UAA College of Engineering
UNIVERSITY *of* ALASKA ANCHORAGE

Structural Design and Creep Testing of Plywood-Polyurethane Structural Insulated Panels (Ply-PU SIPs)

SEAAK Bi-monthly Meeting

Presented By: Scott Hamel, PE, SE, PhD

May 7, 2019

R-Valued HOMES Housing

Alaska Insulated Panels

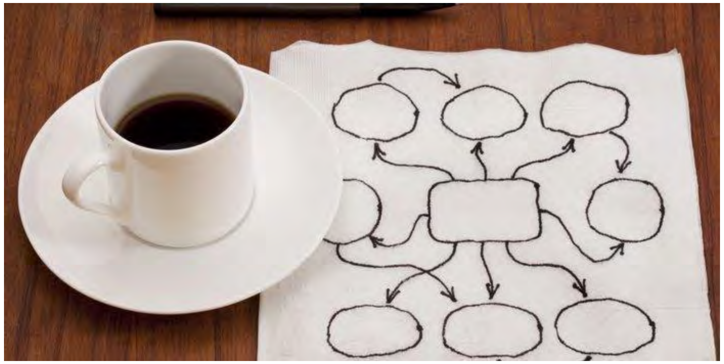
MADE IN ALASKA
Alaskan

Special Thanks to

- Nathaniel Cox, MS, EIT
- Dale McCoy, PE
- David Tatarenko
- Corbin Rowe, UAA Machinist

How this came about...

- Request for testing from Alaska Insulated Panels (AIP)
- Funding from AIP
- Additional Funding:
  - Ted and Gloria Trueblood Endowment
  - UAA Innovate Awards
  - UAA Undergraduate Research Award
- Funding from AIP for R&D...



Topics for Today…

Topics Previously Covered

- R-Value Test
- Compression Tests
- Bending Tests
- Racking Tests

Topics for Today

- Introduction – What are SIPs
- Code Provisions
- Summary of Short-term Testing
- Sandwich theory and Creep Mechanics
- Creep Testing and Analysis
- Proposed Design Code (Bending)
- Comparison - Code vs Tests

Topics for Another Day

- Proposed Design Code (shear, compression, racking, etc)
- Foundation Design
- Joist Composite Construction
- Dynamic Seismic Testing

What is a SIP?

- Structural Insulated Panel (SIP)
  - Provides both the structure and insulation
  - Used for walls, floors, foundation, and roof
- Manufactured "sandwich" composite panel
  - Faces:
    - OSB
    - Plywood
    - Cement Board
    - Metal
    - Fiber-reinforced Polymer (FRP)
  - Core:
    - EPS – Expanded Polystyrene
    - XPS – Extruded Polystyrene
    - PUR – Polyurethane Foam

Characteristics of SIP Insulation

(Cold Climate Housing Research Center, 2015)

Insulation	Approx. R-Value per inch	Water Vapor Permeability (Perm rating of 1 inch)
EPS	3.6	3
XPS	5	1
PU	6	1

AIP Plywood-PU SIPs

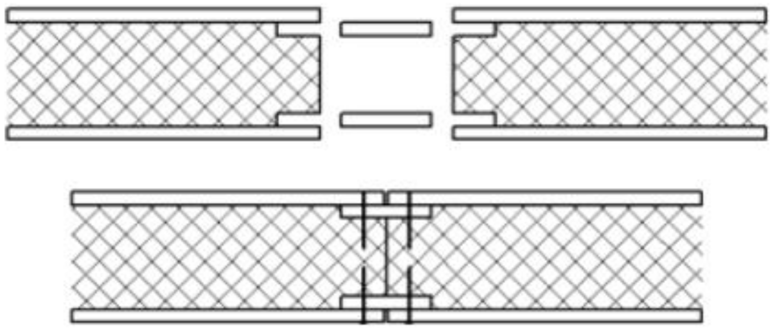
- Higher moisture resistance
  - CDX grade plywood
  - Closed cell polyurethane foam (PUR)
- Stiffer, higher strength
- No Adhesive
- Higher R-value
  - ~8 R/in. (PUR)
  - ~4.6 R/in. (EPS)

Image Courtesy of Alaskan Insulated Panels

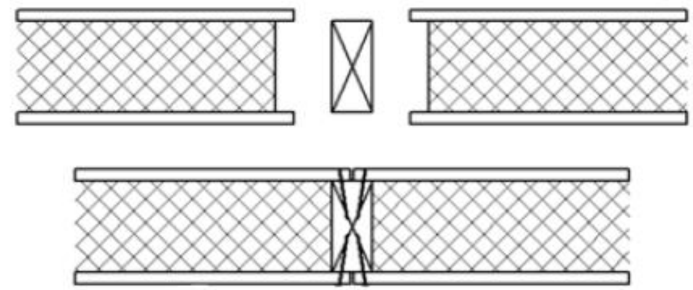
How Are They Made?

- Plywood fastened to 5.5″ edge forms
- Placed into 4′x16′ hydraulic press
- Pressure is applied while liquid foam is injected
- Forms removed and panels customized
- 4x8 Ply-PU SIP:
  - ~120 lbs (3.6 psf)
  - Foam = ~2.2 pcf

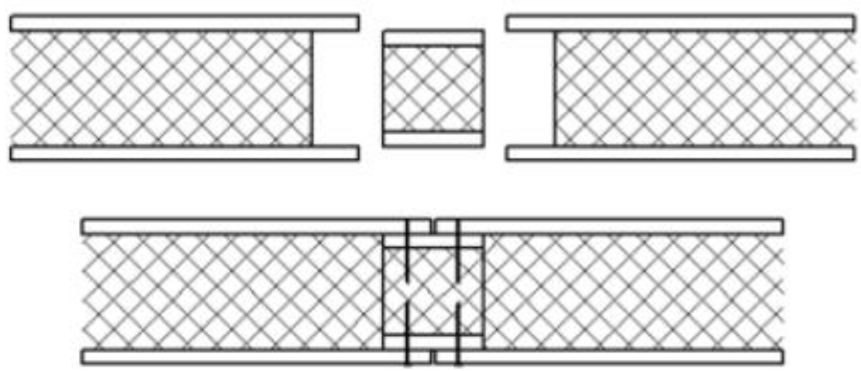
Connection Basics



Surface Spline

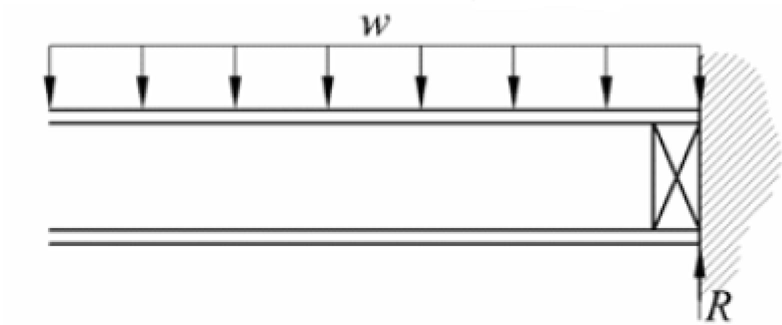


Reinforcing Spline

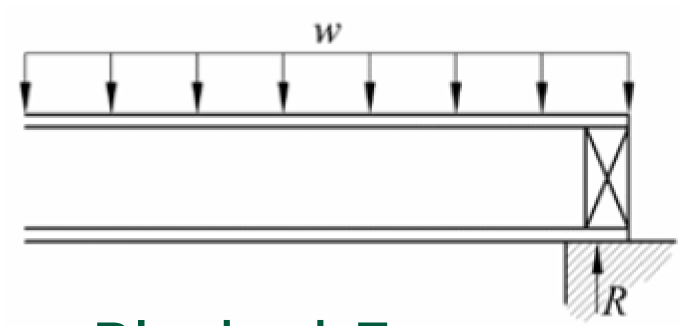


Block Spline

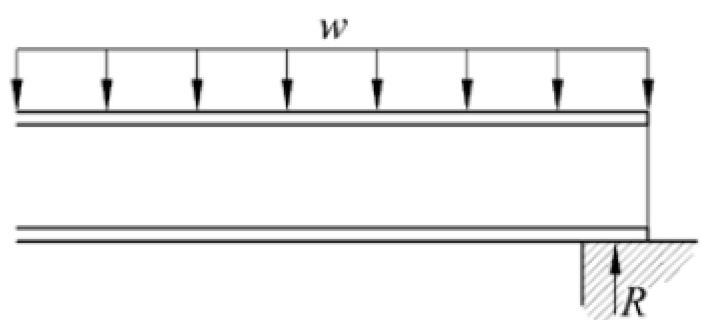
Support Basics



End Supported



Blocked-Face
Bearing Support



Unblocked-Face
Bearing Support

Advantages of SIPs

- Factory controlled QC (high quality)
- Less construction waste on jobsite
- Lower skilled erection workers
- Extremely fast erection
- High R-values

