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Influence of Stacking Sequence and Temperature on Buckling Resistance of GFRP Infill Panel

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***Abstract*—**Glass Fiber Reinforced Polymer (GFRP) is a major evolution for energy dissipation when used as infill material for seismic retrofitting of steel frame, a basic PMC infill wall system consists of two GFRP laminates surrounding an infill of foam core. This paper presents numerical analysis in terms of buckling resistance of GFRP sandwich infill panels system under the influence of environment temperature and stacking sequence of laminate skin. Mode of failure under in-plane compression is studied by means of numerical analysis with ABAQUS platform. Parameters considered in this study are contact length between infill and frame, laminate stacking sequence of GFRP skin and variation of mechanical properties due to increment of temperature. The analysis is done with four cases of simple stacking sequence over a range of temperature. The result showed that both the effect of temperature and stacking sequence alter the performance of entire panel system. The rises of temperature resulted in the decrements of the panel's strength. This is due to the polymeric nature of this material. Additionally, the contact length also displays the effect on the performance of infill panel. Furthermore, the laminate stiffness can be modified by orientation of laminate, which can increase the infill panel strength. Hence, optimal performance of the entire panel system can be obtained by comparing different cases of stacking sequence.

***Keywords*—**Buckling resistance, GFRP infill panel, stacking sequence, temperature dependent.

I. INTRODUCTION

STRUCTURAL frame with infill panels are typically providing an efficient and effective method for bracing building. They are effective because the combined in-plane action of the infill panel and frame are very stiff and strong. The frame, while directly carrying some of the load, primarily serves to transfer and distribute the major part of the load to the infill panel. Therefore, the infill panel is able to resist substantially higher loads before finally collapsing by compressive failure. GFRP infill panel has been introduced as a modern energy dissipating panel because of its high strength to weight ratio. In practical applications, they are being used to retrofit structural elements such as columns, beams, and unreinforced masonry walls to enhance strength and ductility.

Previous literatures have addressed the significance of infill walls, their contribution to enhancing strength, and stiffness of framed buildings subjected to lateral forces. Until now, many researchers have attempted to develop simplified methods for analysis and design of these infill frames when subjected to in-plane forces. The works performed by Jung & Aref [1], [3] present the compressive instability of GFRP infill panel and discuss the influence of properties of GFRP and loading conditions by concept of diagonal sandwich strut models. Results from this study reveal that the failure of global buckling is dominant when designing the GFRP infill panel. The results highlight the key roles of the GFRP skin and influence of stacking sequence on its performance.

The effect of temperature has been mainly considered for foam core. The thermal properties of polymeric materials are important to the function of components and assemblies that will operate in different environments. In preceding study [8], comparison between simple cases of stacking sequence for GFRP skin of infill panel was made with respect to alteration of mechanical properties of core due to temperature variation. The results indicate the rearrangement of laminae orientation can increase performance of panel system but does not affect the sensitivity of panel system due to temperature.

Consequently, this paper expands the analysis with respect to the buckling response of infill panels system under the influence of temperature on the entire panel system. Afterward, buckling strength of the system and sensitivity to temperature variation can be compared when four different cases of stacking sequence are applied for skin.

II. DESIGN AND PERFORMANCE MECHANISM OF GFRP INFILL PANEL

GFRP infill panel has been introduced as a panel material with increased lateral resistance; it employs a sandwich design concept to reduce weight, sound and vibration as well as to improve the structural rigidity of the panel. This design procedure must specify many design variables of both laminate skin [2] and foam core. Such variables include the thickness, fiber orientation, stacking sequence of GFRP laminae, and geometrical parameters. In addition, GFRP sandwich structures expose to very high structural efficiency (ratios of strength or stiffness to weight). In order to obtain the high performance at low cost, the thinly spaced core-shell laminates are designed to provide bending rigidity, and the space between the laminates is filled with polymeric sheet foam.

