

# MASS PLY PANEL POINT-SUPPORTED SLAB TESTING

## REPORT REACTS-02-v.2

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16. Abstract Testing was performed on six full-scale 32 ft by 12 ft point-supported mass ply panels specimens. The testing program included load distribution testing, dynamic testing, and pre-construction load testing per 2018 IBC 1709. Three specimens consisted of 5-ply, 5-1/8" (130 mm) panels and three specimens consisted of 6-ply, 6-1/8" (156 mm) panels. The panels were supported on six points using steel plates. Besides the self-weight, the 5-ply and 6-ply panels had different reference design loads. The reference design load assumed a live load of 40 psf for both the 5-ply and 6-ply specimens, and an assumed superimposed deadload of 12.5 psf and 55 psf for 5-ply and 6-ply specimens, respectively. Results from testing indicate that the 5-ply and 6-ply specimens passed the IBC 1709 pre-construction requirements. Results indicate that the 5-ply and 6-ply specimens exhibited a mean peak load of over 3.28 and 2.56 times the reference design load, respectively. In addition, based on walking footfalls, the bare panels exhibited a mean fundamental frequency of 8.37 Hz and damping ratio of 1.6% for the 5-ply specimens and 10.02 Hz and 1.2% for the 6-ply specimens.			
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SI* (MODERN METRIC) CONVERSION FACTORS									
APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
<b>LENGTH</b>					<b>LENGTH</b>				
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
<b>AREA</b>					<b>AREA</b>				
in <sup>2</sup>	square inches	645.2	millimeters squared	mm <sup>2</sup>	mm <sup>2</sup>	millimeters squared	0.0016	square inches	in <sup>2</sup>
ft <sup>2</sup>	square feet	0.093	meters squared	m <sup>2</sup>	m <sup>2</sup>	meters squared	10.764	square feet	ft <sup>2</sup>
yd <sup>2</sup>	square yards	0.836	meters squared	m <sup>2</sup>	m <sup>2</sup>	meters squared	1.196	square yards	yd <sup>2</sup>
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi <sup>2</sup>	square miles	2.59	kilometers squared	km <sup>2</sup>	km <sup>2</sup>	kilometers squared	0.386	square miles	mi <sup>2</sup>
<b>VOLUME</b>					<b>VOLUME</b>				
fl oz	fluid ounces	29.57	milliliters	ml	ml	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft <sup>3</sup>	cubic feet	0.028	meters cubed	m <sup>3</sup>	m <sup>3</sup>	meters cubed	35.315	cubic feet	ft <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.765	meters cubed	m <sup>3</sup>	m <sup>3</sup>	meters cubed	1.308	cubic yards	yd <sup>3</sup>
~NOTE: Volumes greater than 1000 L shall be shown in m <sup>3</sup> .									
<b>MASS</b>					<b>MASS</b>				
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000 lb)	0.907	megagrams	Mg	Mg	megagrams	1.102	short tons (2000 lb)	T
<b>TEMPERATURE (exact)</b>					<b>TEMPERATURE (exact)</b>				
°F	Fahrenheit	(F-32)/1.8	Celsius	°C	°C	Celsius	1.8C+32	Fahrenheit	°F
*SI is the symbol for the International System of Measurement									

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# 1.0 INTRODUCTION

This report presents an experimental program designed to inform the engineering design of a mass timber point-supported slab solution consisting of mass ply panels (MPP). The report describes the experimental setup, instrumentation, loading protocols, and results of two sets of tests, including (1) dynamic testing, and (2) pre-construction load testing. Results are provided for three 5-ply (MPP, F10-5) and three 6-ply (MPP, F10-6) specimens.

## 2.0 MATERIALS AND METHODS

### 2.1 SPECIMEN DESCRIPTION

Six mass ply panels (MPP) specimens were tested, including:

- Three F10-5 Freres MPP 5-ply 5-1/8" (130 mm).
- Three F10-6 Freres MPP 6-ply 6-1/8" (156 mm).

Specimens were 32 ft long by 12 ft wide and supported on six points, as shown in Figure 1. Figure 2 shows a plan view of the test setup. Note steel shim plates with different dimensions were provided for the 5-ply and 6-ply specimens.

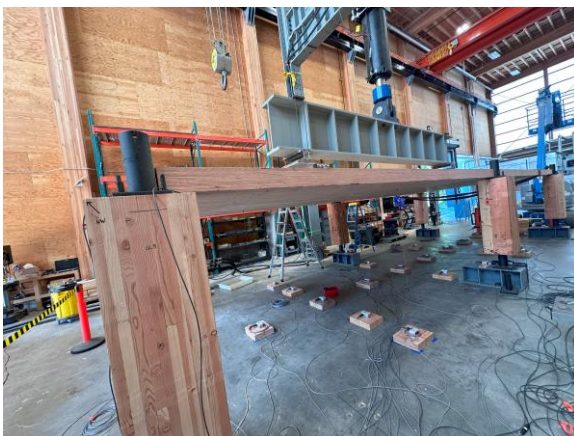


Figure 1: Point supported floor setup.

