y - y\_}{Dt - y\_} \right) \right] \ \text{ if } y > y\_
\end{array}
\right. \\
\text{if } y\_ < \frac{Dt}{2} \\
\quad \left|
\begin{array}{l}
f \leftarrow Fy \cdot \left(\frac{y\_}{Dt - y\_} \right) \cdot \left(\frac{y\_ - y}{y\_} \right) \ \text{ if } y < y\_ \\
f \leftarrow Fy \cdot \left(\frac{y - y\_}{Dt - y\_} \right) \ \text{ if } y > y\_
\end{array}
\right. \\
f
\end{array}
\right.
$$

EP300 Cellular Deck
(Test No. 46)

1. Top:

$L_1 := 3 \cdot Wt$ $\qquad L_1 = 13.5$

$y_1 := \dfrac{t}{2}$ $\qquad y_1 = 0.023$ $\qquad I_1 := 0$

2. Top Arcs:

$L_2 := 6r \cdot \phi$ $\qquad L_2 = 2.801$

$$y_2 := \frac{t}{2} + \left(r - r \cdot \frac{\sin(\phi)}{\phi}\right) \qquad y_2 = 0.122$$

$$I_2 := \left[\left[\frac{(\phi) + \sin(\phi) \cdot \cos(\phi)}{2} - \frac{\sin(\phi)^2}{(\phi)}\right] \cdot r^3\right] \cdot 6 \qquad I_2 = 0.02$$

3. Webs:

$f1 := f(D - AV)$ $\qquad f1 = 28.279$

$f2 := f(AV)$ $\qquad f2 = 35.198$

$$\psi := \left|\frac{f2}{f1}\right| \qquad \psi = 1.245$$

$$Ww := \frac{\left[D - 2(r - r \cdot \cos(\phi))\right]}{\sin(\phi)} \qquad Ww = 2.521$$

$$k := 4 + 2 \cdot (1 + \psi)^3 + 2(1 + \psi) \qquad k = 31.11$$

$$Fcr := k \cdot \frac{\pi^2 E}{12\left(1 - \mu^2\right)} \left(\frac{t}{Ww}\right)^2 \qquad Fcr = 269.034$$

$$\lambda := \sqrt{\frac{f1}{Fcr}} \qquad \lambda = 0.324$$

< 0.673 Fully Effective

$be := Ww$ $\qquad be = 2.521$

EP300 Cellular Deck
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$$comp := \frac{(D + t - AV - y\_)}{\sin(\phi)}$$ $comp = 1.149$

$$b1 := \frac{be}{(3 + \psi)}$$ $b1 = 0.594$

$$b2 := \frac{be}{2}$$ $b2 = 1.26$

$$L_3 := 6 \cdot \min[Ww, (Ww - comp + b1 + b2)]$$ $L_3 = 15.125$

$$y_3 := \frac{(D + t)}{2}$$ $y_3 = 1.543$

$$I_3 := \left[\left(\frac{\cos\left(\frac{\pi}{2} - \phi\right)^2}{12}\right) \cdot Ww^3\right] \cdot 6$$ $I_3 = 7.787$

4. Bottom Arcs:

$$L_4 := 6 \cdot r \cdot \phi$$ $L_4 = 2.801$

$$y_4 := D + \frac{t}{2} - \left(r - r \cdot \frac{\sin(\phi)}{\phi}\right)$$ $y_4 = 2.964$

$$I_4 := \left[\left[\frac{(\phi) + \sin(\phi) \cdot \cos(\phi)}{2} - \frac{\sin(\phi)^2}{(\phi)}\right] \cdot r^3\right] \cdot 6$$ $I_4 = 0.02$

EP300 Cellular Deck
(Test No. 46)

5. Stiffened Hat Bottom:

$\frac{Wb}{t} = 29.736$ $\qquad k := 4$

$Fcr := k \cdot \frac{\pi^2 E}{12(1-\mu^2)} \left(\frac{t}{Wb}\right)^2$ $\qquad Fcr = 120.616$

$f5 := f(D + t)$ $\qquad f5 = 37.261$

$\lambda := \sqrt{\frac{f5}{Fcr}}$ $\qquad \lambda = 0.556$ $\qquad$ > 0.673

$$\rho := \begin{array}{|l} \rho \leftarrow 1.0 \ \text{ if } \ \lambda \le 0.673 \\ \rho \leftarrow \frac{\left(1 - \frac{0.22}{\lambda}\right)}{\lambda} \ \text{ if } \ \lambda > 0.673 \\ \rho \end{array}$$

$\rho = 1$

$L_5 := 2 \cdot Wb \cdot \rho$ $\qquad L_5 = 2.7$

$y_5 := D + \frac{t}{2}$ $\qquad y_5 = 3.063$

$I_5 := 0$

6. Unstiffened Hat Bottom

$\frac{H}{t} = 9.031$ $\qquad k := 0.43$

$Fcr := k \cdot \frac{\pi^2 E}{12(1-\mu^2)} \left(\frac{t}{H}\right)^2$ $\qquad Fcr = 140.576$

$\lambda := \sqrt{\frac{f5}{Fcr}}$ $\qquad \lambda = 0.515$ $\qquad$ > 0.673

$$\rho := \begin{array}{|l} \rho \leftarrow 1.0 \ \text{ if } \ \lambda \le 0.673 \\ \rho \leftarrow \frac{\left(1 - \frac{0.22}{\lambda}\right)}{\lambda} \ \text{ if } \ \lambda > 0.673 \\ \rho \end{array}$$

$\rho = 1$

$L_6 := 2 \cdot H \cdot \rho$ $\qquad L_6 = 0.82$

$y_6 := D + \frac{t}{2}$ $\qquad y_6 = 3.063$

EP300 Cellular Deck
(Test No. 46)

$I_6 := 0$

rho_m :

$$Fc := 3.29 \cdot \frac{E}{\left(\frac{s}{tb}\right)^2}$$

$Fc = 8.79$ < f = Fy = 48.5

$k := 4$

$f7 := f(Dt)$

$f7 = 38.747$

$$\rho m := \min\left(1, 8.0 \frac{Fy}{f7} \cdot \sqrt{\frac{tb \cdot Fc}{Dt \cdot f7}}\right)$$

$\rho m = 0.57$

7. HL

$$S := 1.28 \sqrt{\frac{E}{f7}}$$

$0.328S = 11.584$

$$\frac{HL}{tb} = 7.18$$

<0.328*S Fully Effective

Fully Effective

$$L_7 := HL \cdot \frac{tb}{t}$$

$L_7 = 0.516$

$HL = 0.41$

$$y_7 := Dt - \frac{tb}{2}$$

$y_7 = 3.114$

$I_7 := 0$

EP300 Cellular Deck
(Test No. 46)

8. HA

$k := 4.0$

$$Fcr(w) := k \cdot \frac{\pi^2 E}{12\left(1-\mu^2\right)}\left(\frac{tb}{w}\right)^2$$

$$\lambda t := \frac{1.052}{\left(\sqrt{k}\right)}\left(\frac{HA}{tb}\right)\cdot\sqrt{\frac{Fc}{E}} \qquad \lambda t = 1.057$$

$$\rho t\_HA := \left|\begin{array}{l} \rho \leftarrow 1.0 \ \text{ if } \ \lambda t \le 0.673 \\ \rho \leftarrow \dfrac{\left(1-\dfrac{0.22}{\lambda t}\right)}{\lambda t} \ \text{ if } \ \lambda t > 0.673 \\ \rho \end{array}\right. \qquad \rho t\_HA = 0.749$$

$$\rho\_HA := \left|\begin{array}{l} \lambda \leftarrow \sqrt{\dfrac{f7}{Fcr(HA)}} \\ \rho \leftarrow \min\left[1, \rho t\_HA \cdot \rho m, \left[\dfrac{\left(1-\dfrac{0.22}{\lambda}\right)}{\lambda}\right]\right] \\ \rho \end{array}\right.$$

$$L_8 := HA \cdot \rho\_HA \cdot \frac{tb}{t} \qquad L_8 = 3.394$$

$$y_8 := Dt - \frac{tb}{2} \qquad y_8 = 3.114$$

$I_8 := 0$

EP300 Cellular Deck
(Test No. 46)