Image Courtesy of Alaskan Insulated Panels

Disadvantages of SIPs

- Difficult to modify in the field
- Air infiltration if not sealed properly
- Sometimes require larger equipment for erection
- Creep
- Code compliance challenges

Code Provisions

IRC Code Provisions

- International Residential Code (2012, 2015, 2018)
  - Does not comment on SIP roof or flooring systems
  - Prescriptive requirements for SIP wall systems
    - 2009, 2012 - Section R613
    - 2015, 2018 – Section R610
      - o R610.2 Applicability limits
      - o R610.3 Materials
      - o R610.5 Wall Construction
      - o R610.8 Connection

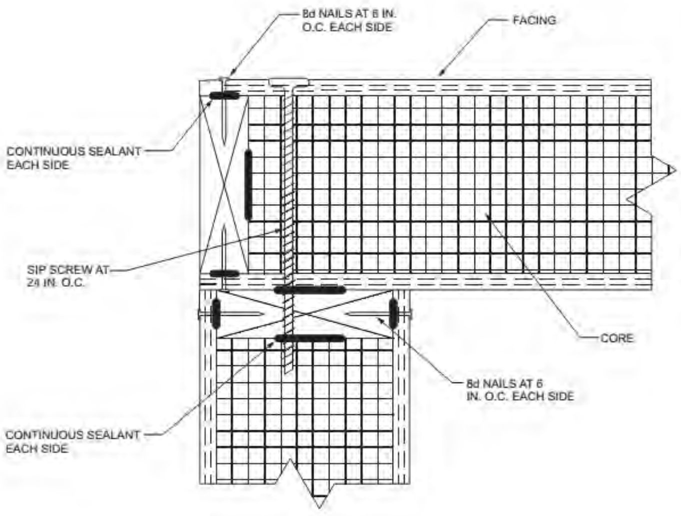


FIGURE R610.9
SIP CORNER FRAMING DETAIL

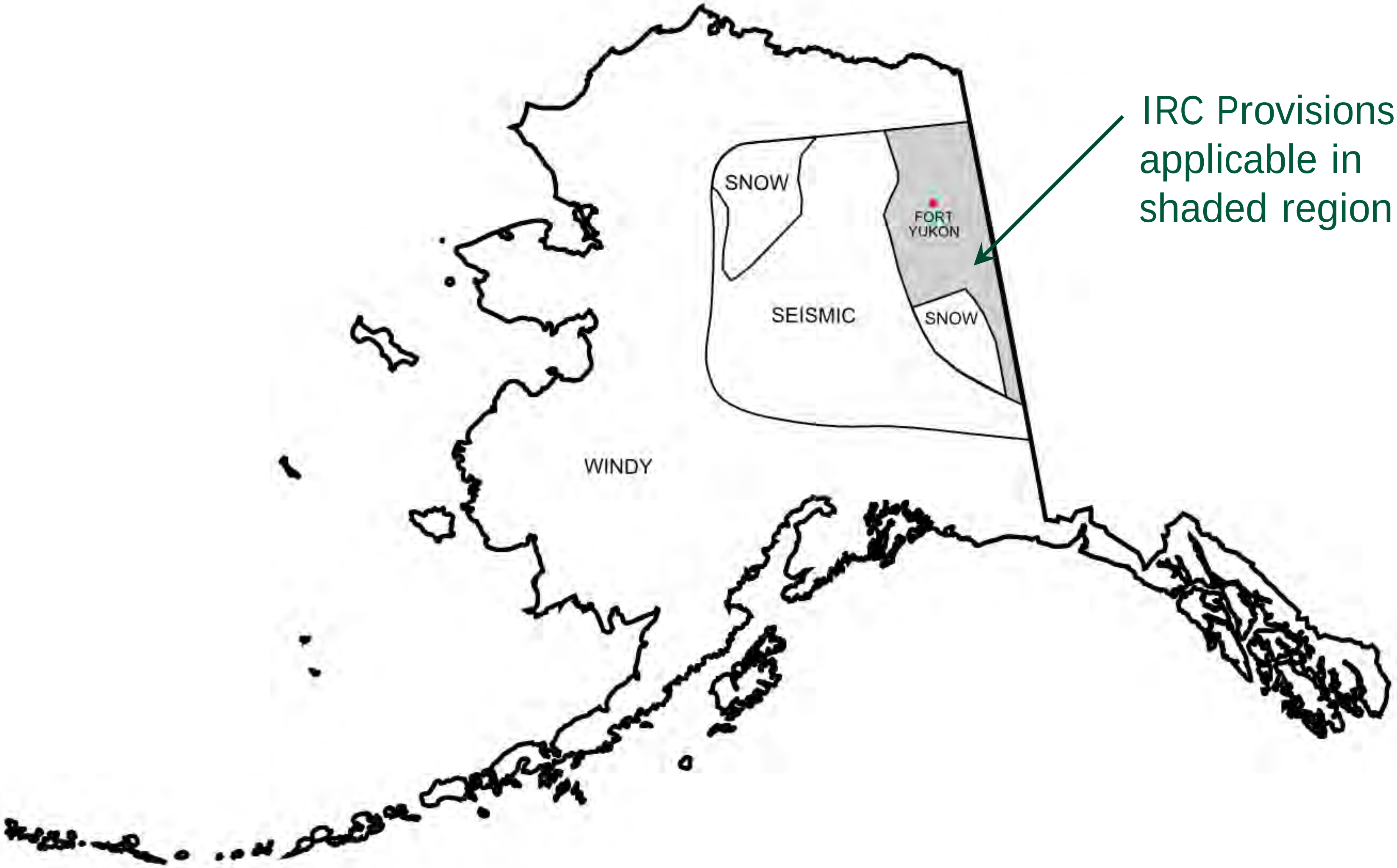
ICC INTERNATIONAL CODE COUNCIL®

Code Provision Limits

R610.2 Applicability Limits

- Buildings < 60 feet in length _|_ to the joist span
- Buildings < 40 feet in width || to the joist span
- Building not greater than two stories in height
- SIPs under these provisions shall be limited to sites where
  - Ultimate design wind speed V_{ult} < 155 mph in Exp. B
  - Ultimate design wind speed V_{ult} < 140 mph in Exp. C
  - Ground snow load < 70 psf
  - Seismic design category is A, B or C.

Code Provision Limits



IRC Provisions applicable in shaded region

IRC Code Provisions

R104.11 Alternative materials, design and methods of construction and equipment.

