# Recent Full-Scale Mechanical and Creep Testing of Structural Insulated Panels (SIPs): A Summary

Laya Khademibami Rubin Shmulsky Christopher Adam Senalik
Roy Daniel Seale Robert J. Ross Mostafa Mohammadabadi
Thomas Williamson Seyed Abolghasem Fatemi

## Abstract

The effects of foam core density, foam discontinuity in the shear zone, and flexural properties based on the effect of duration of load testing on structural insulated panels (SIPs) were investigated. These characteristics were individually evaluated for two SIP depths: 6.5 inches and 12.25 inches. For each of the two depths, SIP specimens were assigned to short-duration 1/3-point bending tests and the other matched SIP specimens were subjected to a 90-day creep test, followed by short-duration 1/3-point bending tests. Half of the specimens contained a foam density of 1.0 lb/ft$^3$ and the other half with 1.2 lb/ft$^3$. Likewise, half of the panels contained an expanded polystyrene (EPS) discontinuity in the bending test shear zone, whereas the other half did not have such joints or discontinuities. The findings showed that SIPs with no EPS discontinuity were approximately twice as strong as those with EPS discontinuity. Regardless of depth classes, the SIP specimens with foam density of 1.2 lb/ft$^3$ had a higher $P_{\max}$ and lower $\Delta y_{\max}$. Additionally, there was no significant difference for $P_{\max}$ and $\Delta y_{\max}$ before and after creep testing within the 12.25-inch depth class or for $P_{\max}$ for the 6.5-inch-deep specimens, but $\Delta y_{\max}$ increased by approximately 7 percent after the creep test in the 6.5-inch-deep specimens. Results indicated that specimens with no foam discontinuity in shear critical areas had more strength in comparison with the specimens with a foam discontinuity and higher density foam cores were stronger for the specific flexural strength test conditions regardless of depth classes.

The concept of structural insulated panels (SIPs) began in 1935 at the Forest Products Laboratory in Madison, Wisconsin. SIPs consist of two wood-based outer layers, typically oriented strand board (OSB), sandwiched around an insulating foam core that is usually expanded polystyrene (EPS). Extruded polystyrene and polyurethane are alternatives for EPS; however, most commercial SIPs utilize EPS foam (Morley 2000, Aldrich et al. 2010). In addition to OSB, several other materials including plywood, magnesium oxide board, fiberglass mat, and composite structural siding panels can be used for the facers. SIPs have had many decades of use in both residential and nonresidential construction because of their reliable strength and stiffness properties that provide a wide range of structural applications. The foam core provides both insulating and mechanical (mainly shear) properties. Thicker foam cores increase the section modulus and moment of inertia and help develop a monolithic composite (McDonald et al. 2018). It is well demonstrated that SIPs have not only been used in wall applications, but they can also be used in roof or floor panels that are subjected to long-term transverse

The authors are, respectively, Assistant Research Professor (lk475@msstate.edu [corresponding author]) and Department Head and Warren S. Thompson Professor (rs26@msstate.edu), Dept. of Sustainable Bioproducts, Mississippi State Univ., Mississippi State; Research General Engineer, USDA Forest Serv., Forest Products Lab., Madison, Wisconsin (christopher.a.senalik@usda.gov); Warren S. Thompson Professor, Dept. of Sustainable Bioproducts, Mississippi State Univ., Mississippi State (dan.seale@msstate.edu); Supervisory Research Gen. Engineer, USDA Forest Serv., Forest Products Lab., Madison, Wisconsin (Robert.j.ross@usda.gov); Assistant Professor, Dept. of Sustainable Bioproducts, Mississippi State Univ., Mississippi State (mm5132@msstate.edu); SIPA TAC Chair, Managing Partner, Timber Engineering LLC, Vancouver, Washington (tomwilliamson@live.com); and Postdoctoral Associate, Dept. of Sustainable Bioproducts, Mississippi State Univ., Mississippi State (sf1006@msstate.edu). This paper was received for publication in April 2024. Article no. 24-00024.