9. HM

$$\lambda t := \frac{1.052}{\left(\sqrt{k}\right)}\left(\frac{HM}{tb}\right)\cdot\sqrt{\frac{Fc}{E}} \qquad \lambda t = 1.057$$

$$\rho t\_HM := \begin{array}{|l} \rho \leftarrow 1.0 \ \text{ if } \ \lambda t \le 0.673 \\ \rho \leftarrow \dfrac{\left(1 - \dfrac{0.22}{\lambda t}\right)}{\lambda t} \ \text{ if } \ \lambda t > 0.673 \\ \rho \end{array} \qquad \rho t\_HM = 0.749$$

$$\rho\_HM := \begin{array}{|l} \lambda \leftarrow \sqrt{\dfrac{f7}{Fcr(HM)}} \\ \rho \leftarrow \min\left[1, \rho t\_HM\cdot \rho m, \left[\dfrac{\left(1 - \dfrac{0.22}{\lambda}\right)}{\lambda}\right]\right] \\ \rho \end{array}$$

$$L_9 := HM\cdot \rho\_HM\cdot \frac{tb}{t} \qquad L_9 = 3.394$$

$$y_9 := Dt - \frac{tb}{2} \qquad y_9 = 3.114$$

$$I_9 := 0$$

EP300 Cellular Deck
(Test No. 46)

10. HB

$$\lambda t := \frac{1.052}{\left(\sqrt{k}\right)}\left(\frac{HB}{tb}\right)\cdot\sqrt{\frac{Fc}{E}}$$ $\lambda t = 1.057$

$$\rho t\_HB := \begin{array}{|l} \rho \leftarrow 1.0 \text{ if } \lambda t \le 0.673 \\ \rho \leftarrow \dfrac{\left(1 - \dfrac{0.22}{\lambda t}\right)}{\lambda t} \text{ if } \lambda t > 0.673 \\ \rho \end{array}$$ $\rho t\_HB = 0.749$

$$\rho\_HB := \begin{array}{|l} \lambda \leftarrow \sqrt{\dfrac{f7}{Fcr(HB)}} \\ \rho \leftarrow \min\left[1, \rho t\_HB\cdot \rho m, \left[\dfrac{\left(1 - \dfrac{0.22}{\lambda}\right)}{\lambda}\right]\right] \\ \rho \end{array}$$

$L_{10} := HB\cdot\rho\_HB\cdot\dfrac{tb}{t}$ $L_{10} = 3.394$

$y_{10} := Dt - \dfrac{tb}{2}$ $y_{10} = 3.114$

$I_{10} := 0$

11. HR

$\dfrac{HR}{tb} = 7.356$ $0.328\cdot S = 11.584$

Fully Effective

$L_{11} := HR\cdot\dfrac{tb}{t}$ $L_{11} = 0.528$

$y_{11} := Dt - \dfrac{tb}{2}$ $y_{11} = 3.114$

$I_{11} := 0$

EP300 Cellular Deck
(Test No. 46)

12. Left Plate Stiffener:

$f12 := f(D)$ $\qquad$ $k := 0.43$

$$Fcr := k \cdot \frac{\pi^2 E}{12\left(1 - \mu^2\right)} \left[\frac{tb}{(GP\_L - tb)}\right]^2 \qquad Fcr = 37.164$$

$$\lambda := \sqrt{\frac{f12}{Fcr}} \qquad \lambda = 0.985 \qquad > 0.673$$

$$\rho := \frac{\left(1 - \frac{0.22}{\lambda}\right)}{\lambda} \qquad \rho = 0.788$$

$$Is := \left(\frac{1}{12}\right)\left(tb \cdot GP\_L^3\right) \qquad Is = 5.667 \times 10^{-3}$$

$$Ia := 0 \qquad Ia = 0$$

$$RI := 1 \qquad RI = 1$$

$$d's := (GP\_L - tb) \cdot \rho \qquad d's = 0.791$$

$$ds := d's \cdot RI \qquad ds = 0.791$$

$$L_{12} := ds \cdot \frac{tb}{t} \qquad L_{12} = 0.994$$

$$y_{12} := D + t - \frac{ds}{2} \qquad y_{12} = 2.69$$

$$I_{12} := \left(\frac{1}{12}\right) \cdot \left(ds^3\right) \cdot \frac{tb}{t} \qquad I_{12} = 0.052$$

EP300 Cellular Deck
(Test No. 46)

13. Right Plate Stiffener:

$f1 := f(Dt)$ $\quad$ $f1 = 38.747$

$f2 := f(Dt - GP\_R)$ $\quad$ $f2 = 8.832$

$\psi := \left|\frac{f2}{f1}\right|$ $\quad$ $\psi = 0.228$

$k := 4 + 2\cdot(1-\psi)^3 + 2(1-\psi)$ $\quad$ $k = 6.465$

$Fcr := k\cdot\frac{\pi^2 E}{12(1-\mu^2)}\left[\frac{tb}{(GP\_R - tb)}\right]^2$ $\quad$ $Fcr = 470.492$

$\lambda := \sqrt{\frac{f1}{Fcr}}$ $\quad$ $\lambda = 0.287$

< 0.673 Fully Effective

$be := GP\_R - tb$ $\quad$ $be = 1.093$

$b1 := \frac{be}{(3-\psi)}$ $\quad$ $b1 = 0.394$

$b2 := be - b1$ $\quad$ $b2 = 0.699$

$L_{13} := (b1 + b2)\cdot\frac{tb}{t}$ $\quad$ $L_{13} = 1.375$

$y_{13} := Dt - tb - \frac{GP\_R - tb}{2}$ $\quad$ $y_{13} = 2.539$

$I_{13} := \left(\frac{1}{12}\right)\left(be^3\right)\frac{tb}{t}$ $\quad$ $I_{13} = 0.137$

EP300 Cellular Deck
(Test No. 46)

14. Right Plate Lip:

$k := 0.43$

$f14 := f(Dt - GP\_R + HP)$

$f14 = 26.716$

$$Fcr := k \cdot \frac{\pi^2 E}{12\left(1-\mu^2\right)}\left(\frac{tb}{HP}\right)^2$$

$Fcr = 79.085$

$$\lambda := \sqrt{\frac{f14}{Fcr}}$$

$\lambda = 0.581$ < 0.673

$d's := HP$

$d's = 0.688$

$ds := d's \cdot RI$

$ds = 0.688$

$$L_{14} := ds \cdot \frac{tb}{t}$$

$L_{14} = 0.865$

$$y_{14} := Dt - GP\_L + \frac{ds}{2}$$

$y_{14} = 2.426$

$$I_{14} := \left(\frac{1}{12}\right)\left(ds^3\right)\frac{tb}{t}$$

$I_{14} = 0.034$

EP300 Cellular Deck
(Test No. 46)

Cumulative:

$$\sum_{i=1}^{14} L_i = 52.208 \qquad \sum_{i=1}^{14} \left(L_i \cdot y_i\right) = 86.286 \qquad \sum_{i=1}^{14} \left[L_i \cdot \left(y_i\right)^2\right] = 223.678$$

$$\sum_{i=1}^{14} I_i = 8.05$$

$$y\_ := \frac{\sum_{i=1}^{14} \left(L_i \cdot y_i\right)}{\sum_{i=1}^{14} L_i} \qquad y\_ = 1.653$$

$$Ix := t \cdot \left[\sum_{i=1}^{14} \left[L_i \cdot \left(y_i\right)^2\right] + \sum_{i=1}^{14} I_i - y\_^2 \cdot \sum_{i=1}^{14} L_i\right] \qquad Ix = 4.046$$

