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Evaluation of Creep Performance of Structural Insulated Panels (SIPs)

Phase 2

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Forest Service

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Abstract

Structural insulated panels (SIPs) were creep-tested to determine the magnitude of long-term deflection and recovery, as well as changes to strength and stiffness, compared with a control group. This report documents the second phase of a two-phase testing process. The first phase was reported in FPL–RN–0332. In this second phase, 56 SIP control specimens were tested in static bending to failure. Of these, 28 were 12 in. wide by 12.25 in. deep by 19 ft long and 28 were 12 in. wide by 6.5 in. deep by 10 ft long. A matching set of 56 specimens were instrumented for deflection and subjected to 90 days of constant (creep) load, which was set at approximately one-third the average short-term breaking strength of their control group per industry practice. They were then monitored unloaded for 30 days for deflection recovery. For the 12.25-in.-deep specimens, the creep deflection was approximately 15% of the corresponding short-term deflection at failure, with a total 30-day recovery of 81%. The 6.5-in.-deep specimens had a creep deflection of 11% of the short-term failure deflection with a total 30-day recovery of 91%. After creep testing, the specimens were static-load-tested to failure. The 12.25-in.-deep specimens failed at about 90% of the non-creep-tested control failure load. The 6.5-in.-deep specimens failed at approximately the same load as the non-creep-tested control specimens. This report documents the findings of the testing of the SIP panels as well as issues of concern encountered during the testing process.

Keywords: creep, static loading, structural insulated panels

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English unit	Conversion factor	SI unit
inch (in.)	25.4	millimeter (mm)
square inch (in ²)	645.16	square millimeter (mm ²)
foot (ft)	0.3048	meter (m)
pound (lb), mass	0.45359	kilogram (kg)
pound (lb), force	4.4482	newton (N)
pound per cubic foot (lb/ft ³)	16.02	kilogram per cubic meter (kg/m ³)
Nominal lumber size (in.)		Standard lumber size (mm)
2 by 6		38 by 140

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Evaluation of Creep Performance of Structural Insulated Panels (SIPs)

Phase 2

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Introduction

Structural insulated panels (SIPs) are a composite building material. They are sandwiches that consist of two layers of structural facers with an insulating layer of foam in between. Typical facers are either sheet metal or oriented strandboard (OSB), and the foam can be expanded polystyrene (EPS), extruded polystyrene (XPS), or polyurethane. This study was limited to an evaluation of SIPs using 0.44-in. (7/16-in.) performance category OSB facers and EPS foam cores at two different thicknesses.

SIPs share the same structural properties as an I-beam or I-column. The rigid insulation core of the SIP functions as a web, and the facers function as flanges. The use of SIPs replaces several components of conventional building such as studs, joists, headers, rafters, and insulation. As such, they can be used for many different applications in wall, roof, and floor systems.

Materials

The test specimens were sampled from a production run at a Structural Insulated Panel Association (SIPA) member manufacturer and are representative of the product under evaluation. For all specimens, the panel facings consisted of PR-N610-rated, 0.44-in. (7/16-in.), Exposure 1 OSB sheathing on both sides and the insulating foam was 1-lb/ft³ EPS. All test specimens were constructed and cut with the OSB strength axis parallel with the panel length. For this study, 65 12-in. by 12.25-in. by 19-ft sections, each with 11.25-in.-thick EPS foam cores, and 65 12-in. by 6.5-in. by 10-ft sections, each with 5.63-in.- (5-5/8-in.-) thick EPS foam cores, were provided for testing. Two groups were tested for each size selected, 28 for short-term bending tests and 28 for long-term creep-rupture bending tests.

Testing Program

To address the creep performance of SIPs, a two-phase testing program was initiated. Phase 1 was a collaboration

between the USDA Forest Service, Forest Products Laboratory (FPL), APA—The Engineered Wood Association (APA), and SIPA as a pilot test program to evaluate basic creep performance parameters using a limited number of test specimens under three load conditions. Separate testing to evaluate shear critical loading conditions was conducted by APA, and the testing to evaluate bending critical creep performance was conducted at FPL. The results of this study were reported by FPL–RN–0332 (McDonald and others 2014). Based on the results of the pilot test program, a more in-depth test program (Phase 2) was undertaken using ASTM D6815 (ASTM 2015) as the basis to establish creep performance factors for SIPs that can potentially be included in the American Wood Council National Design Specification (NDS).

A total of 112 SIP specimens of two different depths were tested in either static (short-term) or creep (long-term) bending following by static testing (Table 1). Two specimen depths, 6.5 and 12.25 in., were selected to represent the range of SIPs typically used in horizontal applications. To determine short-term failure loads and corresponding deflection values, 28 control specimens of each depth were tested in four-point bending (Fig. 1). The spans used were 1.5 in. less than the full length to allow stable, simple supports. Loads were placed symmetrically about the center with a load span one-third of the total span (Fig. 2).