As the racking load is increased on infill frame structures, failure occurs eventually at either the frame or the infill panel. The critical modes of frame failure are tension in the column or shearing of the column or beams. However, if strength of frame is sufficient to prevent its collapse by one of these modes, the increasing racking load eventually produces compressive failure in the infill panel. The failure mode of sandwich GFRP

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infill panel can be generally classified into three categories: (1) instabilities, such as overall buckling, (2) face wrinkling, caused by insufficient plate- or face-bending stiffness and core elastic properties, and (3) fracture, either of the face sheets under compression or of the core under transverse shear. Overall buckling failure has shown to be dominant [3].

The combined behavior of a series of infill frame structures is a complex, statically indeterminate problem. Development of an exact mathematical solution for frame/infill contact lengths may be possible, but rather complicated, involving perhaps a trial-and-error procedure [6]. The mutual interactions of the frame and infill panel play an important part in controlling the stiffness and strength of the infill frame. For diagonally equivalent strut models, it has been shown by previous research [3] that the diagonal stiffness and strength of the infill panel depends primarily on its dimensions, physical properties, and length of contact with the surrounding structural frame. Using the length of contact between the infill and frame, it is possible to make a series of stress analyses for panels loaded diagonally by compressive forces with calculated distributions of interaction over different lengths of contact against the column and beam.

III. Configuration of GFRP Infill Panel and Effect of Temperature

Configuration of the panel system is shown in Fig. 1 with the total thickness of 32 mm, consists of two 6 mm GFRP skins and 20 mm core with the following dimension: 2400 mm × 2200 mm. Properties of core and GFRP lamina are shown in Table I. The numerical analysis referred to laminates skin with constant thickness and was performed by varying fiber orientation in laminae of the GFRP skin layer, this is called stacking sequence. Four cases of stacking sequence were being considered, as the following:

- Case 1: $[0_{20}]_T$
- Case 2: $[0_5/90_{10}/0_5]_S$
- Case 3: $[45_5/\text{-}45_{10}/45_5]_S$
- Case 4: $[0_5/45_5/\text{-}45_5/90_5]_S$

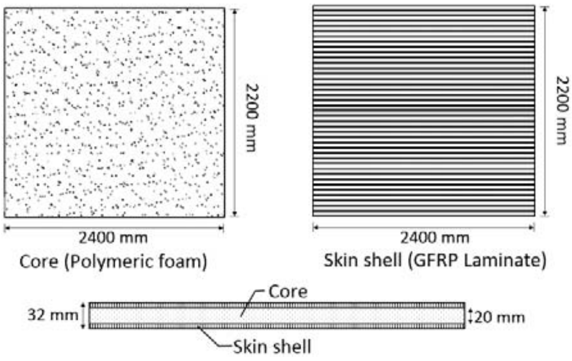

Fig. 1 Configuration of the GFRP infill panel system

In Table I, the GFRP infill panel uses Polystyrene closed-cell foam for the core. Mott [5] has shown that increment of temperature results in reduction of characteristic parameter, such as elastic modulus, yield stress and Poisson's ratio of the solid polymer material, thus affects those of the polymeric foam, this is due to the polymeric nature of this material.

TABLE I
Mechanical Properties of Core and GFRP Skin at –20°C to 60°C

Temp. [°C]	Core		Skin [4]			
	E [MPa]	ν	E_1 [GPa]	E_2 [GPa]	ν_{12}	G_{12} [GPa]
-20	130.7	0.33	57.9	18.9	0.26	10.5
0	125.4	0.33	57.2	17.6	0.26	9.2
20	120.0	0.33	56.4	16.2	0.26	7.8
40	113.9	0.33	55.3	14.9	0.26	6.5
60	110.9	0.33	53.9	13.5	0.26	5.1

IV. Numerical Analysis of the GFRP Infill Panel

A series of three-dimensional static analysis of the GFRP infill panel was conducted in ABAQUS [7]. In the Finite Element (FE) model of the GFRP infill frame structure, only the infill panel was modeled, not the surrounding frames. The core sheet layer was modeled with three-dimensional solid elements (C3D8). The skin plates were modeled by composite layup of GFRP lamina sheet following the four cases and discretized with quadrilateral shell elements (S4R5). A tie constraint was introduced between the nodes of the shell elements and the solid elements. Material properties used for this analysis were given in Table I.