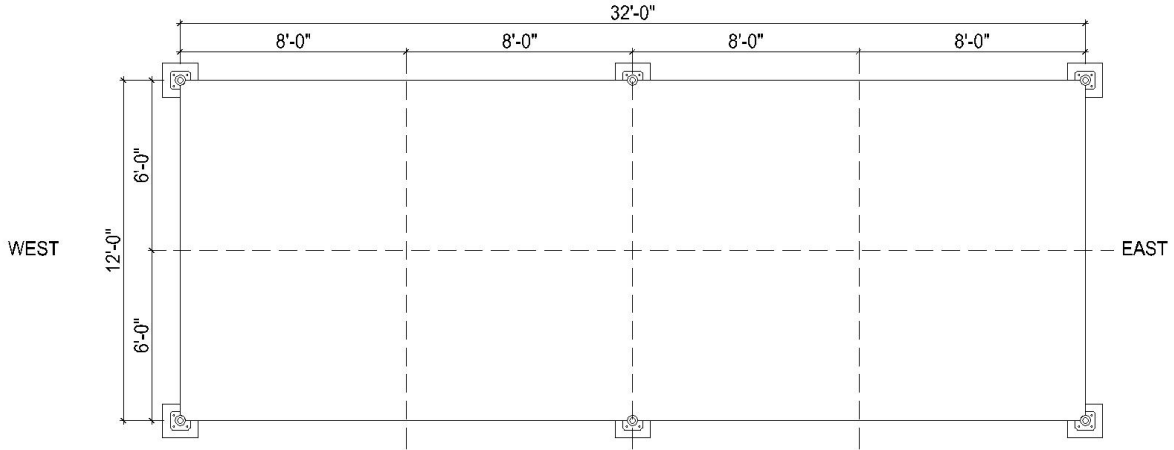


Figure 2: Plan view of the test specimen setup.

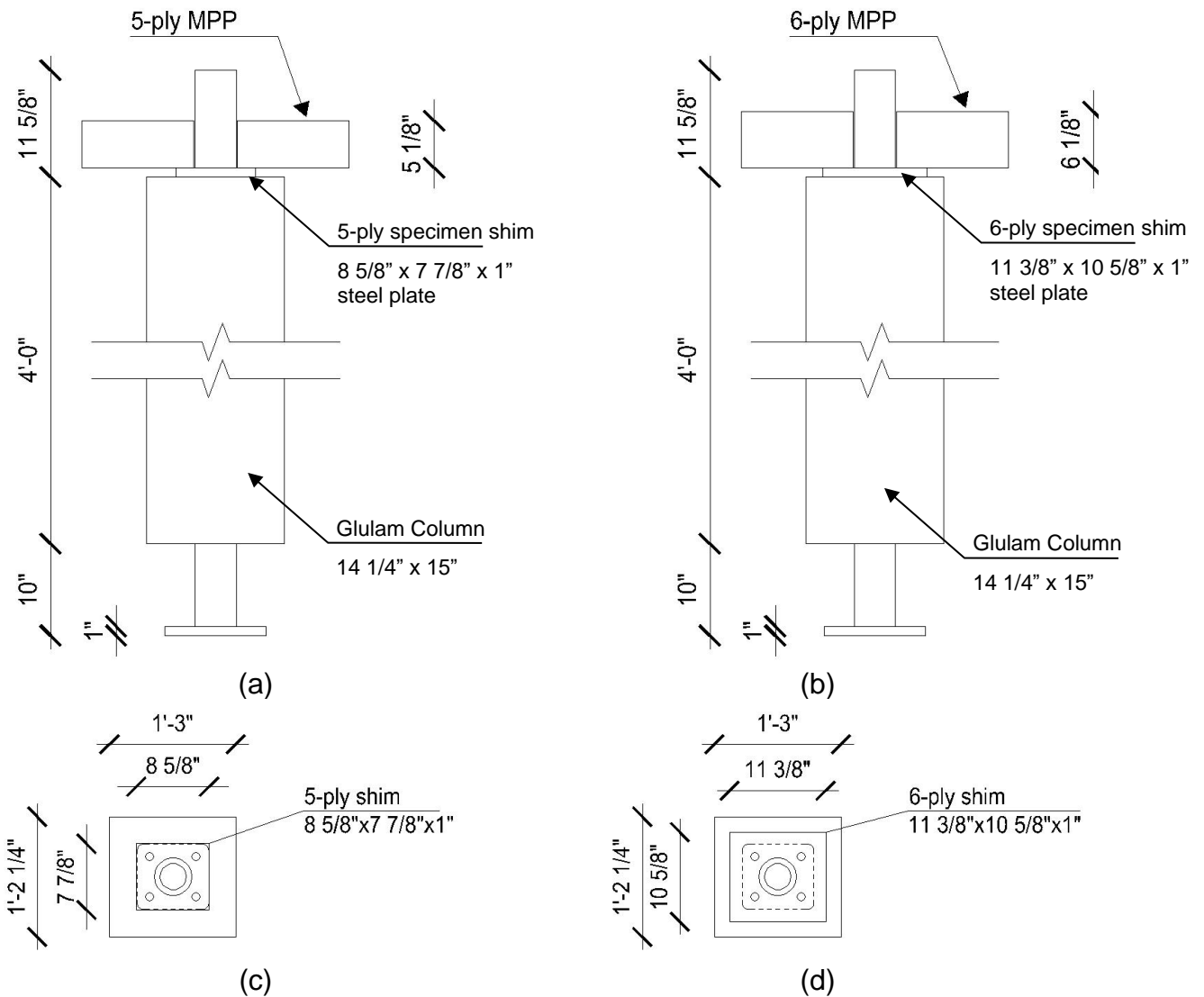


Figure 3: Details of column and panel-to-column connections: (a) 5-ply assembly; (b) 6-ply assembly; (c) 5-ply shim; (d) 6-ply shim.