The provisions of this code are not intended to prevent the installation of any material or to prohibit any design or method of construction not specifically prescribed by this code. The *building official* shall have the authority to approve an alternative material, design or method of construction upon application of the owner or the owner's authorized agent. The *building official* shall first find that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, not less than the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety. Compliance with the specific performance-based provisions of the International Codes shall be an alternative to the specific requirements of this code. Where the alternative material, design or method of construction is not *approved*, the *building official* shall respond in writing, stating the reasons why the alternative was not *approved*.

R104.11.1 Tests.

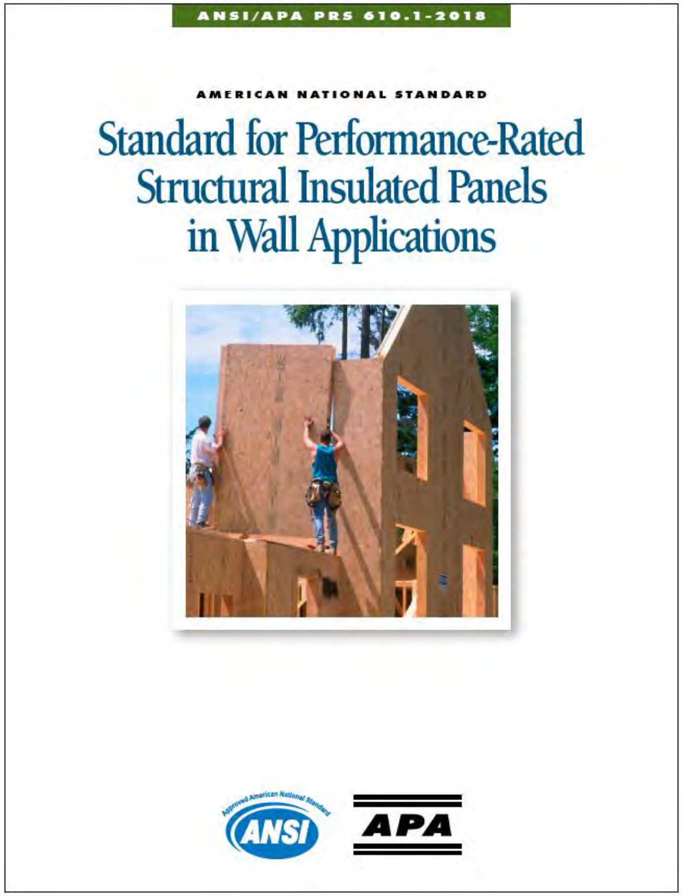
Where there is insufficient evidence of compliance with the provisions of this code, or evidence that a material or method does not conform to the requirements of this code, or in order to substantiate claims for alternative materials or methods, the *building official* shall have the authority to require tests as evidence of compliance to be made at no expense to the *jurisdiction*. Test methods shall be as specified in this code or by other recognized test standards. In the absence of recognized and accepted test methods, the *building official* shall approve the testing procedures. Tests shall be performed by an *approved* agency. Reports of such tests shall be retained by the *building official* for the period required for retention of public records.

Important Documents

ANSI / APA PRS 610.1-2018

Standard for Performance-Rated Structural Insulated Panels in Wall Applications

- Evaluation of structural capacity by
  - Prescriptive Component Method, or
  - Empirical Full-Scale Test Method



Test Standards

- ASTM E1803 (2014) – Standard Test Method for Determining Strength Capacities of Structural Insulated Panels
- ASTM E72 (2015) - Standard Test Methods of Conducting Strength Tests of Panels for Building Construction
- ICC AC04 (2012) – Acceptance Criteria for Sandwich Panels

ASTM INTERNATIONAL

INTERNATIONAL CODE COUNCIL

ICC EVALUATION SERVICE

Standards Documents

- ICC AC04
  - Describes tests and indicates performance limits (deflections)
  - Develops design loads from test results using a factor of safety
  - Heavily references ASTM E72
- PRS 610.1
  - Describes tests and performance acceptance levels (pass/fail)
  - Heavily references ASTM E1803
- ASTM E1803
  - Describes testing for SIPs
  - Heavily references ASTM E72
- ASTM E72
  - Describes tests for panels in general

Standards Documents

- ICC AC04
  - Describes tests and indicates performance limits (deflections)
  - Develops design loads from test results using a factor of safety
  - Heavily references ASTM E72

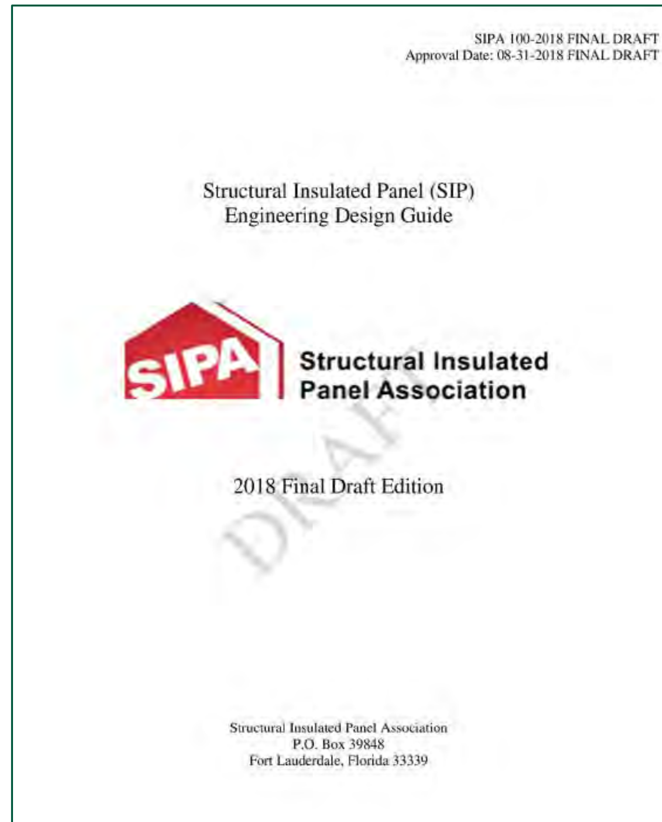
APPENDIX A—OPTIONAL CYCLIC-LOAD TEST REQUIREMENTS FOR SIP SANDWICH PANELS

A1 INTRODUCTION

A1.1 Purpose: The purpose of this appendix is to provide procedures for recognition in ICC-ES, LLC, evaluation reports of structural insulated panels (SIPs) as shear walls for buildings in Seismic Design Categories D, E, and F under the IBC; for townhouses in Seismic Design Categories C, D_o, D_1, D_2 and E under the IRC; and for detached one- and two-family dwellings in Seismic Design Categories D_o, D_1, D_2 and E under the IRC. The reason for this appendix is the absence of referenced standards in the IBC and IRC that can be used to establish code compliance for SIPs used as shear walls in buildings classified in Seismic Design Categories D, E, and F. The basis of this appendix is IBC Section 104.11.