The contacts between beams and infills were modeled by constraining both translational degrees of freedoms for Y- and Z-direction and rotational degree of freedom for Z-direction along the length of contact for both the top and bottom beams, as demonstrated in Fig. 2. Triangular distributed compression load was applied along the length of contact against the columns.

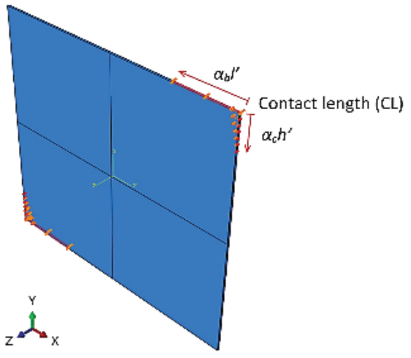

Fig. 2 FE model of the infill panel in ABAQUS

V. Results and Discussions

A. Failure Mode of Panel System

Predominate buckling mode shape of infill panel system are shown in Fig. 3. Eigenvalue, also known as load multiplier, was extracted. By multiplying eigenvalue with the applied load, the most likely load to cause buckling of the panel was obtained. This value is the buckling resistance load of the infill panel.

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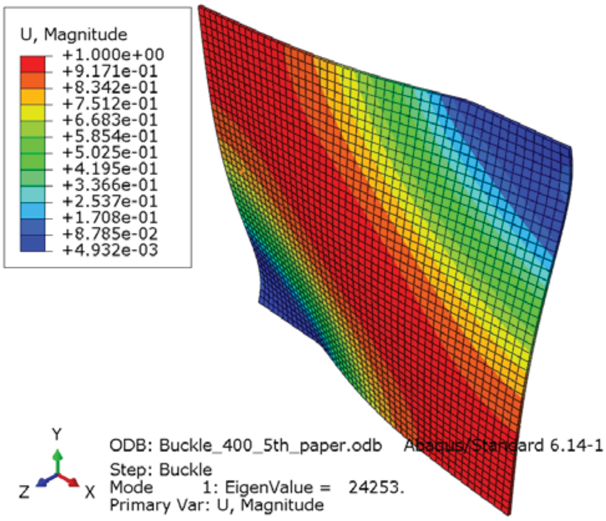

Fig. 3 Buckling failure of GFRP infill panel system

B. Effect of Stacking Sequence

In the design process where laminate is composed by several laminae, we built up our understanding of laminate behavior from the simplest case to a more complicated case. Simply through the rearrangement of stacking sequence, a large gap of fiber orientation angle's effect on buckling strength can be obviously observed in Fig. 4. By orienting the fiber in special orthotropic layers (Case 2), the buckling resistance increased by 24% compared to isotropic layer in Case 1. The maximum resistance was achieved in Case 3, general orthotropic layers, which increased by 55% compared to Case 1. Multiple anisotropic layers orientation in Case 4 was found to be comparable with that of Case 3, which increased 44% compared to Case 1.

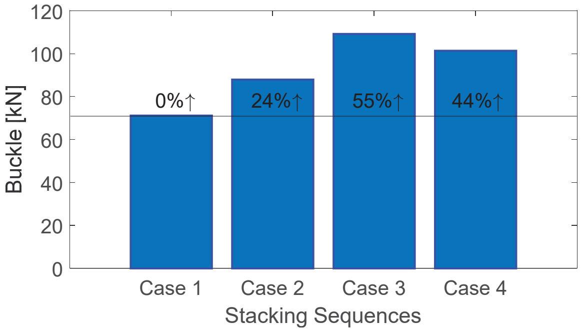

Fig. 4 The effect of stacking sequence on the buckling resistance

Through exploring various orientations of stacking sequence of laminae, we observed that the specific orientation provided in Case 3 offers the best direction that can benefit stiffening properties against buckling which equivalently results in the reinforcement of the overall panel structure. This orienting laminae's sequence into specific orientation leads to the modification of strength and stiffness of panel to go against the critical buckling direction. The best design with the highest buckling resistance strength (Case 3, with increment up to 55% of Case 1) can be selected by exploiting this directional property of laminae.