*The ineria is divided by the width (2 feet) to put it in terms of in^4 per foot width

$$\frac{Ix}{2} = 2.023 \qquad Sx\_bot := \frac{Ix}{2 \cdot (Dt - y\_)} \qquad Sx\_top := \frac{Ix}{2 \cdot y\_}$$

$$Sx := \min(Sx\_bot, Sx\_top)$$

$$Mx := Sx \cdot Fy \qquad Mx = 52.634$$

EP450 Cellular Deck
(Test No. 53)

Inputs

Deck Dimensions:

$D := 4.65$

$R := .12$

$H := .46$

$\phi := \frac{89 \cdot \pi}{180}$

$Wt := 8.49$

$TO := 2.97$

$Wb := 8.49$

$t := .048$

$E := 29500$

$\mu := 0.3$

$r := R + \frac{t}{2}$

$Dt := D + t + tb$

$y\_ := 1.955$

$AV := r \cdot (1 - \cos(\phi)) + \frac{t}{2}$

$AV = 0.165$

Plate Dimensions:

$GP\_L := 1.06$

$HL := 0.79$

$HA := 9.90$

$HM := 2.62$

$HB := 9.9$

$HR := 0.79$

$GP\_R := 1.15$

$HP := 0.63$

$tb := .0458$

$Fy := 43$

$CW := 24$

$s := 4$

$\theta\_stiff := 90$

Upper Stiffener

$RS := 0.13$

$DTS := 0.5$

$TS := 1.27$

$\phi\_stiff := \frac{45.5\pi}{180}$

$rs := RS + \frac{t}{2}$

$AVs := rs \cdot (1 - \cos(\phi\_stiff)) + \frac{t}{2}$

$AVs = 0.07$

$$f(y) := \left| \begin{array}{l} \text{if } y\_ > \frac{Dt}{2} \\ \quad \left| \begin{array}{l} f \leftarrow Fy \cdot \left(\frac{y\_ - y}{y\_} \right) \text{ if } y < y\_ \\ f \leftarrow \left[Fy \cdot \left(\frac{Dt - y\_}{y\_} \right) \cdot \left(\frac{y - y\_}{Dt - y\_} \right) \right] \text{ if } y > y\_ \end{array} \right. \\ \text{if } y\_ < \frac{Dt}{2} \\ \quad \left| \begin{array}{l} f \leftarrow Fy \cdot \left(\frac{y\_}{Dt - y\_} \right) \cdot \left(\frac{y\_ - y}{y\_} \right) \text{ if } y < y\_ \\ f \leftarrow Fy \cdot \left(\frac{y - y\_}{Dt - y\_} \right) \text{ if } y > y\_ \end{array} \right. \\ f \end{array} \right.$$

EP450 Cellular Deck
(Test No. 53)

1. TO:

$L_1 := 4 \cdot TO$ $\quad L_1 = 11.88$

$y_1 := \frac{t}{2}$ $\quad y_1 = 0.024$ $\quad I_1 := 0$

2. Top Web Arcs:

$L_2 := 4r \cdot \phi$ $\quad L_2 = 0.895$

$$y_2 := \frac{t}{2} + \left(r - r \cdot \frac{\sin(\phi)}{\phi}\right) \qquad y_2 = 0.075$$

$$I_2 := \left[\left[\frac{(\phi) + \sin(\phi) \cdot \cos(\phi)}{2} - \frac{\sin(\phi)^2}{(\phi)}\right] \cdot r^3\right] \cdot 4 \qquad I_2 = 1.694 \times 10^{-3}$$

3. TS

$L_3 := 2 \cdot TS$ $\quad L_3 = 2.54$

$$y_2 := DTS + \frac{t}{2} \qquad y_2 = 0.524$$

$I_3 := 0$

4. Top Stiffener Top Arcs

$L_4 := 4rs \cdot \phi\_stiff$ $\quad L_4 = 0.489$

$$y_4 := \frac{t}{2} + \left(rs - rs \cdot \frac{\sin(\phi\_stiff)}{\phi\_stiff}\right) \qquad y_4 = 0.04$$

$$I_4 := \left[\left[\frac{(\phi\_stiff) + \sin(\phi\_stiff) \cdot \cos(\phi\_stiff)}{2} - \frac{\sin(\phi\_stiff)^2}{(\phi\_stiff)}\right] \cdot rs^3\right] \cdot 4 \qquad I_4 = 9.367 \times 10^{-5}$$

EP450 Cellular Deck
(Test No. 53)

5. Top Stiffener Bottom Arc

$$L_5 := 4rs \cdot \phi\_stiff \qquad L_5 = 0.489$$

$$y_5 := DTS + t - \frac{t}{2} - \left(rs - rs \cdot \frac{\sin(\phi\_stiff)}{\phi\_stiff}\right) \qquad y_5 = 0.508$$

$$I_5 := \left[\left[\frac{(\phi\_stiff) + \sin(\phi\_stiff)\cdot\cos(\phi\_stiff)}{2} - \frac{\sin(\phi\_stiff)^2}{(\phi\_stiff)}\right]\cdot rs^3\right]\cdot 4 \qquad I_5 = 9.367 \times 10^{-5}$$

6. Top Stiffener Webs

$$f1 := f(AVs) \qquad f1 = 29.064$$

$$f2 := f(DTS + t - AVs) \qquad f2 = 22.775$$

$$\psi := \left|\frac{f2}{f1}\right| \qquad \psi = 0.784$$

$$Ww := \frac{(DTS + t - 2AVs)}{\sin(\phi\_stiff)} \qquad Ww = 0.572$$

$$L_6 := 4 \cdot Ww \qquad L_6 = 2.287$$

$$y_6 := \frac{(DTS + t)}{2} \qquad y_6 = 0.274$$

$$I_6 := \left[\left(\frac{\cos\left(\frac{\pi}{2} - \phi\_stiff\right)^2}{12}\right)\cdot Ww^3\right]\cdot 4 \qquad I_6 = 0.032$$

EP450 Cellular Deck
(Test No. 53)

7. Webs:

$f1 := f(D - AV)$ $\qquad$ $f1 = 39.002$

$f2 := f(AV)$ $\qquad$ $f2 = 27.592$

$\psi := \left|\frac{f2}{f1}\right|$ $\qquad$ $\psi = 0.707$

$Ww := \frac{(D + t - 2AV)}{\sin(\phi)}$ $\qquad$ $Ww = 4.368$

$k := 4 + 2\cdot(1 + \psi)^3 + 2(1 + \psi)$ $\qquad$ $k = 17.371$

$Fcr := k\cdot\frac{\pi^2 E}{12(1 - \mu^2)}\left(\frac{t}{Ww}\right)^2$ $\qquad$ $Fcr = 55.937$

$\lambda := \sqrt{\frac{f1}{Fcr}}$ $\qquad$ $\lambda = 0.835$ $\qquad$ > 0.673 $\qquad$ Not Fully Effective

$\rho := \frac{\left(1 - \frac{0.22}{\lambda}\right)}{\lambda}$ $\qquad$ $\rho = 0.882$

$comp := \frac{(D + t - AV - y\_)}{\sin(\phi)}$ $\qquad$ $comp = 2.578$

$be := Ww\cdot\rho$ $\qquad$ $be = 3.853$

$b1 := \frac{be}{(3 + \psi)}$ $\qquad$ $b1 = 1.039$

$b2 := \frac{be}{2}$ $\qquad$ $b2 = 1.926$

$L_7 := 4\cdot\min[Ww, (Ww - comp + b1 + b2)]$ $\qquad$ $L_7 = 17.471$

$y_7 := \frac{(D + t)}{2}$ $\qquad$ $y_7 = 2.349$

$I_7 := \left[\left(\frac{\cos\left(\frac{\pi}{2} - \phi\right)^2}{12}\right)\cdot\left(\frac{L_7}{4}\right)^3\right]\cdot 4$ $\qquad$ $I_7 = 27.765$