SIPA Engineering Design Guide

- Produced by Structural Insulated Panel Association (SIPA)
- Schedule:
  - Draft - October 2017
  - Current Draft – August 2018
  - Final – November 2018
- Three Part Document:
  - Specification
  - Commentary
  - Examples


SIPA 100-2018 FINAL DRAFT
Approval Date: 08-31-2018 FINAL DRAFT

Structural Insulated Panel (SIP)
Engineering Design Guide

SIPA Structural Insulated Panel Association

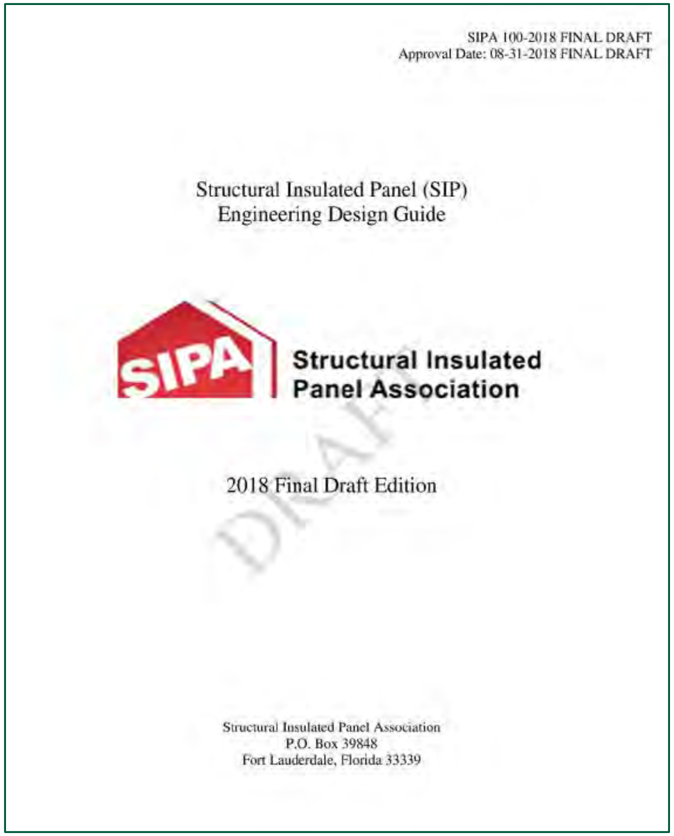
2018 Final Draft Edition

DRAFT

Structural Insulated Panel Association
P.O. Box 39848
Fort Lauderdale, Florida 33339

SIPA Engineering Design Guide

- Specification Covers
  - Flexure**
  - Shear
  - Compression
  - Tension
  - LFR Systems
  - Combined Loads
  - Connections and Joints
  - Openings
  - Reinforced Panels
  - Shells and Folder Plates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Structural Insulated Panel (SIP)
Engineering Design Guide

SIPA Structural Insulated Panel Association

2018 Final Draft Edition

Structural Insulated Panel Association
P.O. Box 39848
Fort Lauderdale, Florida 33339

**Includes Creep and Shear Effects

Short-term Tests Conducted at UAA

AIP Report

STRUCTURAL TESTING AND ANALYSIS OF PLYWOOD-POLYURETHANE STRUCTURALLY INSULATED PANELS (SIPs)

FINAL REPORT

by

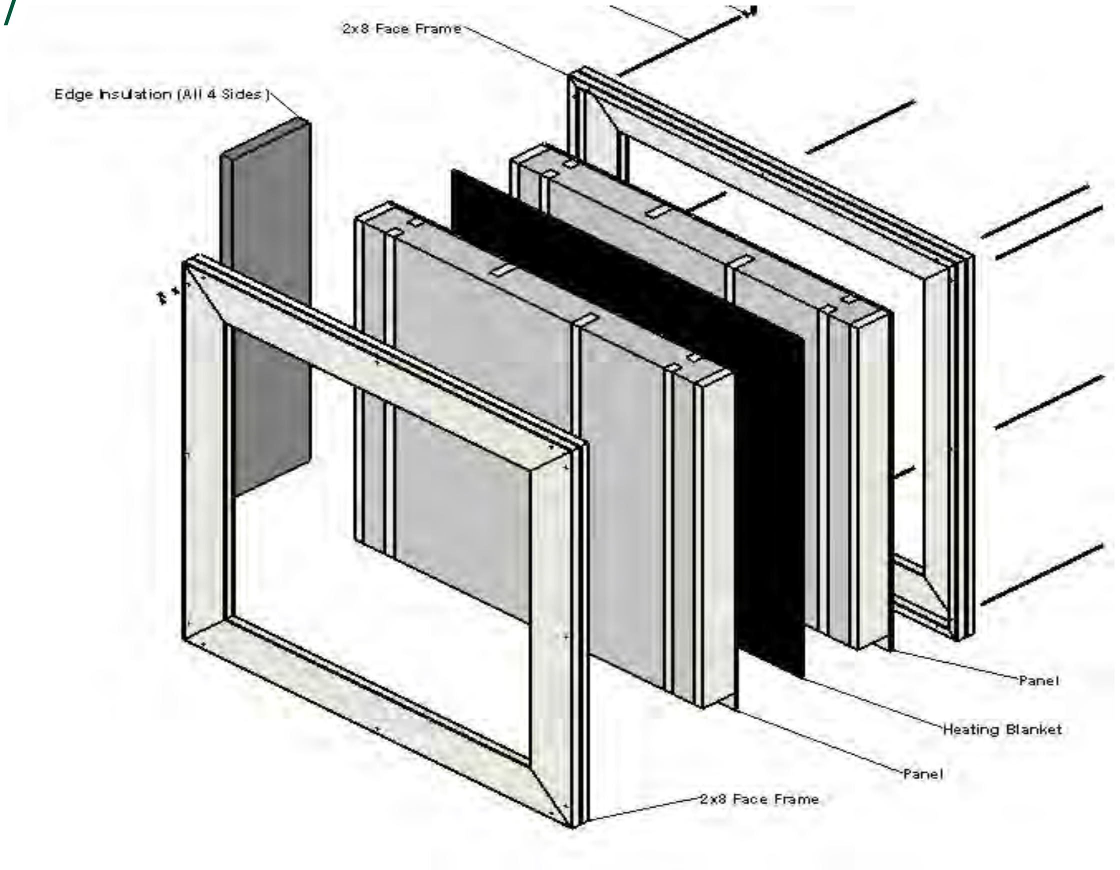
Scott Hamel, P.E., Ph.D.
University of Alaska Anchorage

for
Alaska Insulated Panels
189 E Nelson # 127
Wasilla, Alaska 99654

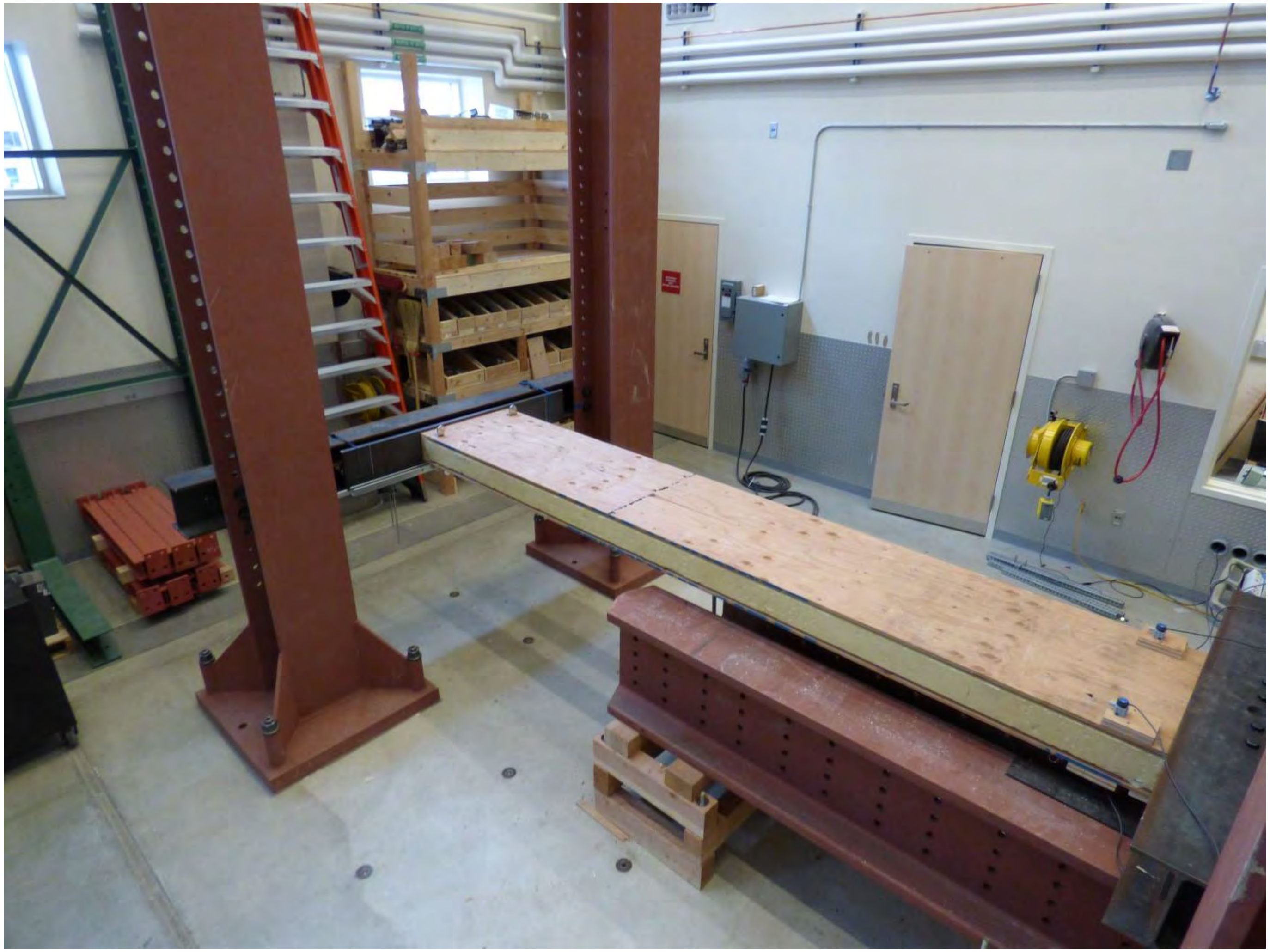
March 5, 2018
1st Revision: September 18, 2018
2nd Revision: September 27, 2018
Anchorage, Alaska

