

Buckling Analysis of Corrucomb[®] – Steel Skin Sandwich Panel

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Abstract

Three buckling scenarios were considered for the design and application of Corrucomb – steel skin sandwich panels: skin dimpling (localized buckling), vertical buckling, and shear buckling. Critical buckling loads for each scenario were calculated for a proposed demonstration office building. The analysis showed that the vertical buckling and shear buckling are of no concern at all, and localized buckling (dimpling) is also satisfied by the corresponding plate bending design.

Introduction

Innomation Inc has developed a proprietary process of corrugating phenolic resin saturated kraft paper into a continuous ribbon of Corrucomb cells with depth over ½” and pitch over ¾”. The ribbon is then assembled into Corrucomb block and cut into dimensions for sandwich lay-up. The two facings for the sandwich panels are tentatively thin steel skins. The finished panel could be as thick as 2 feet.

The sandwich components can be used as a second floor deck, roof and wall envelop panels in office and other commercial buildings. The edges of individual panels are joined to convert such surface system from beam into plate construction, to increase the loading capacity. Plate theory can then be employed to calculate deflection and stresses in plate bending (Xu 2008).

This paper presents the analysis on the buckling aspects of the sandwich structure. Two buckling categories were considered: 1) the buckling of the steel skin due to compressive stresses of plate bending and, 2) the buckling of the diaphragm due to vertical (in-plane) compression and racking shear. Formulas for the analysis were given first and followed with examples of calculation.

Buckling Scenarios

1. Dimpling (Localized Skin Buckling) due to Plate Bending

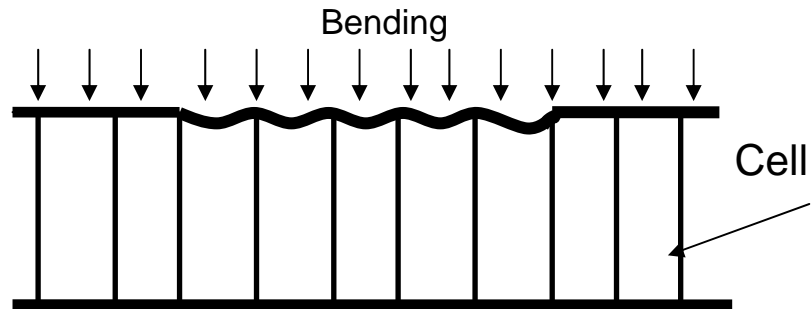


Figure 1 - Dimpling of the skin due to compression stress

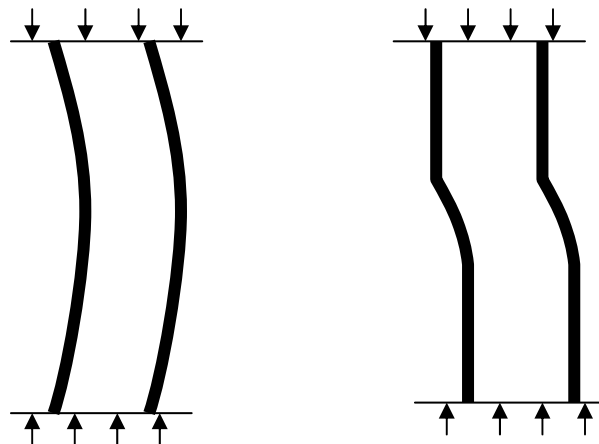
Dimpling is localized buckling of the skin in between the cell walls or pitches (Figure 1). Dimpling occurs if the compressive stress exceeds the critical dimpling stress (σ_{cr}^D), which is given by (Bitzer 1997)

$$\sigma_{cr}^D = 2Et^2/s^2(1-\nu^2) \quad (1)$$

in which E , ν , and t are the modulus of elasticity, Poisson ratio, and thickness of the skin; s is the cell opening or the pitch of the cell.

2. Diaphragm Buckling due to In-plane (Vertical) Load

There are two modes of failure: general buckling and shear crimping (Figure 2). Shear crimping could occur if core shear modulus is too low.



A. General buckling

B. Shear crimping

Figure 2 – Buckling due to in-plane) vertical compression

a. General buckling

General buckling occurs if the vertical load exceeds the critical buckling load (P_{cr}^b , lbs/ft), which for simply supported condition is given by (Hexcel 1987):

$$P_{cr}^b = \pi^2 S / (\ell^2 + \pi^2 S / U) \quad (2)$$

where $S = Ed^2t / (2(1-\nu^2))$, the panel stiffness, d is the thickness of the panel, and $U = cG$ the panel rigidity, c and G are the thickness and shear modulus of the core, and ℓ is the height of the wall.

b. Shear crimping

Shear crimping occurs if critical shear crimping load P_{cr}^s (lbs/ft) is exceeded which is calculated as (Hexcel 1987):

$$P_{cr}^s = 12cG \quad (3)$$

3. *Shear Buckling of Shear Wall*

Figure 3 shows schematically the flow or distribution of wind load to a building. The wind load (F , lbs/ft²) acting against the side wall is translated into a compression force (W , lbs/ft) to the roof diaphragm, and then to the shear force (V , lbs/ft) to the end wall. While the roof diaphragm has to be checked for buckling due to compression as discussed above, the end wall needs to be designed to prevent it from shear buckling. The end wall is also called shear wall.