EP450 Cellular Deck
(Test No. 53)

8. Bottom Web Arcs:

$$L_8 := 4 \cdot r \cdot \phi$$ $$L_8 = 0.895$$

$$y_8 := D + \frac{t}{2} - \left(r - r \cdot \frac{\sin(\phi)}{\phi}\right)$$ $$y_8 = 4.623$$

$$I_8 := \left[\left[\frac{(\phi) + \sin(\phi) \cdot \cos(\phi)}{2} - \frac{\sin(\phi)^2}{(\phi)}\right] \cdot r^3\right] \cdot 4$$ $$I_8 = 1.694 \times 10^{-3}$$

9. Unstiffened Hat Bottom

$$f9 := f(D + t)$$ $$f9 = 42.294$$

$$\frac{H}{t} = 9.583$$ $$k := 0.43$$

$$Fcr := k \cdot \frac{\pi^2 E}{12\left(1 - \mu^2\right)}\left(\frac{t}{H}\right)^2$$ $$Fcr = 124.834$$

$$\lambda := \sqrt{\frac{f9}{Fcr}}$$ $$\lambda = 0.582$$ < 0.673

$$L_9 := 4 \cdot H$$ $$L_9 = 1.84$$

$$y_9 := D + \frac{t}{2}$$ $$y_9 = 4.674$$

$$I_9 := 0$$

rho_m :

$$Fc := 3.29 \cdot \frac{E}{\left(\frac{s}{tb}\right)^2}$$ $$Fc = 12.724$$ < f = Fy = 48.5

$$k := 4$$

$$f10 := f(Dt)$$ $$f10 = 43$$

$$\rho m := \min\left(1, 8.0 \frac{Fy}{f10} \cdot \sqrt{\frac{tb \cdot Fc}{Dt \cdot f10}}\right)$$ $$\rho m = 0.428$$

EP450 Cellular Deck
(Test No. 53)

10. HL

$$S := 1.28\sqrt{\frac{E}{f10}}$$ $0.328S = 10.997$

$$\frac{HL}{tb} = 17.249$$ >0.328*S

$$Is := \left(\frac{1}{12}\right)\left(tb \cdot GP\_L^3\right)$$ $Is = 4.546 \times 10^{-3}$

$$Ia := \min\left[399 \cdot tb^4 \cdot \left(\frac{\frac{HL}{tb}}{S} - 0.328\right)^3, tb^4 \cdot \left(115 \cdot \frac{\frac{HL}{tb}}{S} + 5\right)\right]$$ $Ia = 1.139 \times 10^{-5}$

$$RI\_L := \min\left(1, \frac{Is}{Ia}\right)$$ $RI\_L = 1$

$$n := \max\left(0.582 - \frac{\frac{HL}{t}}{4 \cdot S}, \frac{1}{3}\right)$$ $n = 0.459$

$$k := \left| \begin{array}{l} k \leftarrow \min\left[3.57 \cdot \left(RI\_L^n\right) + 0.43, 4\right] \\ k \leftarrow \min\left[\left[4.82 - \frac{5(GP\_L - tb)}{HL}\right] \cdot \left(RI\_L^n\right) + 0.43, 4\right] \text{ if } 140 \ge \theta\_stiff \ge 40 \wedge 0.25 < (GP\_L - tb) < 0.8 \\ k \end{array} \right.$$

$k = 4$

$$Fcr(w) := k \cdot \frac{\pi^2 E}{12\left(1 - \mu^2\right)} \left(\frac{tb}{w}\right)^2$$ $Fcr = \text{function}$

$$\lambda := \sqrt{\frac{f10}{Fcr(HL)}}$$ $\lambda = 0.346$

< 0.673

Fully Effective

$$L_{10} := HL \cdot \frac{tb}{t}$$ $L_{10} = 0.754$

$$y_{10} := Dt - \frac{tb}{2}$$ $y_{10} = 4.721$

$$I_{10} := 0$$

EP450 Cellular Deck
(Test No. 53)

11. HA

$$\lambda t := \frac{1.052}{\left(\sqrt{k}\right)}\left(\frac{HA}{tb}\right)\cdot\sqrt{\frac{Fc}{E}}$$ $\lambda t = 2.361$ >0.673

$$\rho t\_HA := \left|\begin{array}{l} \rho \leftarrow 1.0 \ \text{ if } \ \lambda t \le 0.673 \\ \rho \leftarrow \dfrac{\left(1 - \dfrac{0.22}{\lambda t}\right)}{\lambda t} \ \text{ if } \ \lambda t > 0.673 \\ \rho \end{array}\right.$$ $\rho t\_HA = 0.384$

$$\rho\_HA := \left|\begin{array}{l} \lambda \leftarrow \sqrt{\dfrac{f10}{Fcr(HA)}} \\ \rho \leftarrow \min\left[1, \rho t\_HA\cdot\rho m, \left[\dfrac{\left(1 - \dfrac{0.22}{\lambda}\right)}{\lambda}\right]\right] \\ \rho \end{array}\right.$$ $\rho\_HA = 0.164$

$$L_{11} := HA\cdot\rho\_HA\cdot\frac{tb}{t}$$ $L_{11} = 1.551$

$$y_{11} := Dt - \frac{tb}{2}$$ $y_{11} = 4.721$

$$I_{11} := 0$$

EP450 Cellular Deck
(Test No. 53)

12. HM

$$\lambda t := \frac{1.052}{\left(\sqrt{k}\right)}\left(\frac{HM}{tb}\right)\cdot\sqrt{\frac{Fc}{E}}$$

$\lambda t = 0.625$ <0.673

$$\rho t\_HM := \left| \begin{array}{l} \rho \leftarrow 1.0 \text{ if } \lambda t \le 0.673 \\ \rho \leftarrow \dfrac{\left(1 - \dfrac{0.22}{\lambda t}\right)}{\lambda t} \text{ if } \lambda t > 0.673 \\ \rho \end{array} \right.$$

$\rho t\_HM = 1$

$$\rho\_HM := \left| \begin{array}{l} \lambda \leftarrow \sqrt{\dfrac{f10}{Fcr(HM)}} \\ \rho \leftarrow \min\left[1, \rho t\_HM\cdot \rho m, \left[\dfrac{\left(1 - \dfrac{0.22}{\lambda}\right)}{\lambda}\right]\right] \\ \rho \end{array} \right.$$

$\rho\_HM = 0.428$

$L_{12} := 1HM\cdot\rho\_HM\cdot\dfrac{tb}{t}$ $\qquad L_{12} = 1.069$

$y_{12} := Dt - \dfrac{tb}{2}$ $\qquad y_{12} = 4.721$

$I_{12} := 0$

13. HB

$$\lambda t := \frac{1.052}{\left(\sqrt{k}\right)}\left(\frac{HB}{tb}\right)\cdot\sqrt{\frac{Fc}{E}}$$

$\lambda t = 2.361$ >0.673

$$\rho t\_HB := \left| \begin{array}{l} \rho \leftarrow 1.0 \text{ if } \lambda t \le 0.673 \\ \rho \leftarrow \dfrac{\left(1 - \dfrac{0.22}{\lambda t}\right)}{\lambda t} \text{ if } \lambda t > 0.673 \\ \rho \end{array} \right.$$

$\rho t\_HB = 0.384$

EP450 Cellular Deck
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$$\rho\_HB := \begin{array}{|l} \lambda \leftarrow \sqrt{\dfrac{f10}{Fcr(HB)}} \\ \rho \leftarrow \min\left[1, \rho t\_HB \cdot \rho m, \left[\dfrac{\left(1-\dfrac{0.22}{\lambda}\right)}{\lambda}\right]\right] \\ \rho \end{array}$$