R-Value Testing

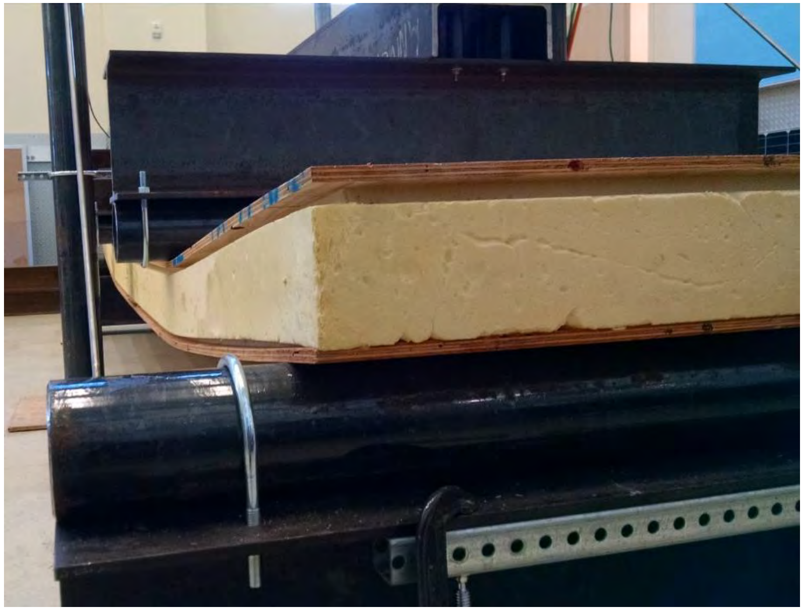
- “Sandwich Test” methodology
- Based on ASTM C177



Compression Test



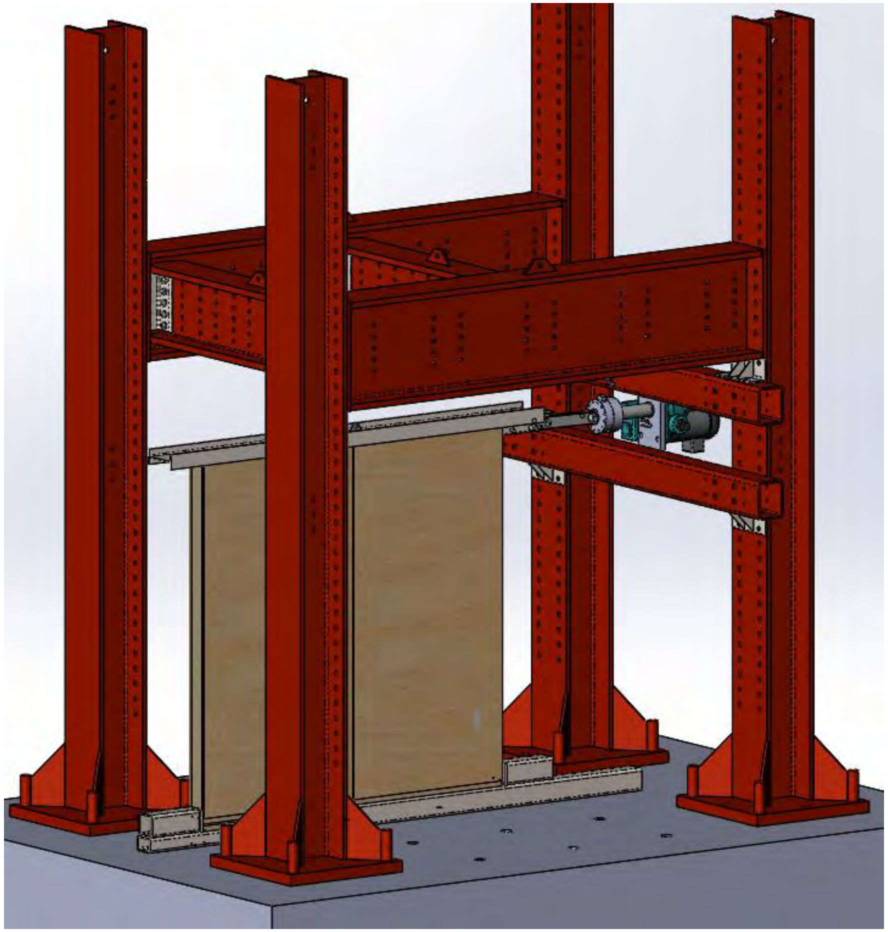
Transverse Bending



Test Conducted

- SIPs with bearing support
  - 4′ span
  - 8′ span
  - 8′ span with field splines in bending
  - 10′ span with field splines in shear
  - 12′ span with factory splines
  - 16′ span with field splines and straps
- SIPs with end support (bottom of wall condition)
- 4′, 6′ and 8′ Lintels

Racking Test

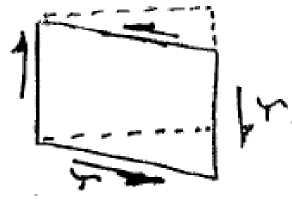


Sandwich Theory and Creep Mechanics

Timoshenko Bending

SMALL ELEMENT (COMPATIBILITY)