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loading (McDonald et al. 2014). The mechanical properties of SIPs have been previously investigated, with promising results in the bending test (Uddin and Du 2014, Fajrin et al. 2017). In one study the static load test to collapse in the form of failure load and maximum deflection at failure were measured for SIPs that were subjected to 5 years of bending tests under two different climate conditions (Ahmed et al. 2016). The results suggested the flexural performance of SIPs is negatively affected with a high-moisture environment, as would be true for all wood-based systems. Furthermore, enhanced dynamic performance by 42 percent was observed for composite SIPs compared with concrete under earthquake load (Uddin and Du 2014). In another study conducted by Fajrin et al. (2017) the flexural properties of the three different SIP types were investigated. The authors suggested that the inclusion of intermediate layers such as lignocellulosic composites, jute fiber composite, and medium-density fiber can significantly enhance the strength of SIPs.

Comparisons of two depths of EPS-based foam core SIPs (16.5 cm and 31.1 cm, equivalent to 6.5 in. and 12.25 in., respectively) in static bending tests (McDonald et al. 2014) and creep behavior (McDonald et al. 2018) have been reported. The foam core typically contains butt-type end joints that act as shear discontinuities. The location of these joints is critical to the flexural performance of the SIP. These can lead to lesser shear capacity if located in high-shear zones in comparison with nonend-jointed foam (without discontinuities) in these zones. Although this factor may be important in shear-critical designs or applications, the occurrence of foam discontinuities is random in the SIP manufacturing process and cannot be controlled for a specific design situation. Although the effects of EPS foam discontinuity as well as foam density on the flexural strength of SIPs have been recognized by the SIP industry and are built into design guidelines, they have not been previously well documented, particularly in combination and at the full-scale specimen level. Furthermore, the influence of creep performance on the strength of various-depth SIPs is not well documented Therefore, the objectives of this research were to investigate the impact of EPS foam discontinuity, the effect of different foam densities in SIPs, and the effect of creep (duration of load) on the strength of 16.5 (6.5-in.)- and 31.1-cm (12.25-in.)-deep SIPs. It is hypothesized that the inclusion of foam density, foam discontinuity, and creep testing could influence SIP flexural performance. The consideration of these factors together in the context of full-scale specimen evaluation is novel.

## Materials and Methods

### Experimental design, foam discontinuity, and foam density

All OSB materials were manufactured by a North American-based commercial production facility and they were APA—The Engineered Wood Association performance-rated panels (PR-N610). All SIP specimens were approximately 29.8 cm (11.8 in.) wide. Two depth categories, 16.5 cm and 31.1 cm (6.5 in. and 12.25 in.), were considered. SIP foam cores were EPS and their OSB facers were 1.11 cm (0.4375 in.) thick. For each of two depth classes tested in this study, SIP specimens were assigned to a short-duration 1/3-point bending test and the other matched SIP specimens were subjected to a 90-day creep test, followed by a short-duration 1/3-point bending test. For reference, 1/3-point bending is a form of four-point bending wherein the span is divided into thirds with the loads placed at the 1/3 points. Furthermore, half of the panels consisted of approximately 0.016 g/cm$^3$ (1.0 lb/ft$^3$) and the other half had a 0.019 g/cm$^3$ (1.2 lb/ft$^3$) EPS foam density. The bending test was performed using a 140-kip capacity Instron universal testing machine (Instron, Norwood, MA) outfitted with a 1/3-point flexure according to the procedure described by Shmulsky et al. (2022) and Khademibami et al. (2023b). Actual average times to failure and load rates for each of the 16.5-cm (6.5-in.) and 31.1-cm (12.25-in.) depths were adjusted according to the procedure described by McDonald et al. (2018). The EPS foam discontinuity (butt joints) location as well as 1/3-point flexural bending setup are shown in Figure 1.