C. Effect of Temperature Variation

Fig. 5 introduces the effect of temperature on buckling resistance of entire panel system for each case of stacking sequence. Similar to mechanical properties shown in Table I, trend of these four curves of buckling resistance was inversely proportional to that of temperature. By observing the slope of these four curves, Fig. 5 shows that, Case 1 stacking sequence was more sensitive to the effect of temperature compare to the other three whereas Case 3 showed the lowest sensitivity. The percentage above each curve represents the increment percentage comparing all cases to Case 1, which is similarly shown in Fig. 4. This value showed that the increment compare to Case 1 of buckling resistance strength was also temperature dependence and it increased proportionally with temperature. Hence, the stacking sequence in Case 3 proved to be the best over the entire range of temperature for both performance and sensitivity to effect of temperature variation.

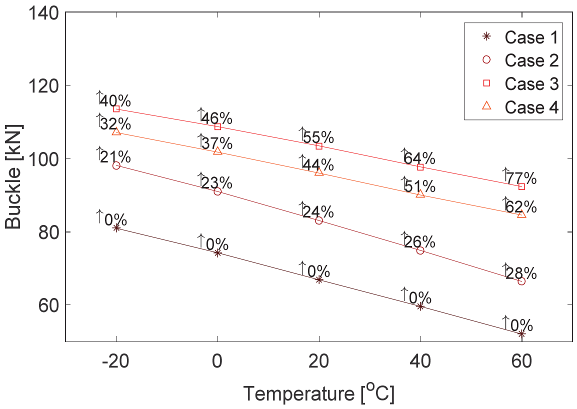

Fig. 5 Buckling resistance in function of temperature for each case of stacking sequences

D. Effect of Temperature Variation Regarding Contact Length

Expanding the curve in Fig. 5 by including the length of contact, Fig. 6 illustrates buckling resistance of panel system in function of contact lengths and temperature for panel system. The number above each point indicates the increment percentage of each case of stacking sequence in comparison with Case 1 (in Fig. 6 (a), which has the value of zero). As prior observed, buckling resistance still preserved the same trend which inversely proportional with temperature. We observed that there occurs the upward displacement of curve's surface as contact length increases. This indicates that buckling resistance increases proportionally to its contact length. This observation has been clearly shown for the case where temperature equal to 20˚C in Fig. 7 and it also showed that the increment is not linear. Therefore, from Figs. 5 and 7, we can conclude that the variation of buckling strength is linear in term of temperature but not that of contact length. Similar to Fig. 5, the percentage above each curve represents the increment percentage comparing all cases to Case 1; however, in this figure it showed minute variation in term of contact length. Case 3 still showed the highest performance in term of both contact length and temperature.