- SHEAR STRAIN (γ) IS THE CHANGE IN ANGLE BETWEEN TWO ORIGINALLY ⊥ FACES



$$\gamma \approx \tan\gamma = \frac{dv}{dx} \quad (1)$$

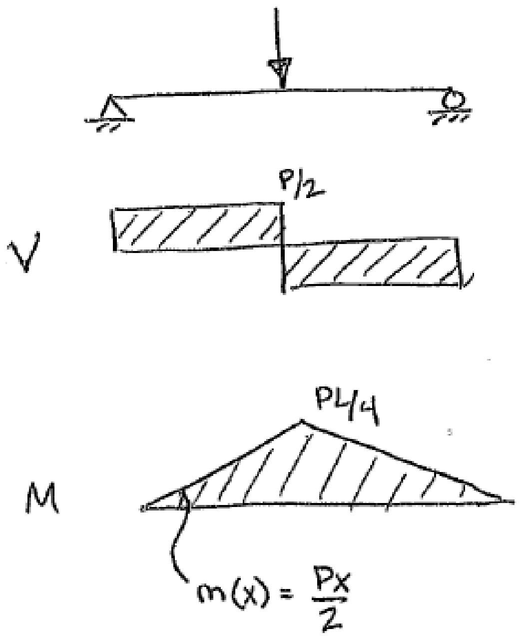
FROM EQUILIBRIUM

$$\tau_{avg} = \frac{V}{A_s} \quad (2)$$

HOOKE'S LAW

$$\tau_{avg} = G\gamma \quad (3)$$

$$A_s = \frac{A}{f_s}$$



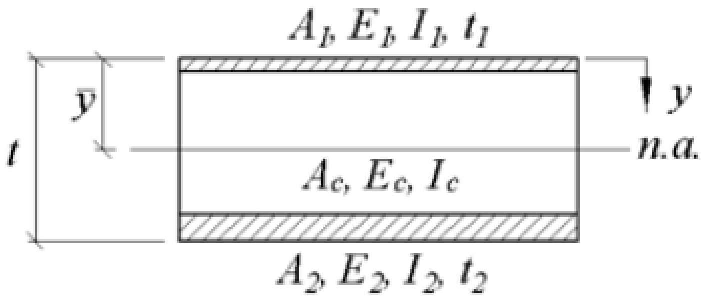
$$\Delta_{l/2} = v_b + v_s$$

$$\boxed{\Delta = -\frac{Pl^3}{48EI} - \frac{Plf_s}{4GA}}$$

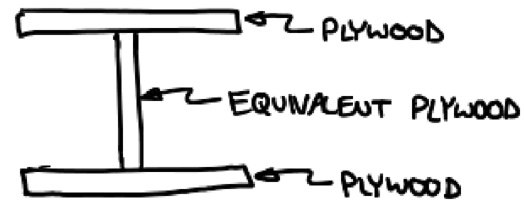
COMBINE (2) AND (3):

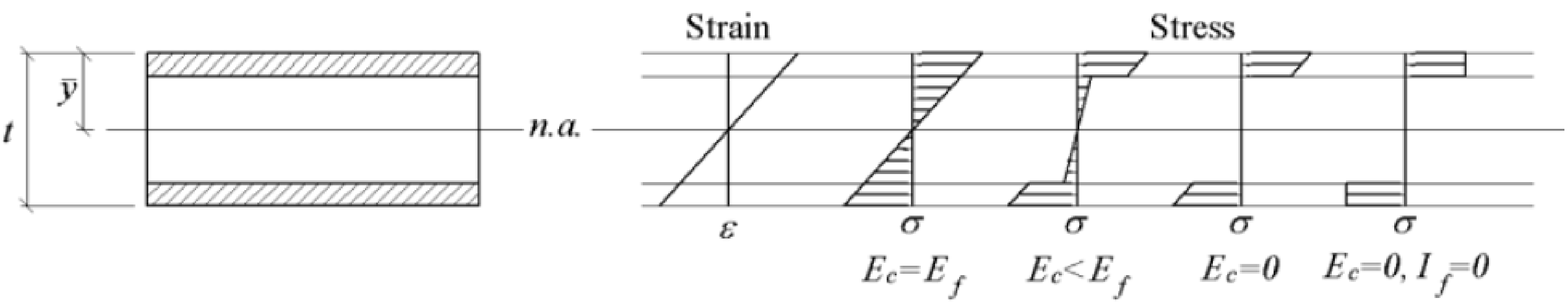
$$\frac{V}{A_s} = G\cdot\gamma = G\left(\frac{dv}{dx}\right) \quad \xrightarrow{\text{REARRANGE}} \quad \frac{dv}{dx} = \frac{V}{GA_s}$$

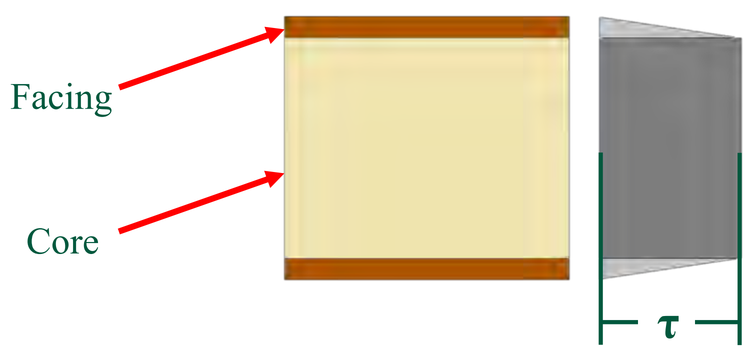
Sandwich Theory



$$n_c = \frac{E_c}{E_1}$$

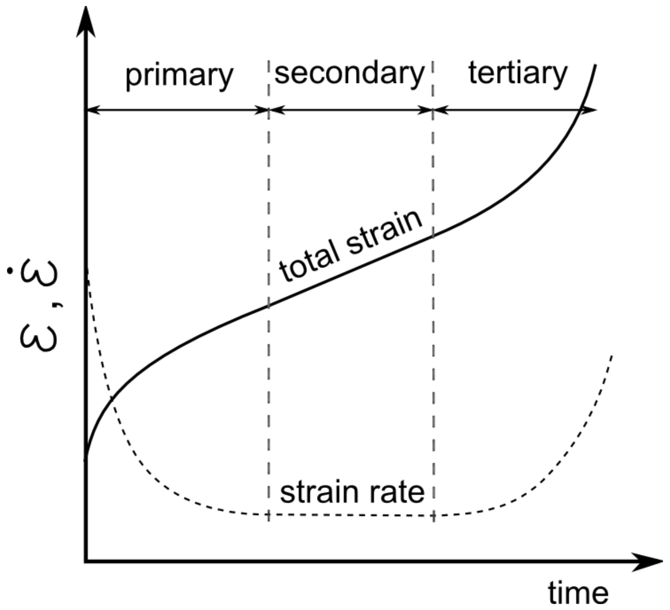


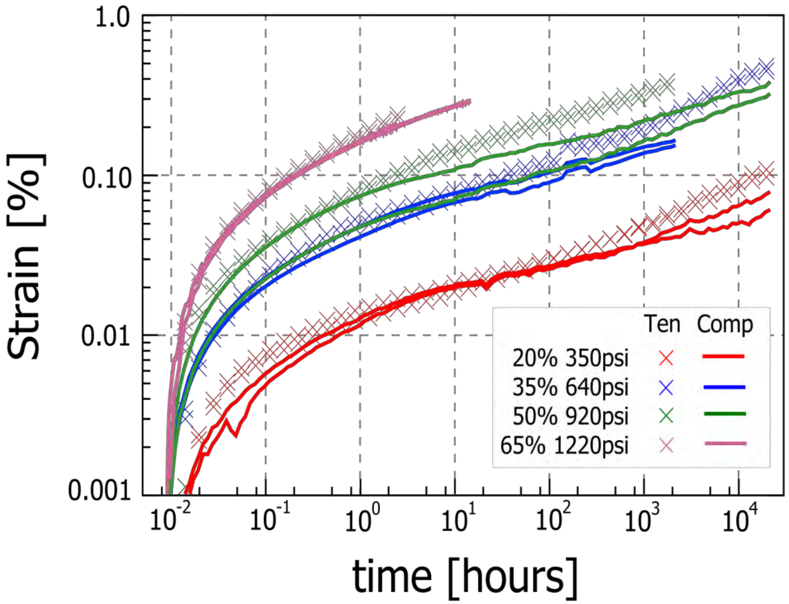




Time-Dependent Deformation

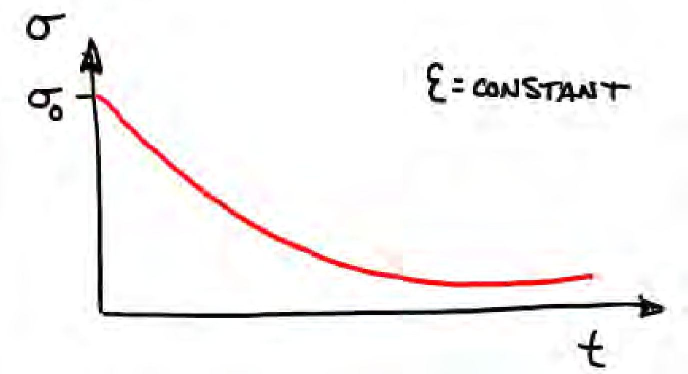
- Creep: time-dependent deformation under constant load
  - Linear Viscoelastic: Behavior is *not* stress-dependent
  - Nonlinear Viscoelastic: Behavior *is* stress-dependent