Table 1—Specimen and test configuration details

Test no.	Sample depth (in.)	Sample width ^a (in.)	Span ^a (in.)	Load level	No. of samples	Duration
1	6.5	12	118.5	To failure	28	1 min
1a	6.5	12	118.5	350 lb	28	90 days
2	12.25	12	226.5	To failure	28	1 min
2a	12.25	12	226.5	350 lb	28	90 days

^aThe bending creep tests used a sample width of 12 in. and a test span of approximately 18 times the structural insulated panel depth.



Figure 1. Static bending test setup: (a) 12.25-in.-deep specimens; (b) 6.5-in.-deep specimens.

It was proposed that moment-critical testing would provide the required results using foam flush end-bearing conditions (that is, no dimension lumber blocks were required at the ends of the specimens).

Test Method

Static Testing

Fifty-six specimens (28 of each depth) were tested in static bending to failure. This process was consistent with “short-term” bending tests per ASTM D6815 with the following deviations noted: (1) the test load used was not as defined in section 5.3.2, (2) the decreasing creep rate was not determined per section 5.4.2, and (3) the fractional deflection was not determined per section 5.4.3. The load was provided by an MTS 244.31 55-kip hydraulic actuator (MTS Systems Corporation, Eden Prairie, Minnesota, USA) (1 kip = 1,000 pounds, force). This was connected to a spreader bar and two swivel heads with 3.5-in.-wide dimension lumber contact points. The specimens were supported by roller stands with 1.5-in.-wide lumber contact points.

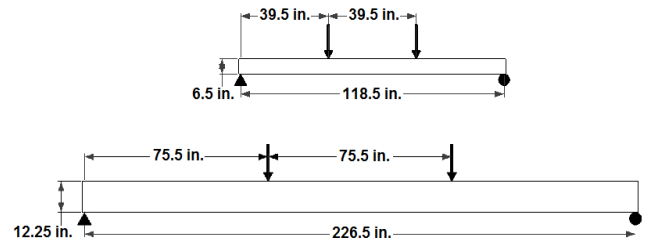


Figure 2. Static loading diagrams for 6.5-in.-deep specimens and 12.25-in.-deep specimens.

The specimens were loaded in four-point symmetric bending. The support span was as large as the geometry allowed, and the load span and shear leg were one-third of the support span (Fig. 2). Specimens were loaded for a constant load head movement of 2 in./min, which caused failure between 30 and 60 s.

Load and deflection data were recorded five times per second throughout the test. The average maximum load (that is, load at failure, P_{Max} in every case) in these short-term tests was used to calculate an appropriate long-term creep load based on $P_{Max}/3$. $P_{Max}/3$ is the basis for establishing all design loads for SIPs based on Section 4.2 of ICC AC04 (ICC 2012) and is used here as the recognized standard industry practice.

Creep Testing

Creep testing used the same four-point test geometry as the static test (Fig. 3). Load was applied by pneumatic actuators (Marsh Bellofram Group of Companies, Newell, West Virginia, USA) with a bore area of 30 in². One actuator was used per load point. Load heads had the same 3.5-in. bearing widths as the static tests. The specimens were supported by an edgewise 2 by 6, giving the same support width as the static tests.



Figure 3. Creep test setup for the 12.25-in.-deep specimens.

Groups of pneumatic actuators were supplied with air via one of three main regulators. Group 1 included the actuators on specimens 1 through 9, group 2 included actuators on specimens 10 through 18, and group 3 included actuators on specimens 19 through 28. Each actuator group had a dedicated main regulator and shutoff. One specimen of each group was equipped with a load cell on each of its two actuators. The air supply was adjusted using the main regulator for each group of actuators until load cells on the monitored specimen within the group indicated the desired load.

The creep test specimens were loaded to 350 lb for both specimen depths, which is approximately one-third of the short-term failure load. The initial load rate was set such that the average time to attain the preselected constant stress level would not exceed the average time to failure of the short-term tests. Thereafter, the specimens were subjected to constant load for a minimum period of 90 days. During this period, midspan deflection readings were taken for each specimen until the 90-day time period had elapsed or until a failure occurred. Deflection readings were taken at regular intervals. No specimen experienced material failure in the 90-day tests. The test load was removed after 90 days, and the midspan deflections continued to be recorded for an additional 30 days.

After the creep recovery period, the creep-tested specimens were statically tested in the same orientation to determine the specimens' residual strength and flexibility after the 90-day creep loading.

Results

Table 2 shows the load and deflection values of the control specimen static tests, the deflection values of the SIPs after

Table 2—Results summary of structural insulated panel testing

Test	Specimen depth	
	12.25 in.	6.5 in.
Static failure load of control specimens, lb	1,014	1,032
Deflection of control specimens at failure, in.	1.251	1.031
Initial elastic deflection at start of creep test, in.	0.462	0.413
Additional deflection caused by creep behavior, in.	0.193	0.129
Total deflection, in.	0.655	0.543
Initial elastic recovery at removal of long-term load, in.	0.448	0.409
Additional recovery caused by creep behavior, in.	0.092	0.080
Total deflection recovered, in.	0.540	0.489
Static failure load of postcreep-tested specimens, lb	917	1,059
Deflection caused by static failure load of postcreep-tested specimens, in.	1.048	1.158

the load was applied initially and that accrued after 90 days of constant load, and the initial deflection recovery after the load was removed plus the additional recovery that occurred after 30 days in the unloaded state. It also shows the load and deflection values of the postcreep specimen static tests after the 30-day recovery period. All values are averages for the 28-specimen test sets. However, as discussed in the Testing Issues section of this report, specimens 6-10 through 6-18 were excluded for the 6.5-in.-depth data set and specimens 12-11 and 12-6 were excluded for the 12.25-in.-depth data set.