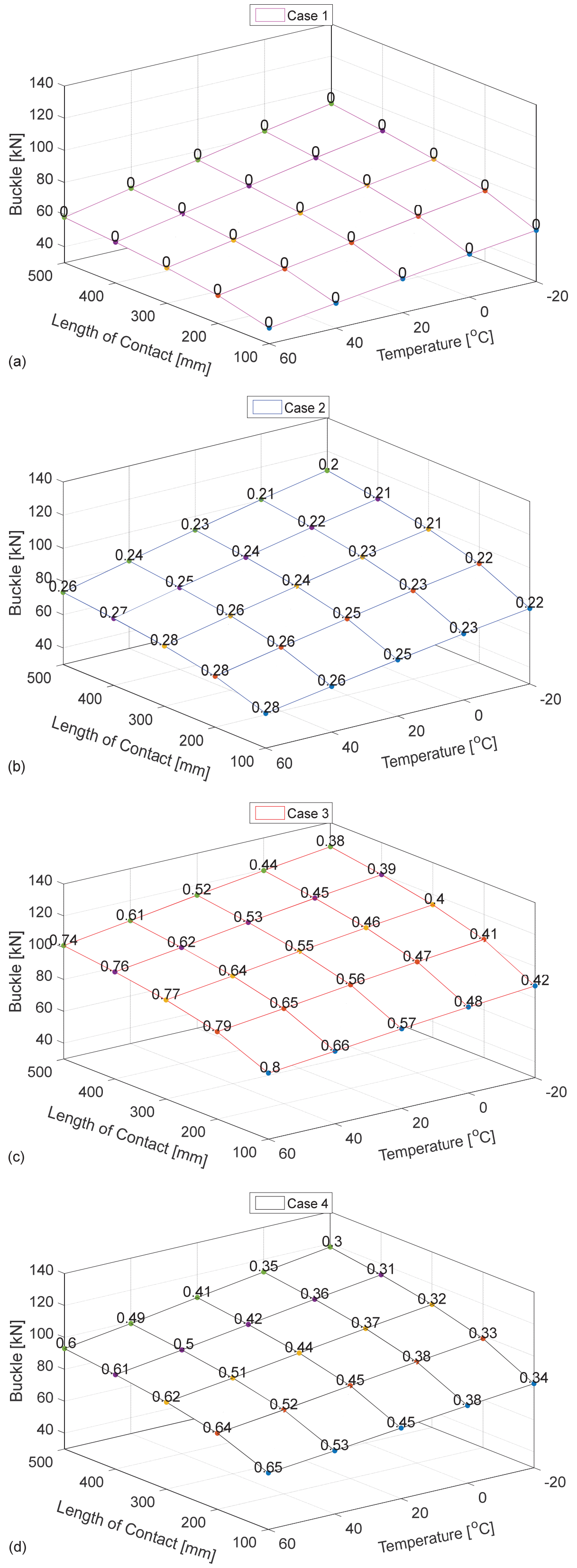

Fig. 6 Buckling resistance in function of temperature and contact length for stacking sequence (a) Case 1, (b) Case 2, (c) Case 3, and (d) Case 4

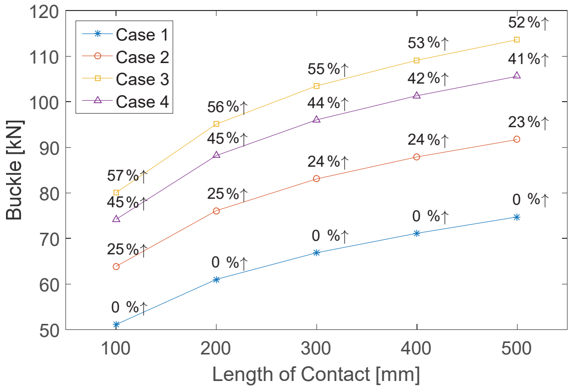

Fig. 7 Buckling resistance in function of contact length for all cases of stacking sequence

Consequently, we can summarize in a more quantitative form, the decrement percentage of buckling resistance in term of temperature of panel system over the considered range of contact length in Fig. 8. The curves were constructed by determining all the decrement percentage (rate) in term of temperature for each case of contact length from Fig. 6. The sense of decrement percentage is normalizing value of buckling resistance decrement rate per 1˚C over the maximum buckling resistance. In Fig. 8, the decrement percentage of buckling resistance for Case 1 had the highest value about 0.45%/˚C, which was twice that of Case 3 (0.24%/˚C).