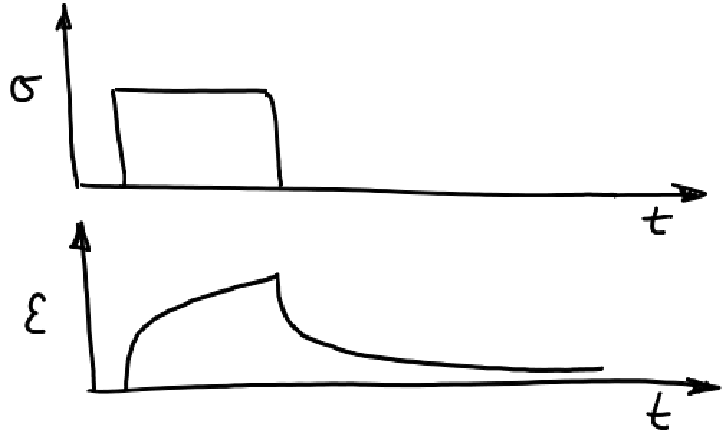


Time-Dependent Deformation

- Relaxation: time-dependent stress reduction under constant displacement



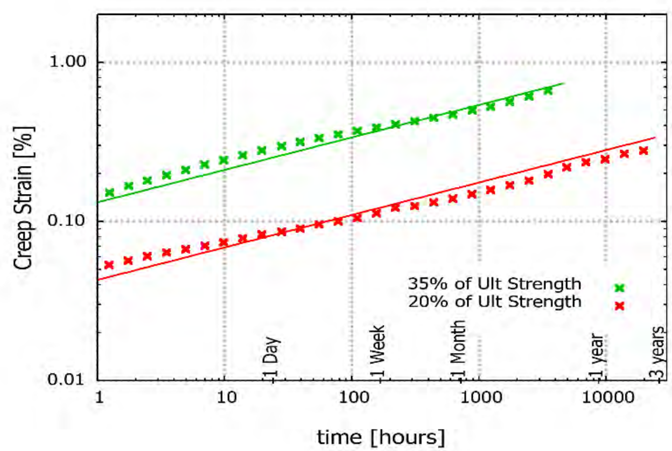
- Recovery: Return toward zero displacement after removal of load



Creep Expressions

- Power Law (Findley):

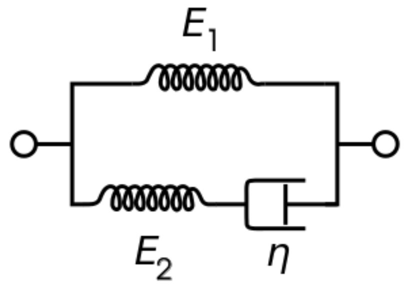
$$\varepsilon(t) = \varepsilon_0 + \varepsilon_t \cdot t^n$$

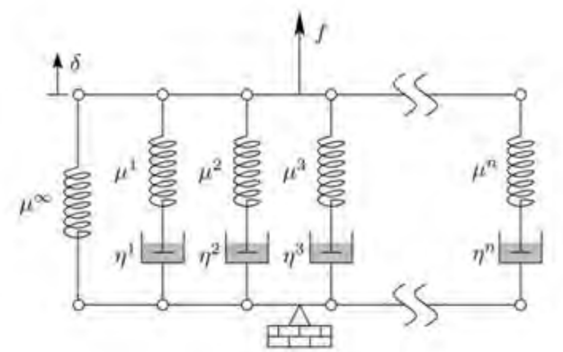


- Nutting Equation:

$$\varepsilon(t) = \varepsilon_0 + m \cdot \sigma^p \cdot t^n$$

Spring and Dashpots:





Time-Dependent Deformation

- Softening: Change in stiffness with time

$$E(t) = \frac{\sigma_0}{\varepsilon_0 + \varepsilon_t \cdot t^n} = \frac{1}{\frac{\varepsilon_0}{\sigma_0} + \frac{\varepsilon_t}{\sigma_0} \cdot t^n} = \frac{1}{\frac{1}{E} + \frac{1}{E_t} \cdot t^n}$$