Load and deflection graphs of each test's creep behavior are presented in Appendix A. Recovery graphs are presented in Appendix B.

Individual numeric creep and recovery results are presented in Appendix C. Static bending results of control and postcreep specimens are presented in Appendix D.

Discussion

Creep Effects

The test results are perhaps best understood when their values are shown in relation to each other, as in Table 3.

These results show that creep deflection was in the range of approximately 30% to 40% of the value of the load's initial elastic deflection. There was significant recovery of total deflection (82%–90%) when the applied load was removed and the specimens were allowed to rest for 30 days (with no load), implying that the creep behavior was at least partially elastic.

The postcreep static test load for the 12.25-in.-deep specimens was at about 90% of the 12.25-in.-deep control

Table 3—Average test results as a comparison of deflection states

Test	Specimen depth	
	12.25 in.	6.5 in.
Creep deflection, as a percentage of initial elastic deflection	42%	31%
Creep deflection, as a percentage of total deflection	29%	24%
Creep deflection, as a percentage of failure deflection	15%	13%
30-day creep deflection recovery, as a percentage of 90-day creep deflection	48%	62%
Total deflection recovery, as a percentage of total creep test deflection	82%	90%
Static bending strength of postcreep-tested specimens as a percentage of control specimen strength	90%	103%
Static deflection of postcreep-tested specimens as a percentage of control specimen deflection	84%	112%
Static plus creep deflection of long-term specimens as a percentage of control specimen deflection	91%	117%

specimen static test load. The postcreep static test load for the 6.5-in.-deep specimens was about the same as the 6.5-in.-deep control specimen static test load. The postcreep static deflection for the 12.25-in.-deep panels was 84% of the control’s value, and the postcreep static deflection for the 6.5-in.-deep panels was 112% of the control’s value.

A comparison of average static test results before and after creep loading shows that the creep loading caused a loss of strength in the 12.25-in.-deep panels of 10% with a 16% lower deflection at failure. For the 6.5-in.-deep panels, creep loading caused a 3% increase in strength values and a 12% increase in deflection at failure. As described in Appendix E, deflection is governed by flexure properties but strength is controlled by shear.

For the 6.5-in.-deep specimens, the 30-day recovery of creep deflection was 62%, whereas it was 48% for the 12.25-in.-deep specimens.

Creep behavior for SIPs under flexural loading with respect to time was modeled using the power model as described in Taylor and others (1997). A description of the application of the model is given in Appendix F.

Testing Issues

As stated in the Test Method section, the long-term loads during the creep testing were applied using pneumatic actuators. Groups of several actuators were linked to common regulators for air supply. There were three groups of actuators: group 1 included actuators on specimens 6-1 through 6-9, group 2 included actuators on specimens 6-10 through 6-18, and group 3 included actuators on specimens 6-19 through 6-28. Each group had a separate air regulator that fed air to all of the actuators. As a result, similarities in curve shape were seen between specimens loaded by a particular group of actuators but not in other groups. A load cell was used to measure the load on one specimen in each group of actuators fed by a common regulator. The regulator pressure was adjusted until the load cell yielded the load desired for the long-term testing. The time-weighted load for each recorded load cell is given in Table 4.

During the period of loading for the 6.5-in. specimens, the specimen groups 1 and 3 demonstrated expected creep deflection. The specimen group 2 demonstrated a lack of noticeable creep deflection relative to specimen groups 1 and 3. Load cell and pressure data from specimen group 2 showed multiple instances of load–pressure loss and readjustment that probably influenced creep displacement. After the pressure was corrected, the creep deflection for the specimens loaded by specimen group 2 began to conform to expected creep behavior, but it was decided to exclude this data from the results.

There were no deflection data for the 12.25-in. creep specimen 12-16 because of a sensor malfunction; however, it was determined that the specimen was loaded correctly and its postcreep static test was valid. Specimen 12-11 displayed a deflection behavior significantly different from all other creep specimens; the deflection increased linearly for approximately 13 days then remained constant or slightly decreased for the subsequent 25 days. This behavior raised concerns regarding the validity of the displacement data and if the observed behavior represented creep or some other phenomenon. As a result, specimen 12-11 was excluded from the results.