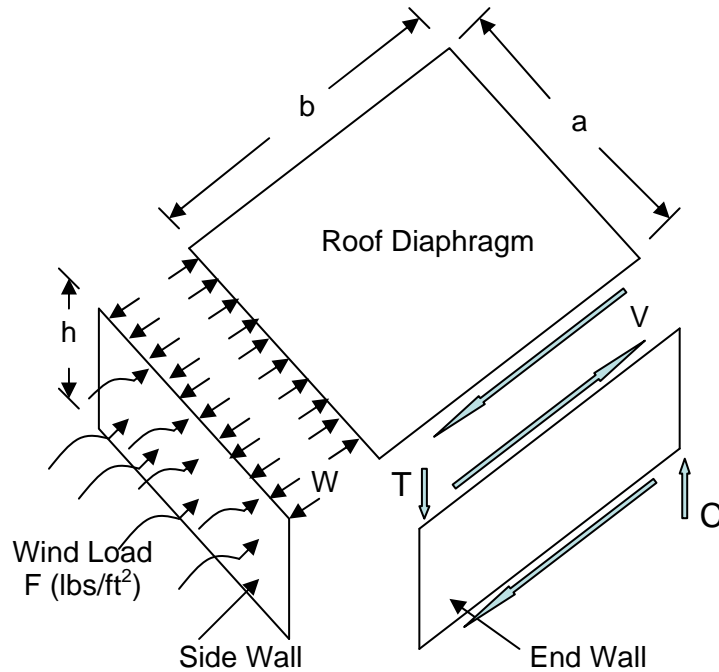


Figure 3 - A schematic showing the distribution of wind load

The compression force to the roof diaphragm and the shear force to the shear wall are given by the following equations:

$$W = Fh/2 \quad (4)$$

and

$$V = Fha/(4b) \quad (5)$$

where a and b are the length and width of the roof diaphragm respectively (Figure 3).

The critical shear buckling load, P, per inch width is given by the following equation (Military Handbook 23A, 1974):

$$P = K\pi^2D/b^2 \quad (6)$$

where D is the bending stiffness per unit width, b is the wall width, and K is related to the following parameter R:

$$R = \pi^2D/(b^2U) \quad (7)$$

in which U is the shear rigidity of the core.

Military Handbook 23A also provides charts for the solution of K for various boundary conditions, geometries (b/h), and parameter R. Shear buckling occurs if $V > P$.

Examples

1. *Dimpling (localized skin buckling)*

Innomation is in the process of building a demonstration office using the steel faced Corrucomb sandwich panels. The office will be a 2-story building of 50'x60'x28', with roof being 50'x60', second floor deck 50'x50', and wall either 28'x50' or 28'x60'. Maximum bending stresses induced to the skin have been calculated for each component using respective ultimate design load, and are summarized in a separate report (Xu 2008). Those stresses are compared with the dimpling stress to check the skin buckling.

Table 1 shows calculated critical dimpling stress, together with the maximum stress of each building components, as a function of skin thickness. The thicknesses of the 2nd floor deck, roof deck and wall are 24", 18" and 5.5", and design loads are 400 lbs/ft², 100 lbs/ft² and 400 lbs/ft² respectively.

Table 1 – Comparison of bending stress with critical dimpling stress

Skin Thickness	Critical Dimpling Stress (psi)	Max Stress of 2 nd Floor Deck (psi)	Max Stress of Roof Deck (psi)	Max Stress of the Wall (psi)
0.0200	46,886	66,796	44,374	88,224
0.0400	187,545	33,398	22,187	44,112
0.0600	421,978	22,265	14,791	29,408
0.0800	750,183	16,699	11,093	22,056

A skin thickness of 0.0400" was deemed necessary for the three components based on plate analysis (Xu 2008). At this skin thickness, the critical dimpling stress exceeded the maximum skin stress, and we conclude that the skin buckling (dimpling) won't occur.

2. *Diaphragm Buckling due to Vertical Load*

The roof diaphragm is used as the example for this buckling mode. The maximum compression load to the roof from the wind force of side wall is $W = 5600$ lbs/ft per Equation (4), assuming a Tornado situation.

Table 2 shows the calculated critical general buckling load and shear crimping load using $G=1000$ psi for 50'x60' diaphragm with $l=b=60'$ and $a=50'$. As these critical loads are far greater than the actual compression force W , we conclude a skin thickness of 0.0400" determined by plate bending is sufficient.

Table 2 – General buckling and shear crimping load of roof diaphragm

Skin Thickness	General Buckling Load (lbs/ft)	Shear Crimping Load (lbs/ft)
0.0200	21925	216000

0.0400	39810	216000
0.0600	54676	216000
0.0800	67229	216000

3. Shear Buckling of Shear Wall

The maximum shear force due to tornado wind per Equation (5) is $V=3360$, assuming $a=60'$ and $b=50'$. The shear wall shall not buckle at this load.

Table 3 shows the parameter R as a function of skin thickness, parameter K read from the chart of the Military handbook (1974) for two boundary conditions, and the calculated critical buckling load per foot width per Equation (6).

Table 3 – Calculation of buckling load per Military Handbook

Skin Thickness (inches)	Parameter R	Parameter K		Buckling load (lbs/ft)	
		All Simply Supported	All Edges Clamped	All Simply Supported	All Edges Clamped
0.0200	0.050	5.4	7.2	17716	23621
0.0400	0.099	4.5	5.6	29527	36745
0.0600	0.149	3.7	4.7	36417	46259
0.0800	0.199	3.4	3.8	44619	49868

The buckling shear load is far greater than the shear load from tornado force for the two boundary conditions, for all skin thicknesses; we conclude that shear buckling is not critical for $t=0.0400''$ which was determined based on plate bending design.

Conclusions

It appears that the localized buckling (dimpling of the skin), vertical (diaphragm) buckling, and shear buckling are also satisfied if the Corrucomb – steel skin sandwich panel are designed for the bending load.

References

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