## 2.2 EXPERIMENTAL SETUP AND INSTRUMENTATION

### 2.2.1 Dynamic Testing

The dynamic testing consisted of three sets of footfall tests. Table 1 lists the dynamic tests performed and the number of times data were collected. The first set of footfall tests consisted of a 190 lbs person walking back and forth from the center of the panel to the east mid-span point of the panel for six times at footfall frequencies of 1.0 Hz, 1.5 Hz, 2.0 Hz, and 2.5 Hz; the lower two frequencies intend to replicate the typical range of walking frequencies in a building, while the higher walking frequencies correspond to an infrequent fast walking or a light jog. The frequency of the footfalls was simulated by the person synchronizing their footfalls with the output of a digital metronome. The second and third sets consisted of a 190 lbs person performing six heel-drops near locations A6 and A10, shown in Figure 4.

Table 1: Dynamic testing excitation information

Test	Type	Footfall Frequency [Hz]	Location* (times)
1	Walking	1.0	A7 => A12/A13 => A7 (6)
2	Walking	1.5	A7 => A12/A13 => A7 (6)
3	Walking	2.0	A7 => A12/A13 => A7 (6)
4	Walking	2.5	A7 => A12/A13 => A7 (6)
5	Heel-drop	-	A6 (6)
6	Heel-drop	-	A10 (6)

\* See locations in Figure 4. For tests 1 to 4 A12/A13 is a point half-way between A12 and A13.

Figure 4 shows the locations of the 13 uniaxial PCB model 393B04 accelerometers used to measure accelerations in the vertical direction. The accelerometers were wired to a National Instruments (NI) data acquisition system (NI cDAQ 9178) using four NI 9234 modules, and data were recorded at 1024 Hz.

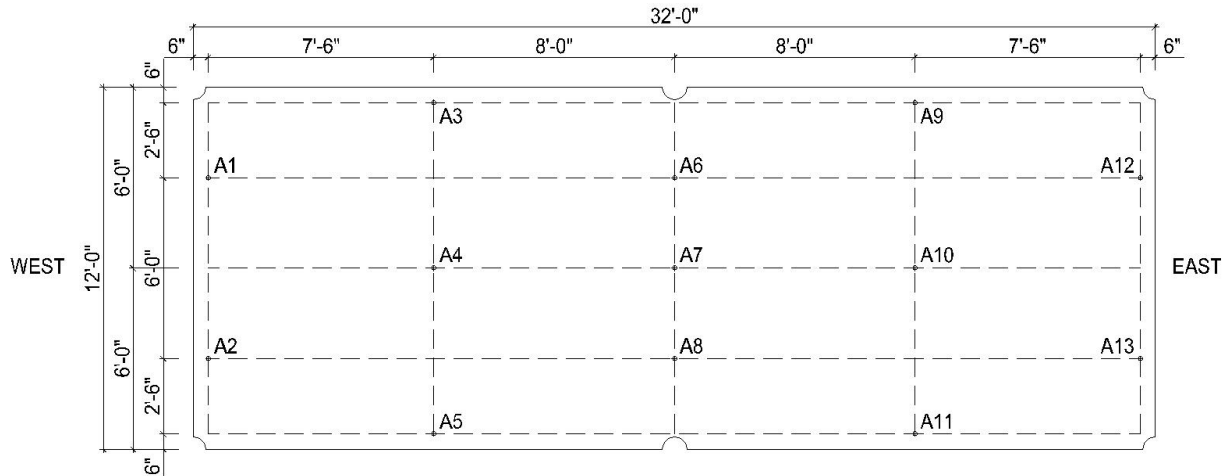


Figure 4: Accelerometer locations.

## 2.2.2 Pre-construction Load Testing

Figure 5 shows a three-dimensional view of the pre-construction loading performed. A steel reaction frame supported a 600-kip actuator that applied the force to a spreader beam, which in turn applied two points loads on the panel, spaced at 17 ft - 8 in.

For the 5-ply and 6-ply specimens, two-part tests were performed, following IBC 1709.3.1 test procedure requirements. First, the 5-ply and 6-ply specimens were loaded for 24 hours to an applied actuator load of 51.8 kips and 86.8 kips, respectively. The 24-hour loads were provided by a REACTS member sub-group as the value corresponding 2.0 times reference design loads; the uniform reference design loads included the self-weight, a live load of 40 psf, and a superimposed dead load of 12.5 psf and 55 psf for the 5-ply and 6-ply, respectively. At the end of the 24-hour period, the actuator load was removed. Once the test assembly recovered more than 75% of the maximum deflection achieved under the 24-hour loading, the assembly was then subjected to increased loading until structural failure was observed. Loading for the structural failure was applied under a displacement-controlled test, with the actuator displacements applied at a rate of 0.5 inches/min.