There was an unexpected correlation between the order of the specimens tested and the maximum load supported during static testing by the specimen. For the control group of 6.5-in. specimens, the maximum load decreased with increasing number of tests with an r^2 value of 0.816. For the control group of 12.25-in. specimens, the maximum load increased with increasing number of tests (r^2 of 0.505). For the 6.5-in. specimen group tested after long-term loading, there was no significant correlation between maximum load and order of testing (r^2 of 0.009). For the 12.25-in. specimens group tested after long-term loading, there was a slight increase in maximum load with increasing number of tests (r^2 of 0.298). Correlation between maximum load and the order the specimens were tested was not expected. Factors examined as possible causes included material handling after receiving the shipment of specimens to the laboratory, handling during testing, load cells, changes in test setup, and ambient conditions, but no conclusive explanation has yet been found for the noted unexpected correlation. However, the coefficient of variation for all static load data sets was within the expected range, and the P_{Max} values were within the expected range based on Phase 1 testing. Therefore, the creep test load of approximately $P_{Max}/3$ or 350 lb was deemed appropriate.

Table 4—Time-weighted load by specimen group

Specimen ID	Thickness (in.)	Specimen group	Time-weighted load (lb)		
			Load cell 1	Load cell 2	Total
6-9	6.5	1–9	184.6	182.4	367.0
6-18	6.5	10–18	—	—	—
6-28	6.5	19–28	185.3	191.5	376.7
12-9	12.25	1–9	197.5	200.2	397.7
12-18	12.25	10–18	192.0	179.0	371.1
12-28	12.25	19–28	178.0	180.2	358.2

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Appendix A—Load and Deflection Graphs of SIP Creep Tests

The graphs in this appendix do not show the initial elastic deflection that occurred when the load was first applied, only the deflection attributable to creep behavior. Each line starts at zero at the earliest time a steady state was reached after loads were applied. For the 12.25-in.-deep specimens (Fig. A1), this occurred at 2 h 25 min. For the 6.5-in.-deep specimens (Fig. A2), this was at 45 min because of the hyper-responsiveness of the pressure regulating instruments.

Some specimens lost pressure for a number of days during the 90-day test. To make up for this, their load time was extended to give them a total of 90 days under creep

loads. The time periods without load were removed from the graphs. The graphs only show the 90 days during which load was applied.

During the final 60 days of the 12.25-in. tests, data were taken once a day, whereas for the 6.5-in. tests, data were taken every hour. This was done to catch discontinuities in the data that did not correspond to creep behavior. As a result, the 6.5-in. graph lines have more ‘noise’ than the 12.25-in. lines, but they should not be considered to be any more or less precise.

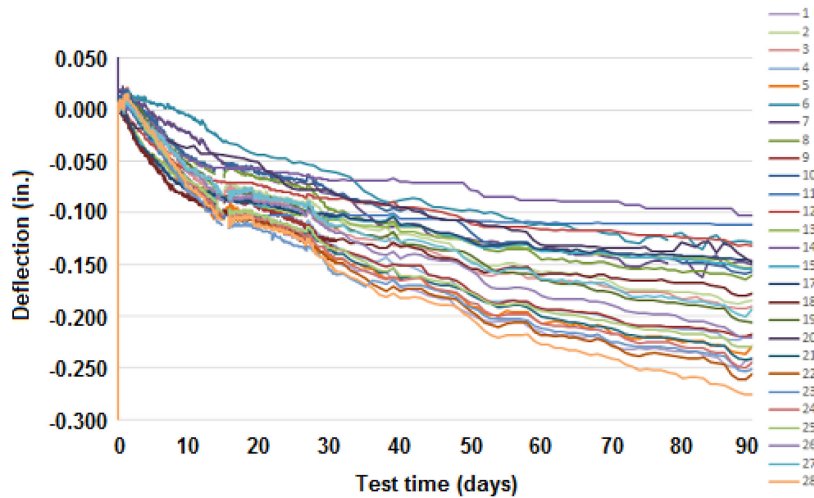


Figure A1. Creep deflection with time, 12.25-in.-deep specimens.

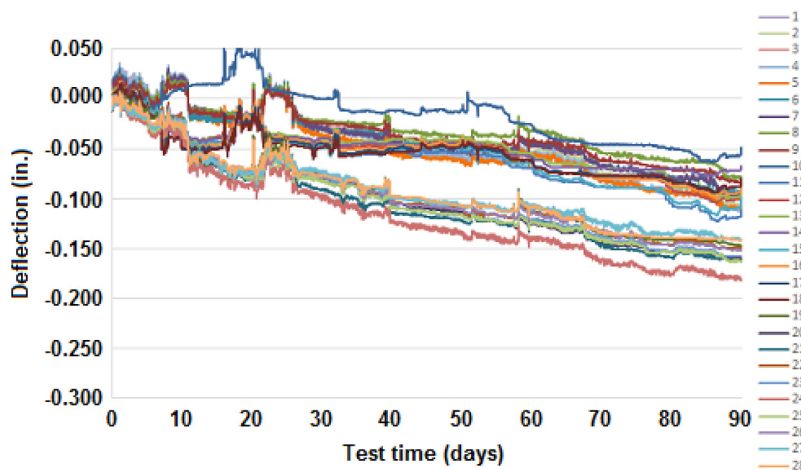


Figure A2. Creep deflection with time, 6.5-in.-deep specimens.