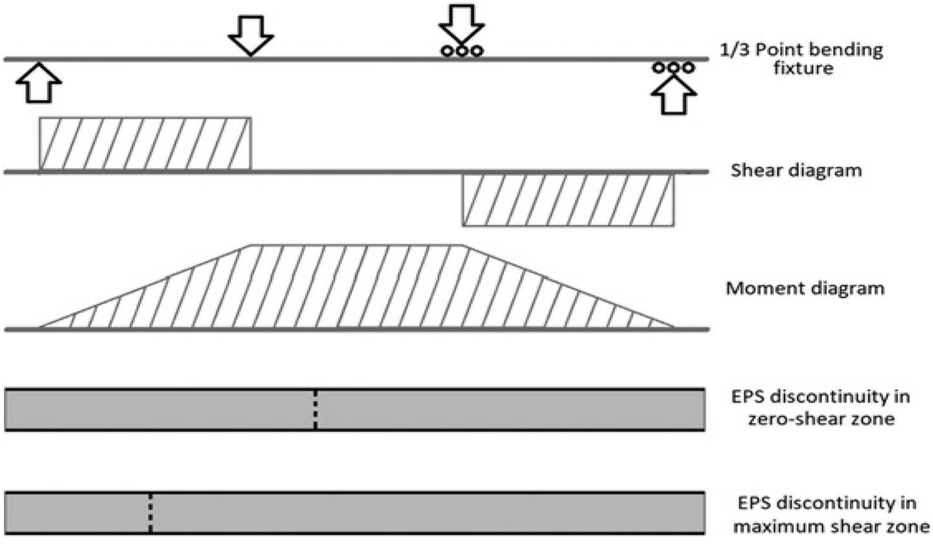

*Figure 1.—Diagram of 1/3-point flexural bending setup along with shear and moment diagrams, and sketch of expanded polystyrene (EPS) foam discontinuity location(s), presented by Shmulsky* et al. *(2022).*

## Flexural testing

The bending tests occurred in three phases for the 16.5-cm and 31.1-cm (6.5-in. and 12.25-in.) depths according to the method described by Khademibami et al. (2023a). Briefly, short-term bending tests with a 1/3-point flexure fixture, at an approximate 18:1 span-to-depth ratio, was used per ASTM D6815 (ASTM International 2015) to determine the creep design load for each depth class. Actual span-to-depth ratios were 17.6 for the 31.1-cm (12.25-in.) depth class (216-in. span length) and 18 for the 16.5-cm (6.5-in.) depth class (117-in. span length) specimens; the test setup is shown in Khademibami et al. (2023a). Next, the ASTM-D6815 (2015) standard was used to evaluate the 90-day full-scale duration of load tests. Design loads for the creep tests were based on the 5 percent point estimate from the short-term bending tests. The results of these creep tests are in preparation. Finally, within 1 week after the conclusion of the creep test the creep test specimens were tested in short-term bending with 1/3-point loading. These results represent flexure performance before and after creep testing. The creep performance of SIPs was measured by the method described by Seale et al. (2024). That reference provides a detailed description of the test fixturing and automated data acquisition system that can be used throughout the duration of a creep test.

## Statistical analysis

Individual SIP specimens served as the experimental unit for all tests. A statistical complete randomized design was used. The mixed effects of the two depth classes were excluded in data analysis because of previously significant differences between 16.5-cm (6.5-in.) and 31.1-cm (12.25-in.) depths. All variables were analyzed individually for the two depth classes using one-way analysis of variance to test for the effects of two foam densities and EPS discontinuities (with or without), as well as before-and-after duration of load testing. A general linear mixed model (PROC GLIMMIX) of SAS 9.4© (SAS Institute 2013) was used and the differences were deemed to be significant at $P \leq 0.05$. Treatment means separation was performed using Fisher's protected least significant difference analysis (Steel and Torrie 1980). The following model was performed for analysis of all data:

$$Y_i = \mu + T_i + E_i$$

where μ is the population mean; $T_i$ is the effect of duration of load (creep test) on the strength and stiffness of SIPs, foam density, or EPS discontinuity ($T = 1$ to 2); and $E_i$ is the residual error.

# Results

## Foam discontinuity

The $P_{\max}$ value of static bending (short-term) test for both 16.5-cm (6.5-in.) and 31.11-cm (12.25-in.) depths for each of the specimens with or without the EPS discontinuity within the zone of maximum shear is illustrated in Figure 2. The statistical differences between SIPs with or without EPS discontinuity for each depth class are presented in Figure 3 ($P \leq 0.0001$). Higher $P_{\max}$ values were observed in specimens that did not contain high-shear-zone EPS discontinuities as compared with those that included EPS discontinuities. Failure mode was in horizontal shear for all the specimens that contained EPS discontinuities.

## Foam density

The results of the static bending (short-term) test for two depth classes and two foam densities are shown in Figure 4. The specimens with the higher foam density resulted in higher $P_{\max}$ ($P \leq 0.0001$) in both depth classes. Deflection, however, was not consistent for the two foam densities and two depth classes. For the 16.5-cm (6.5-in.) depth class, higher foam density resulted in statistically significant lower deflection. For the 31.11-cm (12.25-in.) depth class, higher foam density resulted in statistically significant higher deflection.