Figure 6 shows the sensor layout used to measure the vertical displacement of the panel relative to the strong floor and the relative displacements between the columns and the panel. Sensors with one letter and one number refer to string potentiometers measuring

relative movement in the vertical direction between the underside of the panel and the strong floor. Sensors labeled with “GL” are LVDTs measuring relative movement between the columns and the underside of the panels. Sensors labeled with “OP” are sensors measuring the out-of-plane displacement of the system.

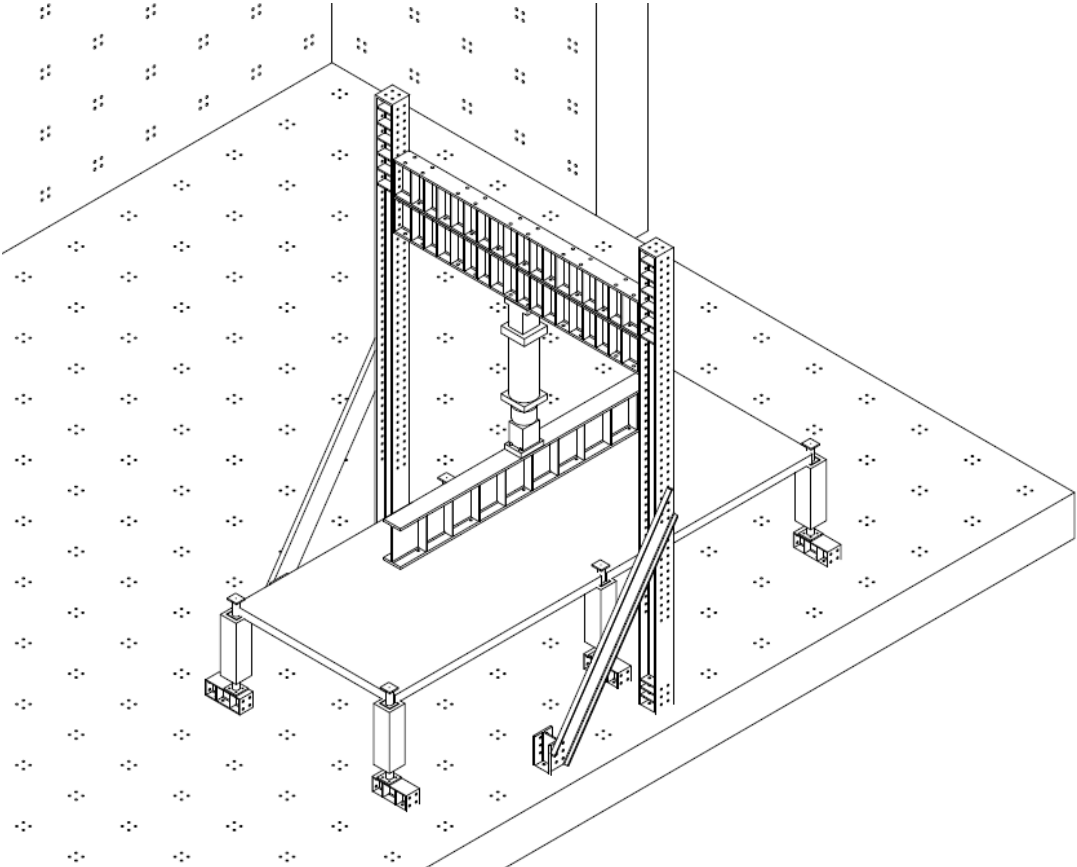


Figure 5: Three-dimensional view of the pre-construction load test setup.

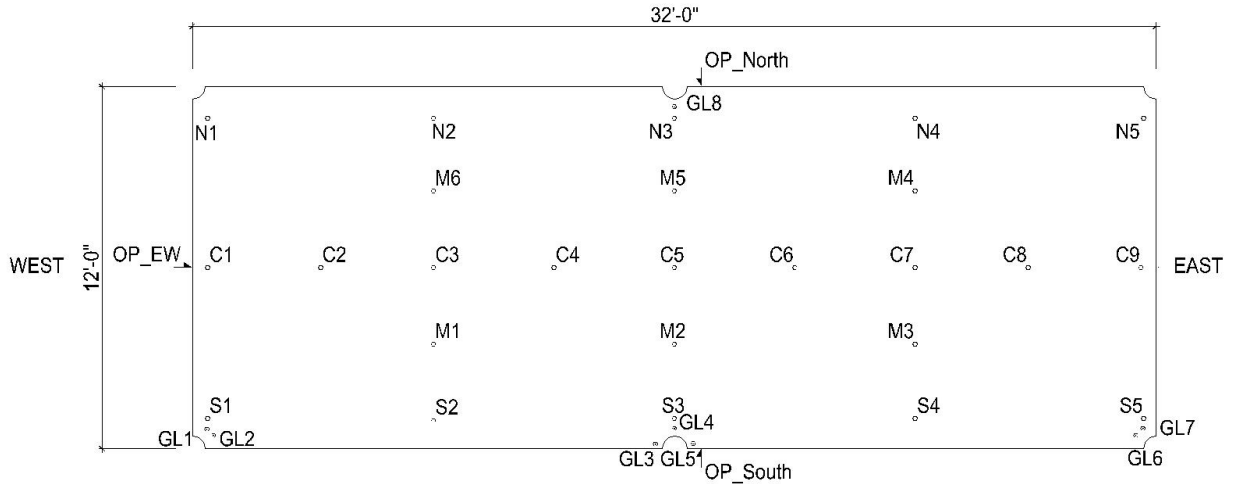


Figure 6: Load to failure testing sensor layout.