Appendix B—Load and Deflection of SIP Recovery after Creep Testing

The graphs in this appendix (Figs. B1 and B2) do not show the initial elastic deflection that occurred when the load was first removed, only the long-term deflection recovery.

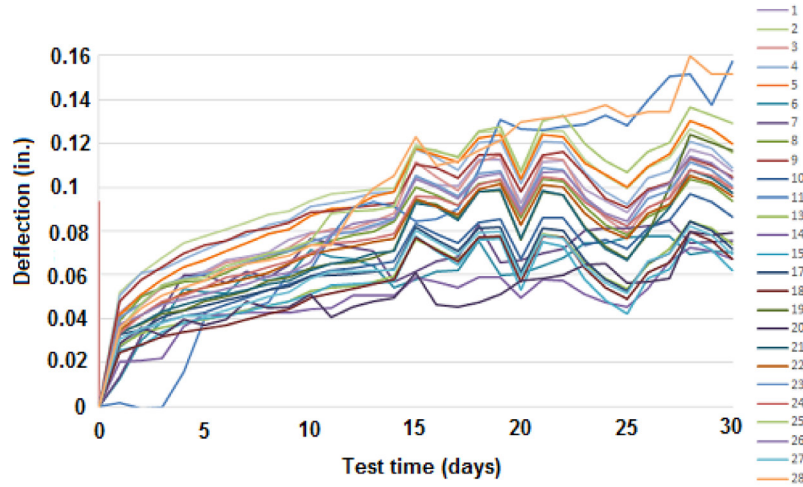


Figure B1. Deflection recovery after removal of load, 12.25-in.-deep specimens.

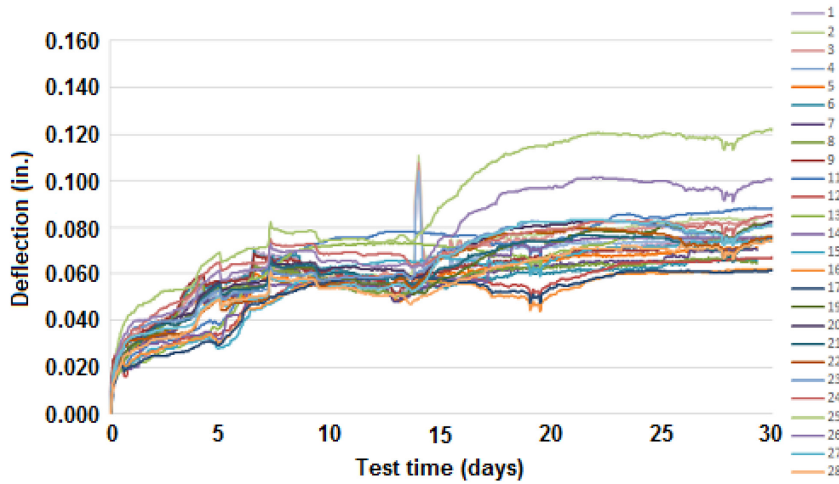


Figure B2. Deflection recovery after removal of load, 6.5-in.-deep specimens.

Appendix C—Creep and Recovery Deflection of Long-Term Bending Tests

Table C1—Creep and recovery deflection, 12.25-in. specimens

Specimen ID	Initial deflection (in.)	Creep deflection (in.)	Initial recovery (in.)	Final recovery (in.)
12-1	0.597	0.243	0.534	0.107
12-2	0.640	0.186	0.535	0.116
12-3	0.592	0.192	0.462	0.098
12-4	0.598	0.220	0.512	0.109
12-5	0.580	0.229	0.524	0.120
12-6	0.588	0.127	0.644	0.071
12-7	0.611	0.147	0.654	0.075
12-8	0.538	0.160	0.470	0.094
12-9	0.564	0.217	0.499	0.105
12-10	0.522	0.157	0.462	0.086
12-11 ^a	—	—	—	—
12-12	0.325	0.132	0.275	0.022
12-13	0.353	0.154	0.323	0.074
12-14	0.309	0.103	0.274	0.067
12-15	0.344	0.154	0.333	0.062
12-16 ^b	—	—	—	—
12-17	0.338	0.146	0.332	0.072
12-18	0.329	0.178	0.327	0.067
12-19	0.380	0.206	0.378	0.117
12-20	0.383	0.143	0.469	0.079
12-21	0.384	0.241	0.414	0.098
12-22	0.444	0.256	0.485	0.096
12-23	0.434	0.251	0.444	0.101
12-24	0.441	0.245	0.479	0.100
12-25	0.432	0.230	0.428	0.129
12-26	0.433	0.220	0.448	0.104
12-27	0.405	0.193	0.423	0.069
12-28	0.450	0.276	0.518	0.152
Average	0.462	0.193	0.448	0.092
CoV ^c , %	23	24	22	29

^aSpecimen 12-11 displayed a behavior significantly different from all other specimens and was excluded.