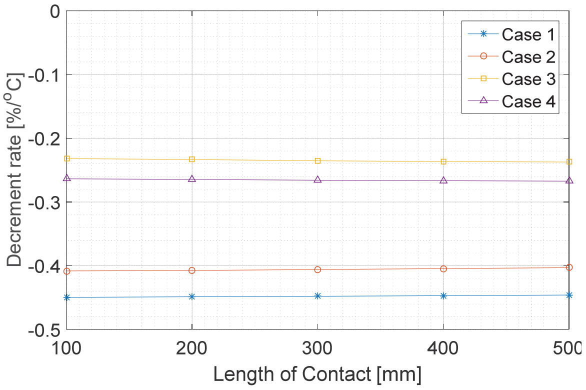

Fig. 8 Comparison of decreasing percentage of buckling resistance

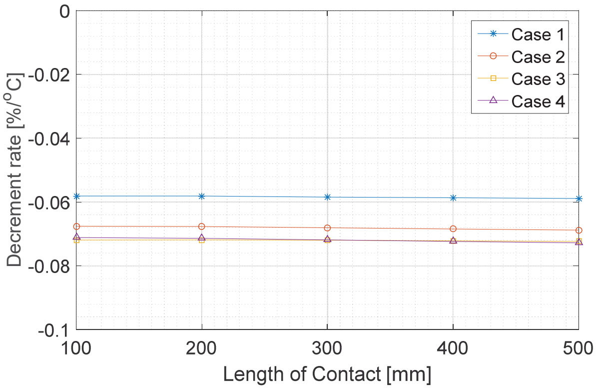

Fig. 9 Result of buckling resistance decrement percentage from [8]

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Comparing the result with those in Fig. 9 from preceding study [8], which temperature variation only alters the mechanical properties of core, showed the decrement rate was much higher in this case of study. This interpreting that sensitivity of temperature on skin layer of GFRP infill panel is more dominant.

VI. CONCLUSIONS

Analytical study of GFRP infill panel with four different stacking sequences of laminate skin were conducted by considering the influence of temperature on mechanical properties of infill panel system. We noted that the design of the stacking sequence for skin layer leads to different performances of the entire panel system. Case 3 which is designed as $[45_5/\text{-}45_{10}/45_5]_S$ proved to be preeminent compare to other cases for both higher performance and less sensitive to effect of temperature variation. This is due to the directional stiffening property of laminate skin that is modified by specific orientation rearrangement of its laminae which results in the effective response to the direction of the most critical buckling. As such, the other lay-up design should be considered by comparing the performance under in-plane compression to determine the optimal stacking sequence.

In the case of temperature influence, it is proven that the entire GFRP infill panel system is thermal dependent. Besides, from this case of study, it is noted that the effect is much higher compare to the case of study in [8] which temperature variation only altered the mechanical properties of core. It means that the sensitivity of skin to temperature variation is immense. Furthermore, the structural parameter, contact length, also affects the performance of the infill panel, nevertheless this is expected because the reduction of strut width of the diagonally equivalent strut models.

Many other choices of stacking sequence are yet to be explored in order to determine an optimized option which can lead to higher performance and less sensitive to variation of temperature. However, in this study, four simple cases of stacking sequence were used for the focus of exploratory and not performance-based, validation was not found to be of critical importance. Nonetheless, this study has developed a trend which serves as a basis for further study to determine optimal stacking sequence and considering other design parameters.

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REFERENCES

[1] Aref, Amjad J., and Woo-Young Jung, “Energy-dissipating polymer matrix composite-infill wall system for seismic retrofitting,” in *Journal of Structural Engineering*, 129(4), pp. 440-448, 2003.

[2] Jones, Robert M., “Mechanics of composite materials”, Taylor & Francis, Philadelphia, 1998.

[3] Jung, Woo-Young, and Amjad J. Aref, “Analytical and numerical studies of polymer matrix composite sandwich infill panels,” in *Composite Structures*, 68(3), pp. 359-370, 2005.

[4] Mivehchi, H., & Varvani-Farahani, A. (2010), “The effect of temperature on fatigue strength and cumulative fatigue damage of FRP composites,” *Procedia Engineering*, *2*(1), 2011-2020.

[5] P.H. Mott, J.R. Dorgan, C.M. Roland, “The bulk modulus and Poisson’s Ratio of incompressible materials,” in *Journal of Sound and Vibration*, 312, pp. 572-575, 2008.

[6] Saneinejad A, Hobbs B. “Inelastic design of infilled frames,” in *Journal of Structural Engineering,* ASCE,121(4):634–650, 1995.

[7] Systèmes, Dassault, ABAQUS User’s & Theory Manuals—Release 6.13-1, Providence, RI, USA, 2013.

[8] Viriyavudh Sim, BuSeog Ju, Woo-Young Jung, “Effect of stacking sequence of GFRP infill with the temperature effect of core material under compression,” in *ICEIT*, 2016.