## Flexural testing

The results of $P_{\max}$ and $\Delta y_{\max}$ from flexural testing before and after creep testing are shown in Figure 5. There were no significant differences of $P_{\max}$ ($P = 0.4172$) or

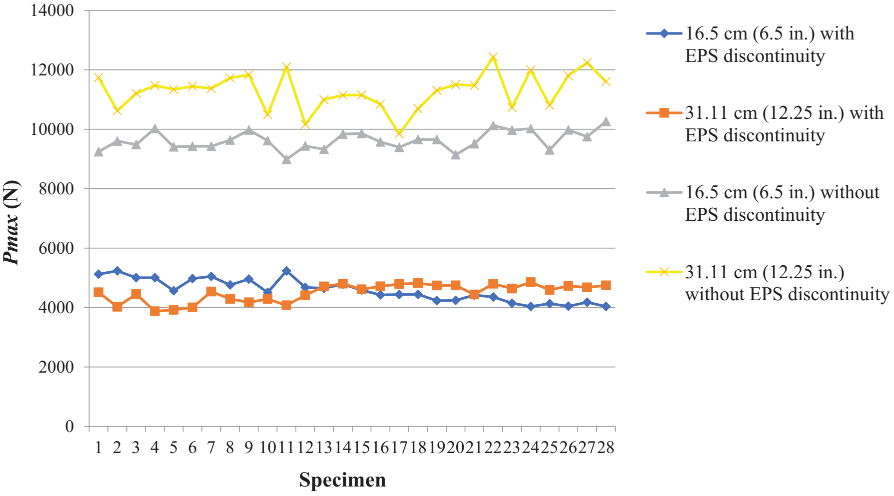

*Figure 2.—Static bending (short-term) test results (individual $P_{max}$) for each of 28 specimens with and without expanded polystyrene (EPS) discontinuity within the zone of maximum shear.*

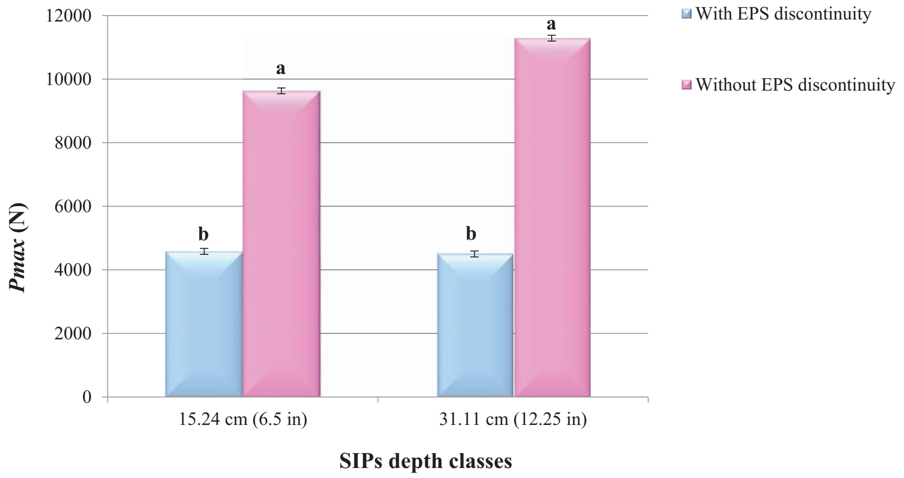

*Figure 3.—Mean* $P_{max}$ *for static bending (short-term) test results for specimens with and without expanded polystyrene (EPS) discontinuity within the zone of maximum shear (*$P \leq 0.0001$*).*

$\Delta y_{\max}$ ($P = 0.4093$) of 31.11-cm (12.25-in.)-deep specimens when analyzed before versus after the creep test. $P_{\max}$ ($P = 0.8241$) values were not significantly different for the 16.5-cm (6.5-in.)-deep specimens when analyzed before versus after the creep test. Statistically higher $\Delta y_{\max}$ ($P = 0.0018$) values were observed among the 16.5-cm (6.5-in.)-deep specimens after versus before creep testing.