^bAs discussed in the Testing Issues section, there were no deflection data for the 12.25-in. creep specimen 12-16 because of a sensor malfunction; however, it was determined that the specimen was loaded correctly and its postcreep static test was valid.

^cCoV, coefficient of variation.

Table C2—Creep and recovery deflection, 6.5-in. specimens

Specimen ID ^a	Initial deflection (in.)	Creep deflection (in.)	Initial recovery (in.)	Final recovery (in.)
6-1	0.473	0.115	0.397	0.074
6-2	0.471	0.109	0.393	0.083
6-3	0.473	0.098	0.390	0.081
6-4	0.454	0.115	0.384	0.074
6-5	0.417	0.111	0.366	0.071
6-6	0.435	0.096	0.375	0.066
6-7	0.426	0.097	0.369	0.070
6-8	0.402	0.080	0.339	0.065
6-9	0.417	0.083	0.359	0.075
6-19	0.344	0.147	0.391	0.083
6-20	0.394	0.160	0.459	0.083
6-21	0.390	0.162	0.439	0.076
6-22	0.371	0.150	0.427	0.077
6-23	0.384	0.158	0.445	0.081
6-24	0.410	0.182	0.475	0.086
6-25	0.457	0.163	0.506	0.123
6-26	0.425	0.152	0.465	0.101
6-27	0.368	0.142	0.412	0.082
6-28	0.344	0.142	0.380	0.075
Average	0.413	0.129	0.409	0.080
CoV ^b , %	10	24	11	16

^aAs discussed in the Testing Issues section, specimens 6-10 through 6-18 were excluded for the 6.5-in. analysis.

^bCoV, coefficient of variation.

Appendix D—Static Bending Results of Control and Postcreep-Tested Specimens

Table D1—Static bending results for 12.25-in. specimens

Control specimen ID	Control tests		Specimen ID	Postcreep tests	
	Maximum load (lb)	Deflection at max. load (in.)		Maximum load (lb)	Deflection at max. load (in.)
12-1 ctrl	1,017	1.235	12-1	911	1.032
12-2 ctrl	907	1.158	12-2	854	0.913
12-3 ctrl	1,003	1.173	12-3	896	0.975
12-4 ctrl	873	1.030	12-4	920	1.045
12-5 ctrl	883	1.025	12-5	883	0.931
12-6 ctrl	902	1.103	12-6	802	0.794
12-7 ctrl	1,022	1.228	12-7	912	1.076
12-8 ctrl	967	1.154	12-8	909	1.043
12-9 ctrl	941	1.180	12-9	928	1.034
12-10 ctrl	966	1.176	12-10	821	0.876
12-11 ctrl	918	1.111	12-11	829	0.940
12-12 ctrl	994	1.251	12-12	813	0.970
12-13 ctrl	1,061	1.384	12-13	858	0.968
12-14 ctrl	1,082	1.360	12-14	805	0.899
12-15 ctrl	1,039	1.272	12-15	882	1.023
12-16 ctrl	1,062	1.298	12-16	999	1.188
12-17 ctrl	1,079	1.358	12-17	957	1.152
12-18 ctrl	1,086	1.452	12-18	971	1.129
12-19 ctrl	1,068	1.269	12-19	1,063	1.299
12-20 ctrl	1,069	1.305	12-20	997	1.167
12-21 ctrl	1,000	1.249	12-21	999	1.157
12-22 ctrl	1,081	1.286	12-22	920	1.088
12-23 ctrl	1,045	1.246	12-23	984	1.189
12-24 ctrl	1,093	1.368	12-24	951	1.092
12-25 ctrl	1,034	1.263	12-25	973	1.063
12-26 ctrl	1,065	1.352	12-26	954	1.074
12-27 ctrl	1,054	1.319	12-27	954	1.140
12-28 ctrl	1,069	1.410	12-28	927	1.088
Average	1,014	1.251	Average	917	1.048
CoV ^a , %	7	9	CoV ^a , %	7	11

^aCoV, coefficient of variation.