$\rho\_HB = 0.164$

$$L_{13} := HB \cdot \rho\_HB \cdot \frac{tb}{t}$$ $L_{13} = 1.551$

$$y_{13} := Dt - \frac{tb}{2}$$ $y_{13} = 4.721$

$$I_{13} := 0$$

14. HR

$\dfrac{HR}{tb} = 17.249$ >0.328*S $0.328 \cdot S = 10.997$

$$Is := \left(\frac{1}{12}\right)\left(tb \cdot GP\_R^3\right)$$ $Is = 5.805 \times 10^{-3}$

$$Ia := \min\left[399 \cdot tb^4 \cdot \left(\frac{\frac{HR}{tb}}{S} - 0.328\right)^3, tb^4 \cdot \left(115 \cdot \frac{\frac{HR}{tb}}{S} + 5\right)\right]$$ $Ia = 1.139 \times 10^{-5}$

$$RI\_R := \min\left(1, \frac{Is}{Ia}\right)$$ $RI\_R = 1$

$$n := \max\left(0.582 - \frac{\frac{HR}{t}}{4 \cdot S}, \frac{1}{3}\right)$$ $n = 0.459$

$$k := \begin{array}{|l} k \leftarrow \min\left[3.57 \cdot \left(RI\_R^n\right) + 0.43, 4\right] \\ k \leftarrow \min\left[\left[4.82 - \dfrac{5(GP\_R - tb)}{HR}\right] \cdot \left(RI\_R^n\right) + 0.43, 4\right] \text{ if } 140 \ge \theta\_stiff \ge 40 \wedge 0.25 < (GP\_R - tb) < 0.8 \\ k \end{array}$$

EP450 Cellular Deck
(Test No. 53)

$k = 4$

$$Fcr := k \cdot \frac{\pi^2 E}{12(1-\mu^2)} \left(\frac{tb}{HR}\right)^2 \qquad Fcr = 358.456$$

$$\lambda := \sqrt{\frac{f10}{Fcr}} \qquad \lambda = 0.346 \quad < 0.673$$

$$L_{14} := HR \cdot \frac{tb}{t} \qquad L_{14} = 0.754$$

$$y_{14} := Dt - \frac{tb}{2} \qquad y_{14} = 4.721$$

$$I_{14} := 0$$

15. Left Plate Stiffener:

$$f1 := f(Dt) \qquad f1 = 43$$

$$f2 := f(Dt - GP\_L) \qquad f2 = 26.656$$

$$\psi := \left|\frac{f2}{f1}\right| \qquad \psi = 0.62$$

$$k := 4 + 2 \cdot (1-\psi)^3 + 2(1-\psi) \qquad k = 4.87$$

$$Fcr := k \cdot \frac{\pi^2 E}{12(1-\mu^2)} \left[\frac{tb}{(GP\_L - tb)}\right]^2 \qquad Fcr = 264.797$$

$$\lambda := \sqrt{\frac{f1}{Fcr}} \qquad \lambda = 0.403 \quad < 0.673$$ Fully Effective

$$be := GP\_L - tb \qquad be = 1.014$$

$$b1 := \frac{be}{(3-\psi)} \qquad b1 = 0.426$$

$$b2 := be - b1 \qquad b2 = 0.588$$

$L_{15} := (b1 + b2)\cdot\dfrac{tb}{t}$ $\qquad L_{15} = 0.968$

$y_{15} := Dt - tb - \dfrac{GP\_L - tb}{2}$ $\qquad y_{15} = 4.191$

$I_{15} := \left(\dfrac{1}{12}\right)\left(be^3\right)\dfrac{tb}{t}$ $\qquad I_{15} = 0.083$

16. Right Plate Stiffener:

$f12 := f(D)$ $\qquad k := 0.43$

$Fcr := k\cdot\dfrac{\pi^2 E}{12\left(1-\mu^2\right)}\left[\dfrac{tb}{(GP\_R - tb)}\right]^2$ $\qquad Fcr = 19.724$

$\lambda := \sqrt{\dfrac{f12}{Fcr}}$ $\qquad \lambda = 1.451$ $\qquad > 0.673$

$$\rho := \begin{array}{|l} \rho \leftarrow 1.0 \ \text{ if } \ \lambda \le 0.673 \\ \rho \leftarrow \dfrac{\left(1 - \dfrac{0.22}{\lambda}\right)}{\lambda} \ \text{ if } \ \lambda > 0.673 \\ \rho \end{array}$$

$\rho = 0.585$

$d's := (GP\_R - tb)\cdot\rho$ $\qquad d's = 0.645$

$ds := d's\cdot RI\_R$ $\qquad ds = 0.645$

$L_{16} := ds\cdot\dfrac{tb}{t}$ $\qquad L_{16} = 0.616$

$y_{16} := D + t - \dfrac{ds}{2}$ $\qquad y_{16} = 4.375$

$I_{16} := \left(\dfrac{1}{12}\right)\cdot\left(ds^3\right)\cdot\dfrac{tb}{t}$ $\qquad I_{16} = 0.021$

EP450 Cellular Deck
(Test No. 53)

17. Left Plate Lip:

$k := 0.43$

$f14 := f(Dt - GP\_L + HP)$

$f14 = 36.37$

$$Fcr := k \cdot \frac{\pi^2 E}{12\left(1-\mu^2\right)} \left(\frac{tb}{HP}\right)^2$$

$Fcr = 60.592$

$$\lambda := \sqrt{\frac{f14}{Fcr}}$$

$\lambda = 0.775$ > 0.673

$$\rho := \left| \begin{array}{l} \rho \leftarrow 1.0 \;\text{ if }\; \lambda \le 0.673 \\ \rho \leftarrow \dfrac{\left(1 - \dfrac{0.22}{\lambda}\right)}{\lambda} \;\text{ if }\; \lambda > 0.673 \\ \rho \end{array} \right.$$

$\rho = 0.924$

$d's := (HP - tb) \cdot \rho$

$d's = 0.54$

$ds := d's \cdot RI\_L$

$ds = 0.54$

$$L_{17} := ds \cdot \frac{tb}{t}$$

$L_{17} = 0.515$

$$y_{17} := Dt - GP\_L + \frac{ds}{2}$$

$y_{17} = 3.954$

$$I_{17} := \left(\frac{1}{12}\right)\left(ds^3\right)\frac{tb}{t}$$

$I_{17} = 0.013$

EP450 Cellular Deck
(Test No. 53)

Cumulative:

$$\sum_{i=1}^{17} L_i = 46.564 \qquad \sum_{i=1}^{17} \left(L_i \cdot y_i\right) = 91.021 \qquad \sum_{i=1}^{17} \left[L_i \cdot \left(y_i\right)^2\right] = 319.674$$

$$\sum_{i=1}^{17} I_i = 27.917$$

$$y\_ := \frac{\displaystyle\sum_{i=1}^{17} \left(L_i \cdot y_i\right)}{\displaystyle\sum_{i=1}^{17} L_i} \qquad y\_ = 1.955$$

$$Ix := t \cdot \left[\sum_{i=1}^{17} \left[L_i \cdot \left(y_i\right)^2\right] + \sum_{i=1}^{17} I_i - y\_^2 \cdot \sum_{i=1}^{17} L_i\right] \qquad Ix = 8.144$$

*The ineria is divided by the width (2 feet) to put it in terms of in^4 per foot width

$$\frac{Ix}{2} = 4.072 \qquad Sx\_bot := \frac{Ix}{2 \cdot (Dt - y\_)} \qquad Sx\_top := \frac{Ix}{2 \cdot y\_}$$

$$Sx := \min(Sx\_bot, Sx\_top) \qquad Sx = 1.46$$

$$Mx := Sx \cdot Fy \qquad Mx = 62.781$$

EP750 Cellular Deck
(Test No. 66)