### 3.0 DATA POST-PROCESSING

Data post-processing for 24-hour load and load-to-structural failure tests were not necessary. Results reported below are based on raw data.

Several data post-processing steps were required to identify modal features for the dynamic testing. First, a correlation analysis between channels was conducted to identify the minimum number of channels required to extract the modal features. Second, for all tests, the signals were decimated to 128 Hz, then a Butterworth filter of order five was applied with cut-off frequencies of 0.5 and 25 Hz. Lastly, for the processed signals, using the Stochastic Subspace Identification (SSI) method, singular values of spectral densities were determined, and frequencies with low complexity were picked from the various tests performed. Analyses were performed using ARTEMIS Modal Pro.

## 4.0 RESULTS

### 4.1 DYNAMIC TESTING

The dynamic test results for each specimen are grouped in three sets, one for the walking tests, and two others for heel-drop excitations applied at locations A6 and A10 (see Figure 4). Figure 7 shows sample mode shapes of the first two modes identified.

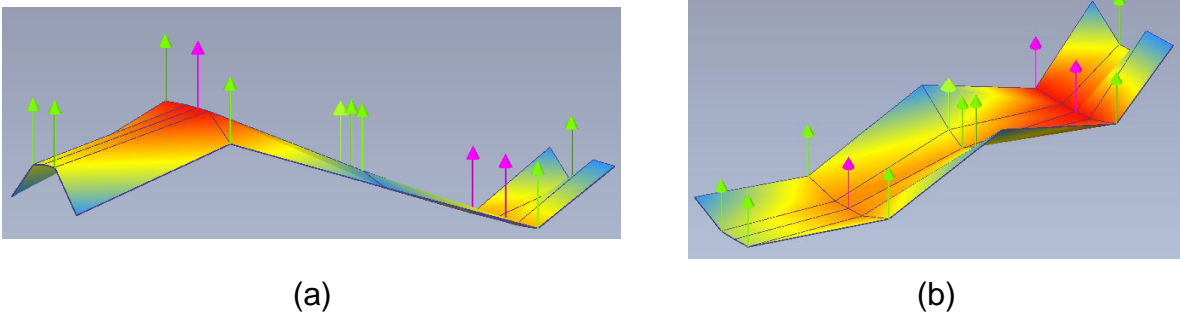


Figure 7: Schematic view of mode shapes identified: (a) mode 1 (b) mode 2.

Table 2 lists the identified modal features (frequencies and damping ratio) for each specimen for the walking tests, with the range of values obtained for the various tests shown in parenthesis. Table 3 and Table 4 list the identified modal features for the heel-drop tests applied at location A6 and A10, respectively.

Table 2: Mean value of the estimated modal features (frequency and equivalent damping ratio) for each specimen for walking excitation. Range of identified parameters are shown in parentheses.

Specimen	Mode 1		Mode 2	
	Identified Freq. [Hz]	Damping ratio [%]	Identified Freq. [Hz]	Damping ratio [%]
5-ply MPP-01	8.876 (8.766 - 8.929)	2.379 (1.016 - 4.138)	9.710 (9.672 - 9.762)	1.234 (0.970 - 1.401)
5-ply MPP-02	7.950 (7.886 - 8.041)	1.186 (0.315 - 1.748)	8.524 (8.452 - 8.572)	1.429 (1.180 - 1.595)
5-ply MPP-03	8.295 (8.204 - 8.379)	1.363 (0.768 - 2.053)	9.036 (8.986 - 9.083)	1.728 (1.391 - 2.432)
<b>Ave. 5-ply</b>	<b>8.374</b>	<b>1.642</b>	<b>9.090</b>	<b>1.464</b>
6-ply MPP-01	10.100 (10.000 - 10.190)	1.254 (0.728 - 1.927)	10.805 (10.710 - 10.920)	1.080 (0.869 - 1.252)
6-ply MPP-02	9.867 (9.757 - 9.918)	1.250 (0.919 - 1.761)	10.631 (10.588 - 10.709)	1.174 (0.914 - 1.829)
6-ply MPP-03	10.082 (10.003 - 10.180)	1.158 (0.432 - 1.917)	10.741 (10.624 - 10.837)	1.550 (1.079 - 1.965)
<b>Ave. 6-ply</b>	<b>10.016</b>	<b>1.220</b>	<b>10.726</b>	<b>1.268</b>

Table 3: Mean value of the estimated modal features (frequency and equivalent damping ratio) for each specimen for heel-drop excitation at A6. Range of identified parameters are shown in parentheses.