Table D2—Static bending results for 6.5-in. specimens

Control specimen ID	Control tests		Specimen ID	Postcreep tests	
	Maximum load (lb)	Deflection at max. load (in.)		Maximum load (lb)	Deflection at max. load (in.)
6-1 ctrl	1,154	1.204	6-1	1,093	1.179
6-2 ctrl	1,179	1.250	6-2	1,062	1.143
6-3 ctrl	1,127	1.199	6-3	1,074	1.141
6-4 ctrl	1,127	1.171	6-4	1,053	1.151
6-5 ctrl	1,029	1.080	6-5	942	1.017
6-6 ctrl	1,121	1.153	6-6	913	0.956
6-7 ctrl	1,137	1.173	6-7	1,085	1.232
6-8 ctrl	1,072	1.035	6-8	1,198	1.410
6-9 ctrl	1,117	1.121	6-9	1,076	1.223
6-10 ctrl	1,016	0.949	6-10	— ^a	—
6-11 ctrl	1,179	1.254	6-11	—	—
6-12 ctrl	1,054	1.003	6-12	—	—
6-13 ctrl	1,047	1.061	6-13	—	—
6-14 ctrl	1,079	1.036	6-14	—	—
6-15 ctrl	1,033	0.986	6-15	—	—
6-16 ctrl	997	0.931	6-16	—	—
6-17 ctrl	1,000	0.962	6-17	—	—
6-18 ctrl	1,001	1.017	6-18	—	—
6-19 ctrl	953	0.904	6-19	1,036	1.141
6-20 ctrl	955	0.901	6-20	1,124	1.308
6-21 ctrl	996	0.883	6-21	1,021	1.040
6-22 ctrl	981	0.997	6-22	1,059	1.156
6-23 ctrl	934	0.945	6-23	1,105	1.218
6-24 ctrl	909	0.877	6-24	1,134	1.331
6-25 ctrl	931	0.908	6-25	1,104	1.160
6-26 ctrl ^b	911	0.911	6-26	1,121	—
6-27 ctrl	942	0.991	6-27	1,067	1.162
6-28 ctrl	909	0.959	6-28	862	0.882
Average	1,032	1.031	Average	1,059	1.158
CoV ^c , %	8	11	CoV ^c , %	8	11

^aAs discussed in the Testing Issues section, specimens 6-10 through 6-18 were excluded for the 6.5-in. analysis.

^bThere were no deflection data for specimen 6-26 because of a sensor malfunction. Maximum load is valid.

^cCoV, coefficient of variation.

Appendix E—Static Bending Failures

The static bending tests typically failed in shear at the manufactured discontinuities in the EPS web (Fig. E1). These discontinuities are points of dramatically decreased shear strength. Also, the industry-published design values for both depths and spans are controlled by shear, and this finding supports the validity of the test data.

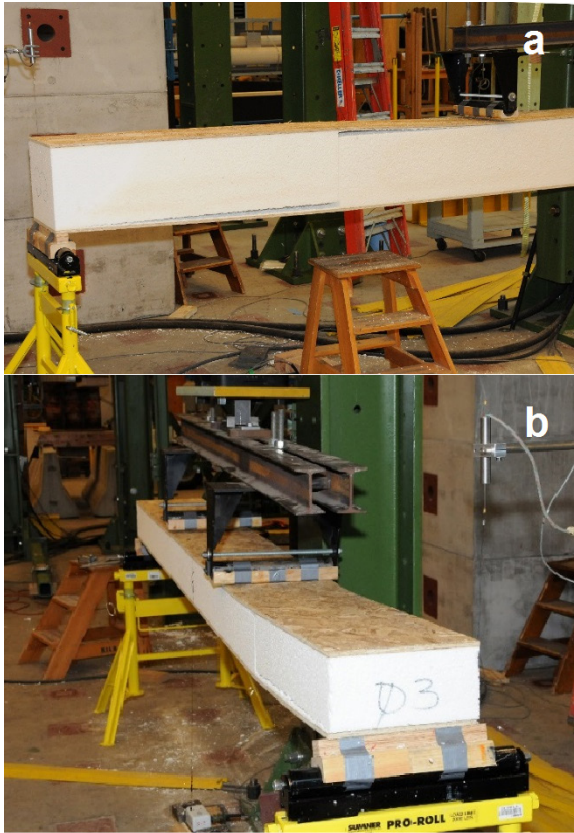


Figure E1. Typical static bending failure: (a) 12.25-in.-deep specimens; (b) 6.5-in.-deep specimens.

Appendix F—Modeling of Creep Behavior

Creep behavior for SIPs under flexural loading with respect to time was modeled by Taylor and others (1997). Taylor and others examined four distinct models for creep behavior: a three-, four-, and five-element viscoelastic model and a power model. Based on a comparison with the raw data, the five-element viscoelastic model and the power model were recommended for modeling creep behavior of SIPs for a 3-month load duration. In this study, SIPs were placed under constant load for a period of 90 days. The power model was selected to represent the creep behavior. The general form of the power model is given in the following equation:

$$\Delta(t) = \Delta_0 + A_1 t^{A_2}$$

Where $\Delta(t)$ is the total time-dependent deflection; Δ_0 is the initial deflection, and A_1 and A_2 are creep parameters (Taylor and others 1997). The initial deflection, Δ_0 , is equal to zero, simplifying the power model to the form given in the following equation:

$$\Delta(t) = A_1 t^{A_2}$$

There were 28 SIP specimens measuring 12.25 in. thick. Of the 28 specimens, 26 conformed to expected creep behavior regarding deflection with respect to time. As stated in Appendix C, there were no usable deflection data for specimen 12-16. Specimen 12-11 displayed a deflection behavior significantly different from all other creep specimens; the deflection increased linearly for approximately 13 days then remained constant or slightly decreased for the subsequent 25 days. The behavior raised concerns regarding the validity of the displacement data and if the observed behavior represented creep or some other