Inputs

Deck Dimensions:

$D := 7.65$

$R := .12$

$H := .55$

$\phi := \frac{89 \cdot \pi}{180}$

$Wt := 8.49$

$TO := 2.97$

$Wb := 8.49$

$t := .0455$

$E := 29500$

$\mu := 0.3$

$r := R + \frac{t}{2}$

$Dt := D + t + tb$

$y\_ := 3.05$

$AV := r \cdot (1 - \cos(\phi)) + \frac{t}{2}$

$AV = 0.163$

Plate Dimensions:

$GP\_L := 1.06$

$HL := 0.79$

$HA := 9.9$

$HM := 3.3$

$HB := 9.90$

$HR := 0.79$

$GP\_R := 1.15$

$HP := 0.63$

$tb := .0458$

$Fy := 44$

$CW := 24$

$s := 4$

$\theta\_stiff := 90$

Upper Stiffener

$RS := 0.13$

$DTS := 0.50$

$TS := 1.27$

$\phi\_stiff := \frac{45.5\pi}{180}$

$rs := RS + \frac{t}{2}$

$AVs := rs \cdot (1 - \cos(\phi\_stiff)) + \frac{t}{2}$

$AVs = 0.068$

$$f(y) := \left| \begin{array}{l} \text{if } y\_ > \frac{Dt}{2} \\ \quad \left| \begin{array}{l} f \leftarrow Fy \cdot \left(\frac{y\_ - y}{y\_}\right) \text{ if } y < y\_ \\ f \leftarrow \left[Fy \cdot \left(\frac{Dt - y\_}{y\_}\right) \cdot \left(\frac{y - y\_}{Dt - y\_}\right)\right] \text{ if } y > y\_ \end{array} \right. \\ \text{if } y\_ < \frac{Dt}{2} \\ \quad \left| \begin{array}{l} f \leftarrow Fy \cdot \left(\frac{y\_}{Dt - y\_}\right) \cdot \left(\frac{y\_ - y}{y\_}\right) \text{ if } y < y\_ \\ f \leftarrow Fy \cdot \left(\frac{y - y\_}{Dt - y\_}\right) \text{ if } y > y\_ \end{array} \right. \\ f \end{array} \right.$$

EP750 Cellular Deck
(Test No. 66)

1. TO:

$L_1 := 4 \cdot TO$ $\qquad L_1 = 11.88$

$y_1 := \frac{t}{2}$ $\qquad y_1 = 0.023$

$I_1 := 0$

2. Top Web Arcs:

$L_2 := 4r \cdot \phi$ $\qquad L_2 = 0.887$

$$y_2 := \frac{t}{2} + \left(r - r \cdot \frac{\sin(\phi)}{\phi}\right) \qquad y_2 = 0.074$$

$$I_2 := \left[\left[\frac{(\phi) + \sin(\phi) \cdot \cos(\phi)}{2} - \frac{\sin(\phi)^2}{(\phi)}\right] \cdot r^3\right] \cdot 4 \qquad I_2 = 1.65 \times 10^{-3}$$

3. TS

$L_3 := 2 \cdot TS$ $\qquad L_3 = 2.54$

$y_2 := DTS + \frac{t}{2}$ $\qquad y_2 = 0.523$

$I_3 := 0$

4. Top Stiffener Top Arcs

$L_4 := 4rs \cdot \phi\_stiff$ $\qquad L_4 = 0.485$

$$y_4 := \frac{t}{2} + \left(rs - rs \cdot \frac{\sin(\phi\_stiff)}{\phi\_stiff}\right) \qquad y_4 = 0.038$$

$$I_4 := \left[\left[\frac{(\phi\_stiff) + \sin(\phi\_stiff) \cdot \cos(\phi\_stiff)}{2} - \frac{\sin(\phi\_stiff)^2}{(\phi\_stiff)}\right] \cdot rs^3\right] \cdot 4 \qquad I_4 = 9.141 \times 10^{-5}$$

EP750 Cellular Deck
(Test No. 66)

5. Top Stiffener Bottom Arc

$$L_5 := 4rs\cdot\phi\_stiff \qquad L_5 = 0.485$$

$$y_5 := DTS + t - \frac{t}{2} - \left(rs - rs\cdot\frac{\sin(\phi\_stiff)}{\phi\_stiff}\right) \qquad y_5 = 0.507$$

$$I_5 := \left[\left[\frac{(\phi\_stiff) + \sin(\phi\_stiff)\cdot\cos(\phi\_stiff)}{2} - \frac{\sin(\phi\_stiff)^2}{(\phi\_stiff)}\right]\cdot rs^3\right]\cdot 4 \qquad I_5 = 9.141\times 10^{-5}$$

6. Top Stiffener Webs

$$f1 := f(AVs) \qquad f1 = 27.964$$

$$f2 := f(DTS + t - AVs) \qquad f2 = 24.132$$

$$\psi := \left|\frac{f2}{f1}\right| \qquad \psi = 0.863$$

$$Ww := \frac{(DTS + t - 2AVs)}{\sin(\phi\_stiff)} \qquad Ww = 0.573$$

$$L_6 := 4\cdot Ww \qquad L_6 = 2.292$$

$$y_6 := \frac{(DTS + t)}{2} \qquad y_6 = 0.273$$

$$I_6 := \left[\left(\frac{\cos\left(\frac{\pi}{2} - \phi\_stiff\right)^2}{12}\right)\cdot Ww^3\right]\cdot 4 \qquad I_6 = 0.032$$

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7. Webs:

$f1 := f(D + t - AV)$ $\qquad$ $f1 = 42.042$

$f2 := f(AV)$ $\qquad$ $f2 = 27.077$

$\psi := \left|\dfrac{f2}{f1}\right|$ $\qquad$ $\psi = 0.644$

$Ww := \dfrac{(D + t - 2AV)}{\sin(\phi)}$ $\qquad$ $Ww = 7.371$

$k := 4 + 2\cdot(1 + \psi)^3 + 2(1 + \psi)$ $\qquad$ $k = 16.176$

$Fcr := k\cdot\dfrac{\pi^2 E}{12\left(1 - \mu^2\right)}\left(\dfrac{t}{Ww}\right)^2$ $\qquad$ $Fcr = 16.435$

$\lambda := \sqrt{\dfrac{f1}{Fcr}}$ $\qquad$ $\lambda = 1.599$ $\qquad$ > 0.673 $\qquad$ Not Fully Effective

$\rho := \dfrac{\left(1 - \dfrac{0.22}{\lambda}\right)}{\lambda}$ $\qquad$ $\rho = 0.539$

$comp := \dfrac{(D + t - AV - y\_)}{\sin(\phi)}$ $\qquad$ $comp = 4.483$

$be := Ww\cdot\rho$ $\qquad$ $be = 3.975$

$b1 := \dfrac{be}{(3 + \psi)}$ $\qquad$ $b1 = 1.091$

$b2 := \dfrac{be}{2}$ $\qquad$ $b2 = 1.987$

$L_7 := 4\cdot(Ww - comp)$ $\qquad$ $L_7 = 11.55$

$y_7 := AV + (Ww - comp)\dfrac{\sin(\phi)}{2}$ $\qquad$ $y_7 = 1.607$

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$$I_7 := \left[\left(\frac{\cos\left(\frac{\pi}{2}-\phi\right)^2}{12}\right)\cdot\left(\frac{L_7}{4}\right)^3\right]\cdot 4$$ $$I_7 = 8.022$$

$$L_{18} := 4\cdot(b2)$$ $$L_{18} = 7.949$$

$$y_{18} := y\_ + \frac{b2\cdot\sin(\phi)}{2}$$ $$y_{18} = 4.043$$

$$I_{18} := \left[\left(\frac{\cos\left(\frac{\pi}{2}-\phi\right)^2}{12}\right)\cdot\left(\frac{L_{18}}{4}\right)^3\right]\cdot 4$$ $$I_{18} = 2.615$$

$$L_{19} := 4\cdot(b1)$$ $$L_{19} = 4.363$$

$$y_{19} := D + t - AV - \frac{b1\cdot\sin(\phi)}{2}$$ $$y_{19} = 6.987$$

$$I_{19} := \left[\left(\frac{\cos\left(\frac{\pi}{2}-\phi\right)^2}{12}\right)\cdot\left(\frac{L_{19}}{4}\right)^3\right]\cdot 4$$ $$I_{19} = 0.432$$