Specimen	Mode 1		Mode 2	
	Identified Freq. [Hz]	Damping ratio [%]	Identified Freq. [Hz]	Damping ratio [%]
5-ply MPP-01	8.826 (8.816 - 8.833)	0.836 (0.751 - 0.916)	9.627 (9.620 - 9.632)	1.215 (1.141 - 1.310)
5-ply MPP-02	8.014 (8.005 - 8.024)	0.491 (0.434 - 0.644)	8.554 (8.528 - 8.574)	1.309 (1.197 - 1.446)
5-ply MPP-03	8.343 (8.324 - 8.376)	0.486 (0.384 - 0.615)	9.040 (9.027 - 9.047)	1.063 (0.963 - 1.110)
<b>Ave. 5-ply</b>	<b>8.395</b>	<b>0.604</b>	<b>9.073</b>	<b>1.196</b>
6-ply MPP-01	10.143 (10.100 - 10.170)	0.732 (0.5571 - 1.077)	10.808 (10.800 - 10.830)	1.094 (1.041 - 1.191)
6-ply MPP-02	9.896 (9.878 - 9.908)	0.659 (0.586 - 0.754)	10.630 (10.583 - 10.651)	1.373 (1.149 - 1.523)
6-ply MPP-03	10.065 (10.057 - 10.081)	0.712 (0.604 - 0.799)	10.719 (10.708 - 10.731)	1.147 (1.086 - 1.235)
<b>Ave. 6-ply</b>	<b>10.035</b>	<b>0.701</b>	<b>10.719</b>	<b>1.205</b>

Table 4: Mean value of the estimated modal features (frequency and equivalent damping ratio) for each specimen for heel-drop excitation at A10. Range of identified parameters are shown in parentheses.

Specimen	Mode 1		Mode 2	
	Identified Freq. [Hz]	Damping ratio [%]	Identified Freq. [Hz]	Damping ratio [%]
5-ply MPP-01	8.777 (8.643 - 8.914)	3.705 (3.315 - 4.736)	9.583 (9.523 - 9.602)	1.438 (1.352 - 1.505)
5-ply MPP-02	8.024 (8.013 - 8.037)	1.895 (1.732 - 2.130)	8.520 (8.506 - 8.533)	1.512 (1.279 - 1.656)
5-ply MPP-03	8.353 (8.311 - 8.385)	1.543 (1.343 - 1.772)	8.989 (8.950 - 9.045)	1.701 (1.540 - 1.891)
<b>Ave. 5-ply</b>	<b>8.385</b>	<b>2.381</b>	<b>9.031</b>	<b>1.550</b>
6-ply MPP-01	10.055 (10.040 - 10.070)	2.116 (1.842 - 2.502)	10.748 (10.740 - 10.770)	1.161 (1.099 - 1.209)
6-ply MPP-02	9.889 (9.860 - 9.911)	2.387 (2.128 - 2.812)	10.600 (10.579 - 10.613)	1.505 (1.411 - 1.666)
6-ply MPP-03	10.001 (9.984 - 10.016)	1.667 (1.469 - 1.840)	10.650 (10.629 - 10.662)	1.412 (1.357 - 1.505)
<b>Ave. 6-ply</b>	<b>9.982</b>	<b>2.057</b>	<b>10.666</b>	<b>1.359</b>

## **4.2 PRE-CONSTRUCTION LOAD TESTS**

### **4.2.1 5-ply Specimens**

Under the 24-hour loading, the maximum average peak displacement measured at C3 was 2.569 in. After the 24-hour load was removed, the displacement recovered more than 75% of the maximum displacement essentially instantaneously. As an example, Figure 8 shows the actuator force versus displacement results for sensor C3 for the one of the 5-ply specimens. Other responses for other samples were identical.

Figure 9 shows the actuator force versus displacement sensor C3 results for the three 5-ply panels. The peak loads observed were 90.13 kips, 81.81 kips, and 82.61 kips, for specimens MPP-5-ply-01, MPP-5-ply-02, and MPP-5-ply-03, respectively, for an average peak load of 84.85 kips, which is 3.28 times the reference design load provided by the REACTS members of 25.9 kips.

Figure 10 shows sample test pictures of the structural load to failure test for the 5-ply panels. The primary failure mode was a bending failure in the short-span (weak axis) direction initiated at a third of the span where the seam of the bottom plies was located. All panels exhibited tension cracks to the top lamella of the top 1" ply, which was not observed to propagate further down in the lamellas; these cracks were perpendicular to the long-span, strong axis direction, and were concentrated near the column; they extended 12 to 18 inches from the edge of the panel. The mean load at which the tension cracks were observed was 54.3 kips. Post peak load, two panels of the panels also presented notable interply rolling shear near the center column.