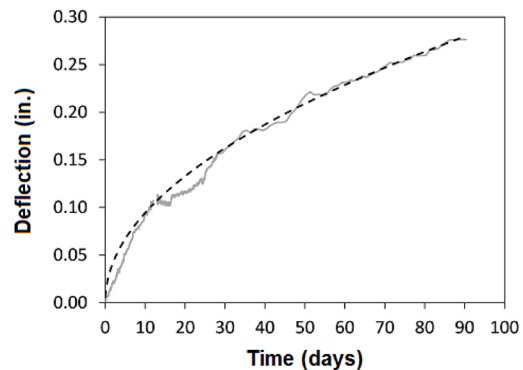


Figure F1. Representative deflection versus time data set with fitted power model curve. The data shown are from the 12.25-in. specimen 12-28. The solid gray line is the recorded data; the dashed black line is the fitted power model.

phenomenon. As a result, specimens 12-11 and 12-16 were excluded from the modeling process. A typical SIP deflection curve for the 12.25-in. specimens with respect to time is shown in Figure F1. There are two distinct regions, an early time region in which the change in rate of deflection changes rapidly, and a late time region in which the change in rate of deflection is steady. For the 12.25-in.-thick panels used in this study, the transition between those two deflection rates was at approximately 30 days. If the power model fit included the early time region of the deflection curve (0 to 30 days), then the modeled deflection overestimated the actual deflection during the late time region and became increasingly divergent with increasing time. If the power model excluded the early time region, then the modeled deflection estimated the late time region deflection to within $\pm 5\%$, but the early time region was overestimated. It was decided to fit the power model only to the late time region (30 to 90 days) because the model converges with the actual data at time 0 and 30 days. The same modeling process was used on the 6.5-in. SIP specimens. A typical SIP deflection curve for the 6.5-in. specimens with respect to time is shown in Figure F2.

The creep parameters, A_1 and A_2 , and the coefficient of determination (r^2) values for each of the 26 12.25-in. specimens and the 19 6.5-in. specimens are given in Table F1. As stated in the Testing Issues section, a reduction in load to cylinder group 2 during the long-term loading caused a lack of noticeable creep for a significant portion of the test. As a result, it was decided to exclude the specimens in specimen group 2, which included specimens 6-10 through 6-18, from the modeling process.

Table F1—Structural insulated panel creep parameters (A_1 and A_2) and coefficient of determination (r^2) for 12.25-in. and 6.5-in. specimens

Specimen ID	12.25-in. specimens			6.5-in. specimens		
	A_1	A_2	r^2	A_1	A_2	r^2
1	0.0322	0.459	0.9844	0.0096	0.585	0.8938
2	0.0188	0.517	0.9747	0.0063	0.658	0.8903
3	0.0270	0.440	0.9759	0.0068	0.633	0.8954
4	0.0289	0.459	0.9810	0.0059	0.693	0.9145
5	0.0362	0.421	0.9815	0.0084	0.606	0.8846
6	0.0191	0.441	0.9875	0.0070	0.618	0.8728
7	0.0326	0.350	0.9655	0.0076	0.598	0.8565
8	0.0241	0.431	0.9716	0.0044	0.669	0.8538
9	0.0319	0.439	0.9831	0.0042	0.700	0.9153
10	0.0139	0.548	0.9635	—	—	—
12	0.0236	0.383	0.9828	—	—	—
13	0.0368	0.316	0.9864	—	—	—
14	0.0154	0.421	0.8989	—	—	—
15	0.0301	0.363	0.9874	—	—	—
17	0.0329	0.337	0.9871	—	—	—
18	0.0439	0.310	0.9596	—	—	—
19	0.0178	0.546	0.9843	0.0138	0.539	0.9474
20	0.0143	0.518	0.9916	0.0122	0.581	0.9815
21	0.0286	0.475	0.9872	0.0208	0.465	0.9341
22	0.0331	0.458	0.9867	0.0148	0.525	0.9500
23	0.0359	0.432	0.9841	0.0147	0.537	0.9589
24	0.0313	0.460	0.9869	0.0191	0.503	0.9635
25	0.0322	0.440	0.9893	0.0145	0.544	0.9700
26	0.0218	0.514	0.9809	0.0142	0.536	0.9573
27	0.0206	0.504	0.9807	0.0151	0.502	0.9477
28	0.0303	0.494	0.9851	0.0136	0.538	0.9560

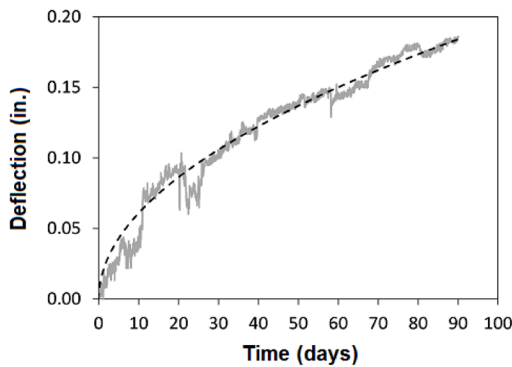


Figure F2. Representative deflection versus time data set with fitted power model curve. The data shown are from the 6.5-in. specimen 6-24. The solid gray line is the recorded data; the dashed black line is the fitted power model.