8. Bottom Web Arcs:

$$L_8 := 4\cdot r\cdot\phi$$ $$L_8 = 0.887$$

$$y_8 := D + \frac{t}{2} - \left(r - r\cdot\frac{\sin(\phi)}{\phi}\right)$$ $$y_8 = 7.622$$

$$I_8 := \left[\left[\frac{(\phi) + \sin(\phi)\cdot\cos(\phi)}{2} - \frac{\sin(\phi)^2}{(\phi)}\right]\cdot r^3\right]\cdot 4$$ $$I_8 = 1.65\times 10^{-3}$$

9. Unstiffened Hat Bottom

$$f9 := f(D + t)$$ $$f9 = 43.57$$

$$\frac{H}{t} = 12.088$$ $$k := 0.43$$

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$$Fcr := k\cdot\frac{\pi^2 E}{12\left(1-\mu^2\right)}\left(\frac{t}{H}\right)^2$$ $Fcr = 78.463$

$$\lambda := \sqrt{\frac{f9}{Fcr}}$$ $\lambda = 0.745$ > 0.673

$$\rho := \begin{array}{|l} \rho \leftarrow 1.0 \ \text{ if } \lambda \le 0.673 \\ \rho \leftarrow \dfrac{\left(1-\dfrac{0.22}{\lambda}\right)}{\lambda} \ \text{ if } \lambda > 0.673 \\ \rho \end{array}$$ $\rho = 0.946$

$L_9 := 4\cdot H\cdot\rho$ $L_9 = 2.081$

$y_9 := D + \frac{t}{2}$ $y_9 = 7.673$

$I_9 := 0$

rho_m :

$$Fc := 3.29\cdot\frac{E}{\left(\frac{s}{tb}\right)^2}$$ $Fc = 12.724$ < f = Fy = 44

$k := 4$

$f10 := f(Dt)$ $f10 = 44$

$$\rho m := \min\left(1, 8.0\cdot\frac{Fy}{f10}\cdot\sqrt{\frac{tb\cdot Fc}{Dt\cdot f10}}\right)$$ $\rho m = 0.331$

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10. HL

$$S := 1.28\sqrt{\frac{E}{f10}}$$ $0.328S = 10.871$

$$\frac{HL}{tb} = 17.249$$ >0.328*S

$$Is := \left(\frac{1}{12}\right)\left(tb\cdot GP\_L^{3}\right)$$ $Is = 4.546 \times 10^{-3}$

$$Ia := \min\left[399\cdot tb^{4}\cdot\left(\frac{\frac{HL}{tb}}{S} - 0.328\right)^{3}, tb^{4}\cdot\left(115\cdot\frac{\frac{HL}{tb}}{S} + 5\right)\right]$$ $Ia = 1.251 \times 10^{-5}$

$$RI\_L := \min\left(1, \frac{Is}{Ia}\right)$$ $RI\_L = 1$

$$n := \max\left(0.582 - \frac{\frac{HL}{t}}{4\cdot S}, \frac{1}{3}\right)$$ $n = 0.451$

$$k := \left|\begin{array}{l} k \leftarrow \min\left[3.57\cdot\left(RI\_L^{n}\right) + 0.43, 4\right] \\ k \leftarrow \min\left[\left[4.82 - \frac{5(GP\_L - tb)}{HL}\right]\cdot\left(RI\_L^{n}\right) + 0.43, 4\right] \text{ if } 140 \ge \theta\_stiff \ge 40 \wedge 0.25 < (GP\_L - tb) < 0.8 \\ k \end{array}\right.$$

$k = 4$

$$Fcr(w) := k\cdot\frac{\pi^{2}E}{12\left(1 - \mu^{2}\right)}\left(\frac{tb}{w}\right)^{2}$$ Fcr = function

$$\lambda := \sqrt{\frac{f10}{Fcr(HL)}}$$ $\lambda = 0.35$ < 0.673

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Fully Effective

$L_{10} := HL \cdot \frac{tb}{t}$ $\quad L_{10} = 0.795$

$y_{10} := Dt - \frac{tb}{2}$ $\quad y_{10} = 7.718$

$I_{10} := 0$

11. HA

$\lambda t := \frac{1.052}{(\sqrt{k})} \left(\frac{HA}{tb}\right) \cdot \sqrt{\frac{Fc}{E}}$ $\quad \lambda t = 2.361$ >0.673

$$\rho t\_HA := \left| \begin{array}{l} \rho \leftarrow 1.0 \ \text{ if } \ \lambda t \le 0.673 \\ \rho \leftarrow \frac{\left(1 - \frac{0.22}{\lambda t}\right)}{\lambda t} \ \text{ if } \ \lambda t > 0.673 \\ \rho \end{array} \right.$$

$\rho t\_HA = 0.384$

$$\rho\_HA := \left| \begin{array}{l} \lambda \leftarrow \sqrt{\frac{f10}{Fcr(HA)}} \\ \rho \leftarrow \min\left[1, \rho t\_HA \cdot \rho m, \left[\frac{\left(1 - \frac{0.22}{\lambda}\right)}{\lambda}\right]\right] \\ \rho \end{array} \right.$$

$L_{11} := HA \cdot \rho\_HA \cdot \frac{tb}{t}$ $\quad L_{11} = 1.266$

$y_{11} := Dt - \frac{tb}{2}$ $\quad y_{11} = 7.718$

$I_{11} := 0$

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12. HM

$$\lambda t := \frac{1.052}{\left(\sqrt{k}\right)}\left(\frac{HM}{tb}\right)\cdot\sqrt{\frac{Fc}{E}}$$ $\lambda t = 0.787$ >0.673

$$\rho t\_HM := \left| \begin{array}{l} \rho \leftarrow 1.0 \ \text{ if } \ \lambda t \le 0.673 \\ \rho \leftarrow \dfrac{\left(1 - \dfrac{0.22}{\lambda t}\right)}{\lambda t} \ \text{ if } \ \lambda t > 0.673 \\ \rho \end{array} \right.$$ $\rho t\_HM = 0.915$

$$\rho\_HM := \left| \begin{array}{l} \lambda \leftarrow \sqrt{\dfrac{f10}{Fcr(HM)}} \\ \rho \leftarrow \min\left[1, \rho t\_HM \cdot \rho m, \left[\dfrac{\left(1 - \dfrac{0.22}{\lambda}\right)}{\lambda}\right]\right] \\ \rho \end{array} \right.$$

$$L_{12} := 1HM \cdot \rho\_HM \cdot \frac{tb}{t}$$ $L_{12} = 1.006$

$$y_{12} := Dt - \frac{tb}{2}$$ $y_{12} = 7.718$

$$I_{12} := 0$$

13. HB

$$\lambda t := \frac{1.052}{\left(\sqrt{k}\right)}\left(\frac{HB}{tb}\right)\cdot\sqrt{\frac{Fc}{E}}$$ $\lambda t = 2.361$ >0.673

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$$\rho t\_HB := \begin{array}{|l} \rho \leftarrow 1.0 \ \ \text{if} \ \ \lambda t \le 0.673 \\ \rho \leftarrow \dfrac{\left(1 - \dfrac{0.22}{\lambda t}\right)}{\lambda t} \ \ \text{if} \ \ \lambda t > 0.673 \\ \rho \end{array}$$