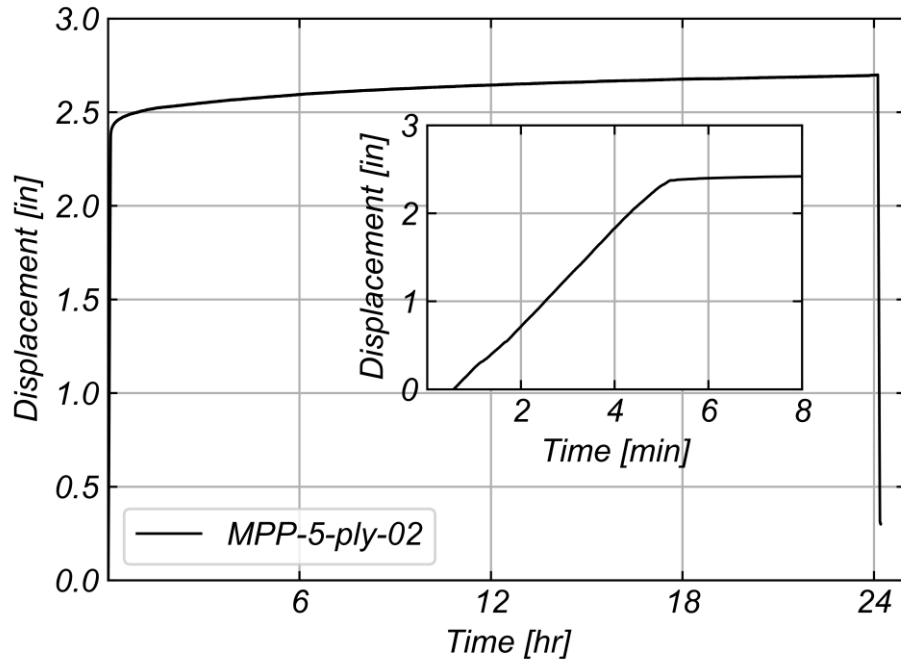


Figure 8: Sample results for displacement at C3 (under west load point) over the 24-hour load test for the 5-ply specimen.

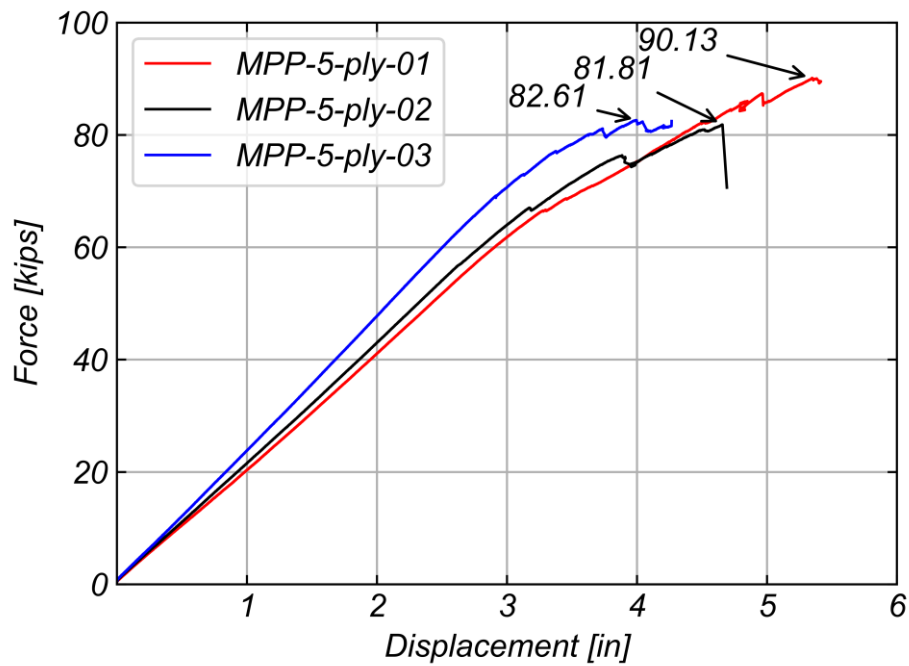


Figure 9: Actuator force versus displacement at location C3 (under west load point) for the 5-ply specimens.



(a)



(b)



(c)



(d)

Figure 10: 5-ply panel test photographs. (a) Panel pre-loading; (b) bending failure initiation at the seam of the bottom layer; (c) tension cracks at the center column; (d) rolling shear failure at the center column.

#### 4.2.2 6-ply Specimens

Under the 24-hour loading, the maximum average peak displacement measured at C3 was 2.737 in. After the 24-hour load was removed, the displacement recovered more than 75% of the maximum displacement. As an example, Figure 11 shows the displacement of point C3 over the 24-hour load test for specimen MPP-6-ply-02.

Figure 12 shows sample test pictures of the structural load to failure test for the 6-ply panels. In all specimens, tension cracks were observed near the center columns, similarly to what was observed in the 5-ply panels. The load at which the tension cracks were recorded was 61 kips. In two of the panels (MPP-6-ply-01 and MPP-6-ply-02), the primary

failure mode was rolling shear, while in one panel, the primary failure mode was weak axis bending at the mid-span of the panel (MPP-6-ply-03).

Figure 13 shows the actuator force versus displacement sensor C3 results for the three 6-ply panels. The peak loads observed were 114.35 kips, 110.47 kips, and 109.15 kips, for specimens MPP-6-ply-01, MPP-6-ply-02, and MPP-6-ply-03, respectively, for an mean peak load of 111.32 kips, which is 2.56 times the reference design load of 43.4 kips.