## Discussion

The aim of this study was to determine the flexural properties of two SIP depths with differing foam densities, with and without EPS foam discontinuity in high-shear zones and before versus after creep testing. Findings showed that for both depth classes $P_{\max}$ was about twice as high for SIPs without foam discontinuity in the high-shear zone (between

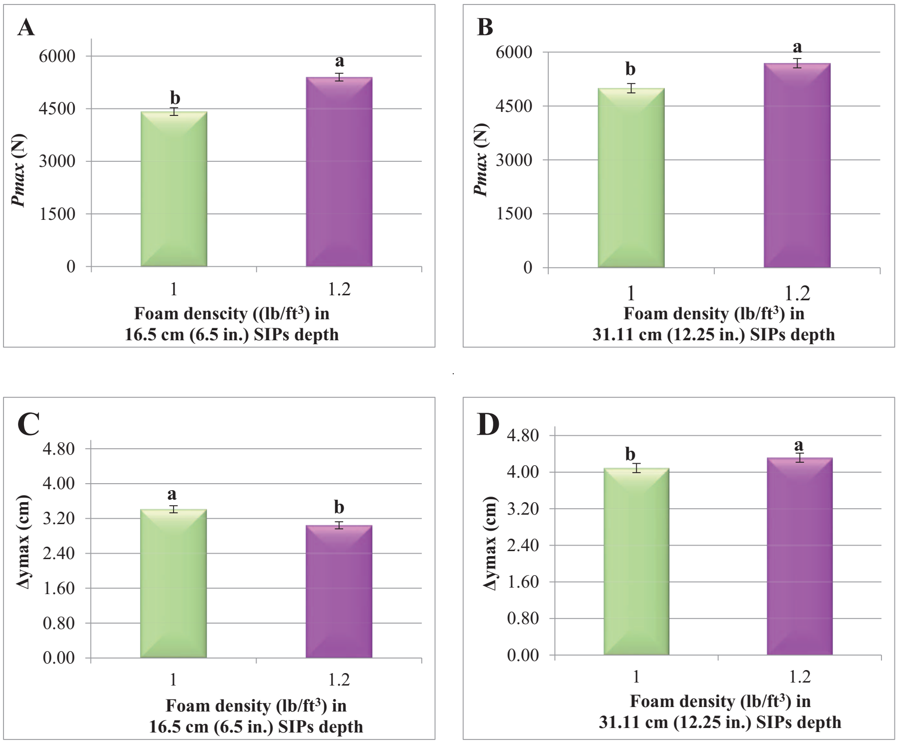

*Figure 4.—Results of* $P_{max}$ *values for two foam densities (0.019 g/cm*$^3$ *[1.2 lb/ft*$^3$*] and 0.016 g/cm*$^3$ *[1.0 lb/ft*$^3$*]) within 16.5-cm (6.5-in.) and 31.11-cm (12.25-in.) structural insulated panel (SIP) depths. (A) Mean* $P_{max}$ *for 0.019 g/cm*$^3$ *(1.2 lb/ft*$^3$*) foam density within 16.5-cm (6.5-in.) SIP depth.* $P \leq 0.0001$*. (B) Mean* $P_{max}$ *for 0.016 g/cm*$^3$ *(1.0 lb/ft*$^3$*) foam density within 31.11-cm (12.25-in.) SIP depth.* $P \leq 0.0001$*. (C) Mean* $\Delta y_{max}$ *for 0.019 g/cm*$^3$ *(1.2 lb/ft*$^3$*) foam density within 16.5-cm (6.5-in.) SIP depth.* $P \leq 0.0001$*. (D) Mean* $\Delta y_{max}$ *for 0.016 g/cm*$^3$ *(1.0 lb/ft*$^3$*) foam density within 31.11-cm (12.25-in.) SIP depth.* $P \leq 0.0001$*. Treatment means within the same column within effect with no common superscripts (a, b) are significantly different (*$P \leq 0.05$*).*