$\rho t\_HB = 0.384$

$$\rho\_HB := \begin{array}{|l} \lambda \leftarrow \sqrt{\dfrac{f10}{Fcr(HB)}} \\ \rho \leftarrow \min\left[1, \rho t\_HB \cdot \rho m, \left[\dfrac{\left(1 - \dfrac{0.22}{\lambda}\right)}{\lambda}\right]\right] \\ \rho \end{array}$$

$L_{13} := HB \cdot \rho\_HB \cdot \dfrac{tb}{t}$ $\qquad L_{13} = 1.266$

$y_{13} := Dt - \dfrac{tb}{2}$ $\qquad y_{13} = 7.718$

$I_{13} := 0$

14. HR

$\dfrac{HR}{tb} = 17.249$ $\qquad$ >0.328*S $\qquad 0.328 \cdot S = 10.871$

$Is := \left(\dfrac{1}{12}\right)\left(tb \cdot GP\_R^3\right)$ $\qquad Is = 5.805 \times 10^{-3}$

$Ia := \min\left[399 \cdot tb^4 \cdot \left(\dfrac{\frac{HR}{tb}}{S} - 0.328\right)^3, tb^4 \cdot \left(115 \cdot \dfrac{\frac{HR}{tb}}{S} + 5\right)\right]$ $\qquad Ia = 1.251 \times 10^{-5}$

$RI\_R := \min\left(1, \dfrac{Is}{Ia}\right)$ $\qquad RI\_R = 1$

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$$n := \max\left(0.582 - \frac{\frac{HR}{t}}{4\cdot S}, \frac{1}{3}\right)$$ $n = 0.451$

$$k := \begin{array}{|l} k \leftarrow \min\left[3.57\cdot\left(RI\_R^{n}\right) + 0.43, 4\right] \\ k \leftarrow \min\left[\left[4.82 - \frac{5(GP\_R - tb)}{HR}\right]\cdot\left(RI\_R^{n}\right) + 0.43, 4\right] \ \text{if} \ 140 \ge \theta\_stiff \ge 40 \wedge 0.25 < (GP\_R - tb) < 0.8 \\ k \end{array}$$

$k = 4$

$$Fcr := k\cdot\frac{\pi^2 E}{12\left(1 - \mu^2\right)}\left(\frac{tb}{HR}\right)^2$$ $Fcr = 358.456$

$$\lambda := \sqrt{\frac{f10}{Fcr}}$$ $\lambda = 0.35$ < 0.673

$$L_{14} := HR\cdot\frac{tb}{t}$$ $L_{14} = 0.795$

$$y_{14} := Dt - \frac{tb}{2}$$ $y_{14} = 7.718$

$$I_{14} := 0$$

15. Left Plate Stiffener:

$f1 := f(Dt)$ $f1 = 44$

$f2 := f(Dt - GP\_L)$ $f2 = 34.058$

$$\psi := \left|\frac{f2}{f1}\right|$$ $\psi = 0.774$

$$k := 4 + 2\cdot(1 - \psi)^3 + 2(1 - \psi)$$ $k = 4.475$

$$Fcr := k\cdot\frac{\pi^2 E}{12\left(1 - \mu^2\right)}\left[\frac{tb}{(GP\_L - tb)}\right]^2$$ $Fcr = 243.317$

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$\lambda := \sqrt{\frac{f1}{Fcr}}$ $\lambda = 0.425$ < 0.673 Fully Effective

$be := GP\_L - tb$ $be = 1.014$

$b1 := \frac{be}{(3-\psi)}$ $b1 = 0.456$

$b2 := be - b1$ $b2 = 0.559$

$L_{15} := (b1 + b2)\cdot\frac{tb}{t}$ $L_{15} = 1.021$

$y_{15} := Dt - tb - \frac{GP\_L - tb}{2}$ $y_{15} = 7.188$

$I_{15} := \left(\frac{1}{12}\right)\left(be^3\right)\frac{tb}{t}$ $I_{15} = 0.088$

16. Right Plate Stiffener:

$f12 := f(D)$ $k := 0.43$

$Fcr := k\cdot\frac{\pi^2 E}{12\left(1-\mu^2\right)}\left[\frac{tb}{(GP\_R - tb)}\right]^2$ $Fcr = 19.724$

$\lambda := \sqrt{\frac{f12}{Fcr}}$ $\lambda = 1.479$ > 0.673

$$\rho := \begin{array}{|l} \rho \leftarrow 1.0 \text{ if } \lambda \le 0.673 \\ \rho \leftarrow \frac{\left(1 - \frac{0.22}{\lambda}\right)}{\lambda} \text{ if } \lambda > 0.673 \\ \rho \end{array}$$

$\rho = 0.576$

$d's := (GP\_R - tb)\cdot\rho$ $d's = 0.636$

$ds := d's\cdot RI\_R$ $ds = 0.636$

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$L_{16} := ds \cdot \frac{tb}{t}$ $\quad L_{16} = 0.64$

$y_{16} := D + t - \frac{ds}{2}$ $\quad y_{16} = 7.378$

$I_{16} := \left(\frac{1}{12}\right) \cdot \left(ds^3\right) \cdot \frac{tb}{t}$ $\quad I_{16} = 0.022$

17. Left Plate Lip:

$k := 0.43$

$f14 := f(Dt - GP\_L + HP)$

$f14 = 39.967$

$Fcr := k \cdot \frac{\pi^2 E}{12\left(1 - \mu^2\right)} \left(\frac{tb}{HP - tb}\right)^2$ $\quad Fcr = 70.465$

$\lambda := \sqrt{\frac{f14}{Fcr}}$ $\quad \lambda = 0.753$ $\quad > 0.673$

$$\rho := \left| \begin{array}{l} \rho \leftarrow 1.0 \ \text{ if } \lambda \le 0.673 \\ \rho \leftarrow \dfrac{\left(1 - \dfrac{0.22}{\lambda}\right)}{\lambda} \ \text{ if } \lambda > 0.673 \\ \rho \end{array} \right.$$

$\rho = 0.94$

$d's := (HP - tb) \cdot \rho$ $\quad d's = 0.549$

$ds := d's \cdot RI\_L$ $\quad ds = 0.549$

$L_{17} := ds \cdot \frac{tb}{t}$ $\quad L_{17} = 0.553$

$y_{17} := Dt - GP\_L + \frac{ds}{2}$ $\quad y_{17} = 6.956$

$I_{17} := \left(\frac{1}{12}\right)\left(ds^3\right) \frac{tb}{t}$ $\quad I_{17} = 0.014$

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Cumulative:

$$\sum_{i=1}^{19} L_i = 52.741 \qquad \sum_{i=1}^{19} \left(L_i \cdot y_i\right) = 161.022 \qquad \sum_{i=1}^{19} \left[L_i \cdot \left(y_i\right)^2\right] = 967.221$$

$$\sum_{i=1}^{19} I_i = 11.228$$

$$y\_ := \frac{\sum_{i=1}^{19} \left(L_i \cdot y_i\right)}{\sum_{i=1}^{19} L_i} \qquad y\_ = 3.053$$

$$Ix := t \cdot \left[\sum_{i=1}^{19} \left[L_i \cdot \left(y_i\right)^2\right] + \sum_{i=1}^{19} I_i - y\_^2 \cdot \sum_{i=1}^{19} L_i\right] \qquad Ix = 22.151$$

*The ineria is divided by the width (2 feet) to put it in terms of in^4 per foot width

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$\frac{Ix}{2} = 11.076$

$Sx\_bot := \frac{Ix}{2 \cdot (Dt - y\_)}$

$Sx\_top := \frac{Ix}{2 \cdot y\_}$

$Sx := \min(Sx\_bot, Sx\_top)$

$Sx = 2.362$

$Mx := Sx \cdot Fy$

$Mx = 103.946$