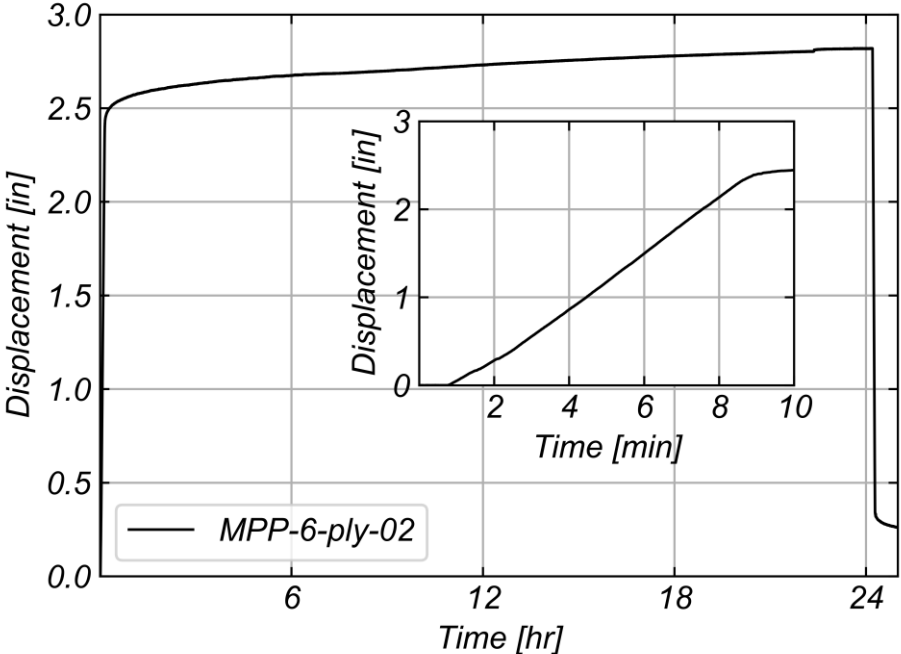
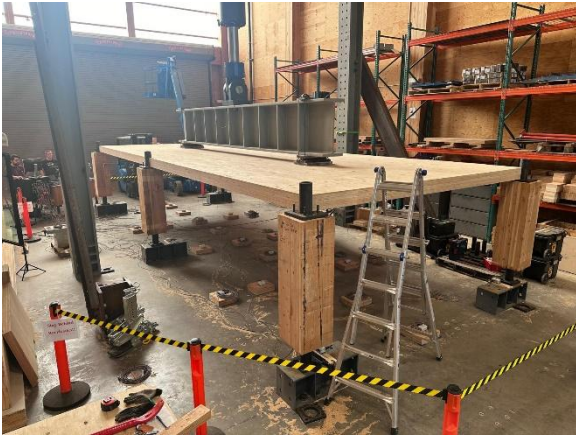


Figure 11: Displacement at C3 (under west load point) over the 24-hour load test for the 6-ply specimen.



(a)



(b)



(c)



(d)

Figure 12: 6-ply panel test photographs. (a) Panel pre-loading; (b) rolling shear failure of the first specimen; (c) tension cracks near the center column and rolling shear failure of the second specimen; (d) bending failure at mid-span of the third specimen.

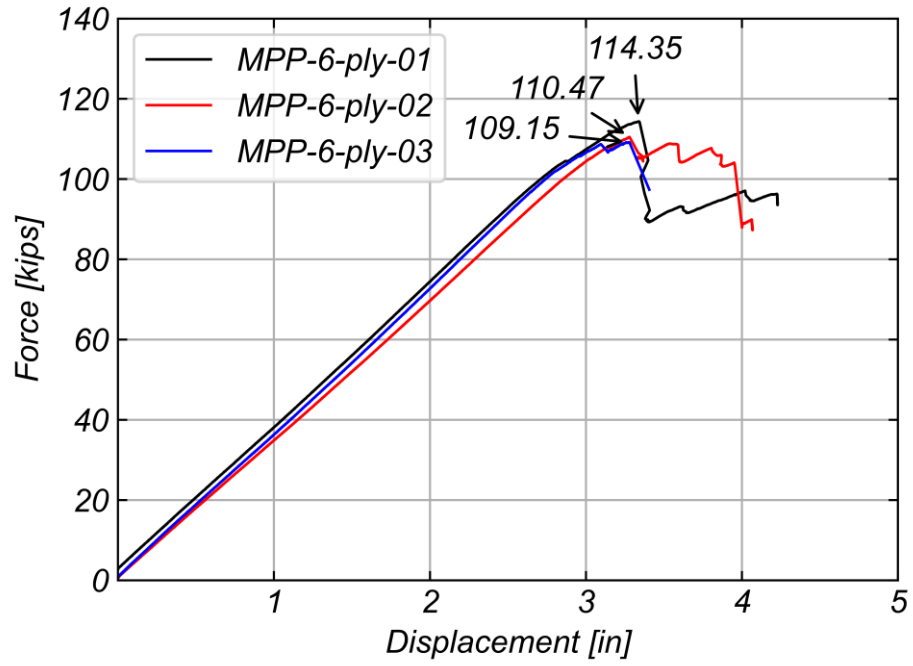


Figure 13: Actuator force versus displacement at location C2 (under south load point) for the 6-ply specimens.

## 5.0 CONCLUSION

Testing was performed on six full-scale 32 ft by 12 ft point-supported mass ply panels specimens. The testing program included dynamic testing and pre-construction load testing per 2018 IBC 1709. Three specimens consisted of 5-ply 5-1/8" (130 mm) panels, and three specimens consisted of 6-ply 6-1/8" (156 mm) panels.

Results from the testing of the 5-ply and 6-ply panels show that the specimens:

1. Recovered instantaneously 75% of the deflections reached after a 24-hour constant load test performed at a specified load of two times the reference design load.
2. The 5-ply specimens exhibited a mean peak load of over 3.28 times the reference design load and the 6-ply specimens exhibited a mean peak load of over 2.56 times the reference design load.
3. For the walking tests, the 5-ply specimens exhibited a fundamental frequency of 8.37 Hz and a damping ratio of 1.6%. The 6-ply specimens exhibited a fundamental frequency of 10.02 Hz and a damping ratio of 1.2%.