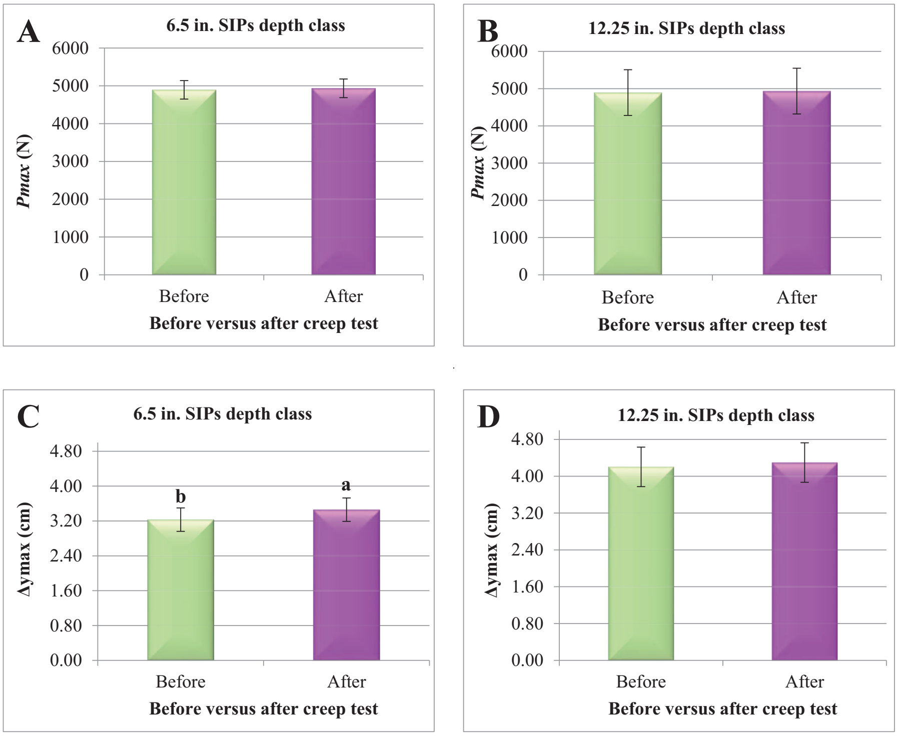

*Figure 5.—Results of static bending (short-term) test before versus after creep test of structural insulated panel (SIP) specimens in two depth classes: 16.5 cm (6.5 in.) and 31.11 cm (12.25 in.). (A) Mean $P_{max}$ before and after bending test within 16.5-cm (6.5-in.) SIP depth class. $P = 0.8241$. (B) Mean $P_{max}$ before and after bending test within 31.11-cm (12.25-in.) SIP depth class. $P = 0.0018$. (C) Mean $\Delta y_{max}$ before and after bending test within 16.5-cm (6.5-in.) SIP depth class. $P = 0.4172$. (D) Mean $\Delta y_{max}$ before and after bending test within 31.11-cm (12.25-in.) SIP depth class. $P = 0.4093$. Treatment means within the same column within effect with no common superscripts are significantly different ($P \leq 0.05$).*

the reaction support and the load head) versus those with foam butt joints in those zones. Shmulsky et al. (2022) suggested that a portion of the difference in potential design load or stress appears linked to the lower coefficient of variation (COV) values for $P_{\max}$ for those specimens with no EPS discontinuities in the high-shear zone as compared with those with discontinuities or when both types are pooled. This phenomenon can occur when two similar materials have differing variability because the design load or stress is based on the lower 5 percent point estimate. Also, the failure mode for the specimens without foam discontinuities was controlled by the tensile and compression strength of the OSB and not the foam. Therefore, to increase conservatism and reduce variability, it is suggested to include at least one discontinuity in the foam in the zone of maximum shear when SIPs are subjected to 1/3-point bending. However, it is noted that the inclusion of EPS foam discontinuity does result in lesser load capacity.

The results of this study demonstrate that higher foam density yields had a greater strength and a lesser deflection as compared with the lower foam density. This finding was consistent for both SIP depths. Khademibami et al. (2023b) suggested that the superior results associated with higher foam density could be associated with the greater polymer mass, and less air, in the foam's bulk matrix.

For the 31.11-cm (12.25-in.)-deep specimens tested in bending before versus after creep testing, no significant differences in strength and stiffness were observed. The 16.5-cm (6.5-in.)-deep specimens tested in bending also had no significant difference in strength but developed higher $\Delta y_{\max}$ after creep testing.

## Conclusions

In conclusion, the influences of foam discontinuity, foam density, and creep performance (duration of load) on the strength and stiffness of SIPs on two depth classes, 16.5 cm (6.5 in.) and 31.11 cm (12.25 in.), were investigated. Findings revealed that regardless of depth class, an increase in flexural strength was observed when foam with no butt joints occurred in the high-shear zone or when higher foam density was used. For the 31.11-cm (12.25-in.)-deep specimens, no statistical changes in $P_{\max}$ and $\Delta y_{\max}$ before and after creep test loading were seen. In 16.5-cm (6.5-in.)-deep specimens, $P_{\max}$ values did not differ but $\Delta y_{\max}$ was approximately 7 percent higher after creep test loading. Lower strength and higher COV were seen in specimens with foam discontinuities in the shear zone. In addition, greater foam density leads to greater strength and lesser deflection.

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