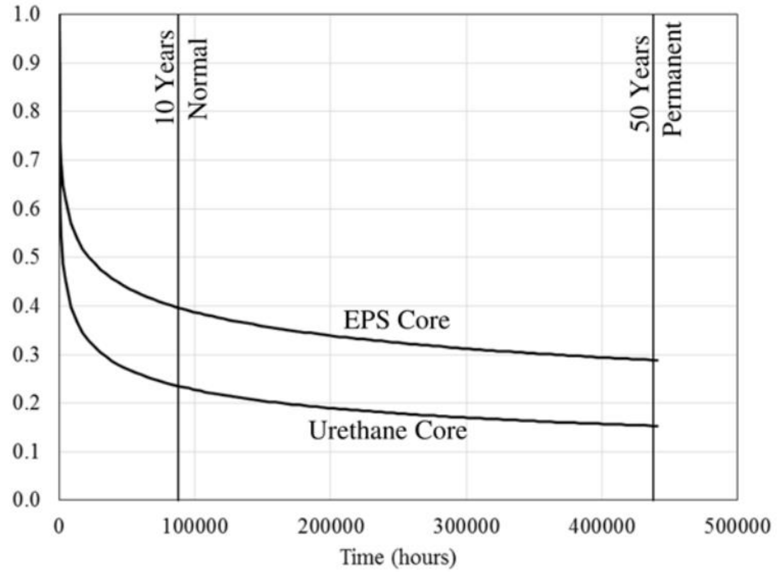
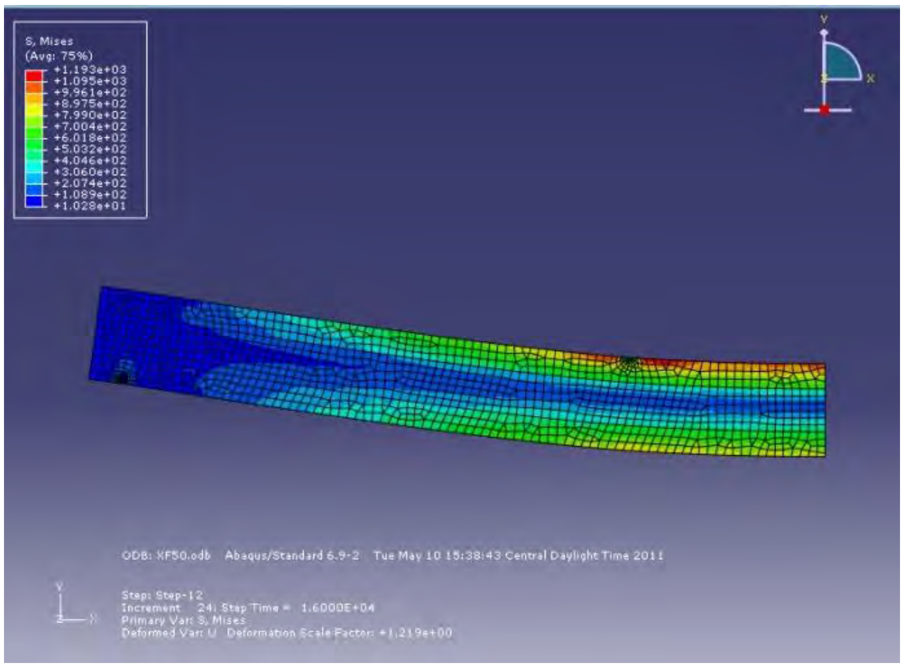
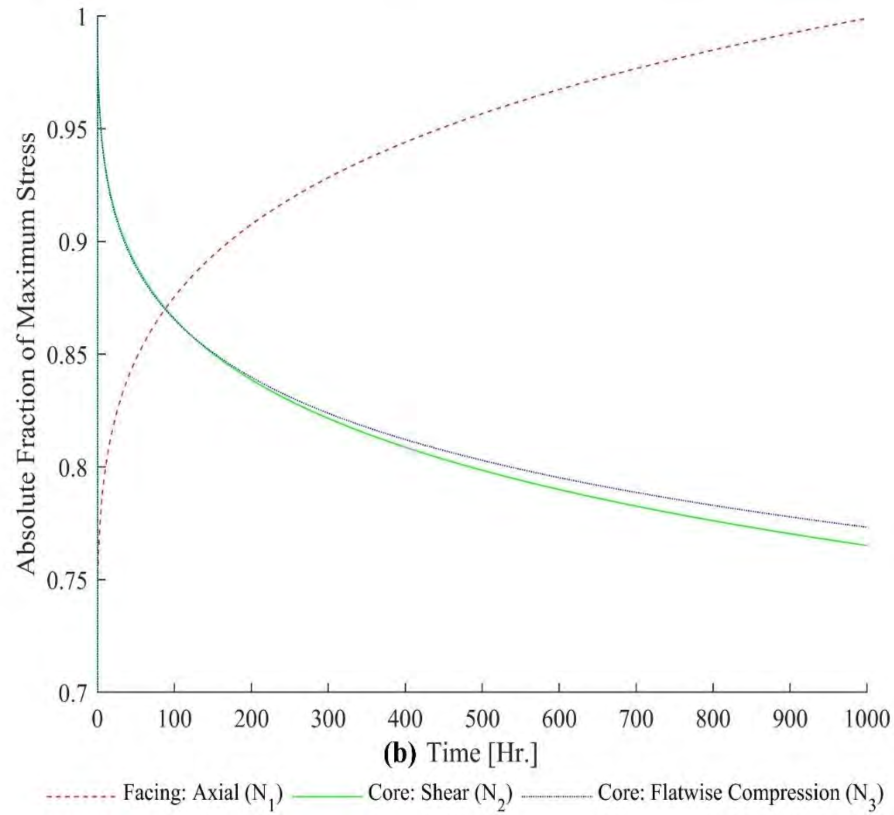


Figure C4.2.2-1: Time-Effect Factor for OSB Faced SIPs [13]

Creep Mechanics





UAA Creep Testing and Analysis

PU-Ply SIP Testing (Cox)

- Component Testing
  - Quasi-Static Shear Testing
  - Quasi-Static Compression Testing
  - Time-dependent Shear Testing
  - Time-dependent Compression Testing
- Full-Scale Testing
  - Quasi-Static Single Span Transverse Bending (with 5 minute holds)
  - Time-dependent Multi-span Transverse Bending (42 days)

Quasi-Static Shear Test

2-way rotation fixture

PUR Specimen

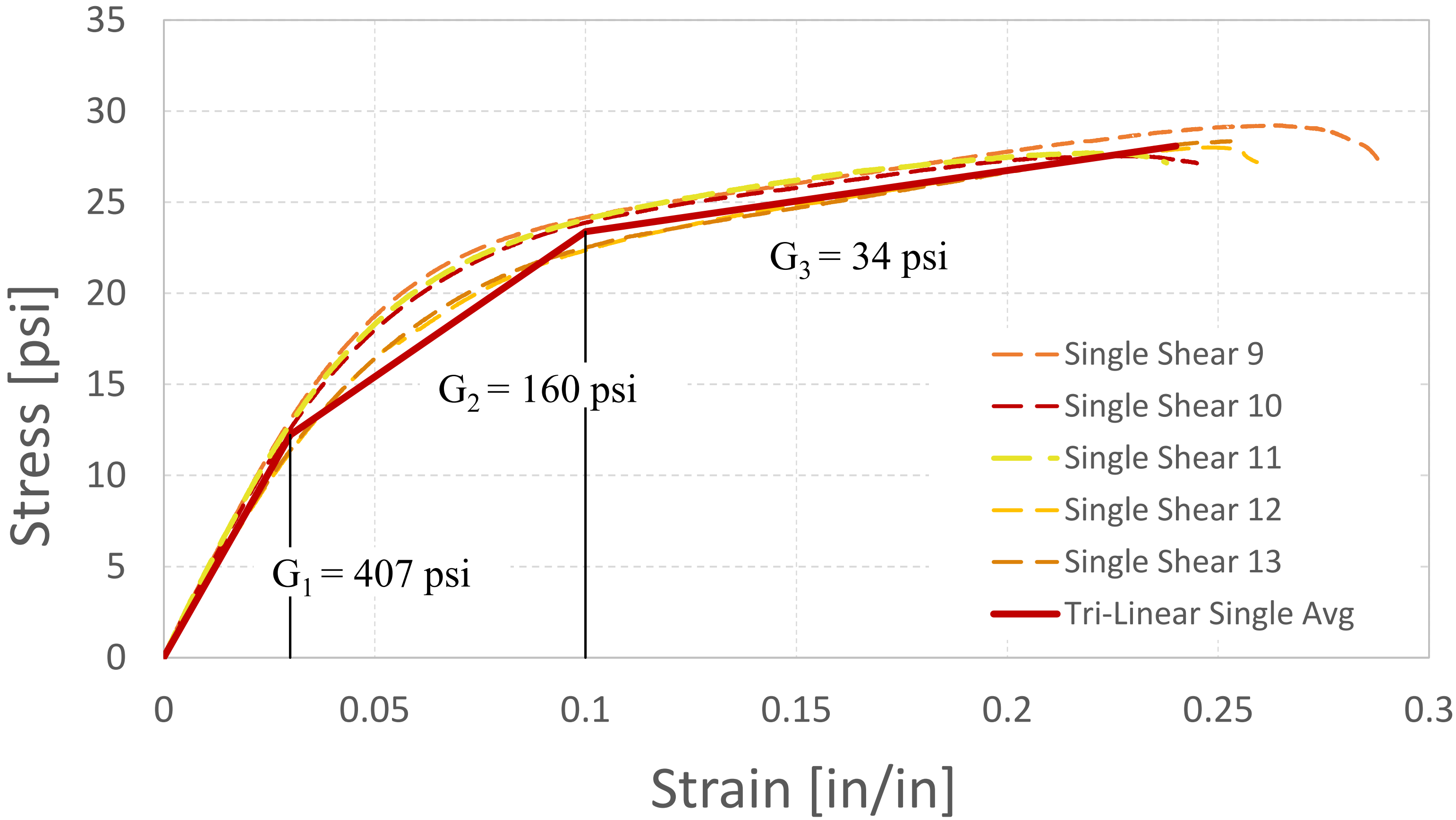
±¼” LVDT

- **Based on ASTM C273** – Standard Test Method for Shear Properties of Sandwich Core Materials
- **15 Specimens Tested, 5 Analyzed**
  - 10 failed to pass ASTM C273 requirements due to loading time to failure or undesired mode-of-failure
  - Nominal Geometry: 1” (thick) x 2” (wide) x 12” (long)

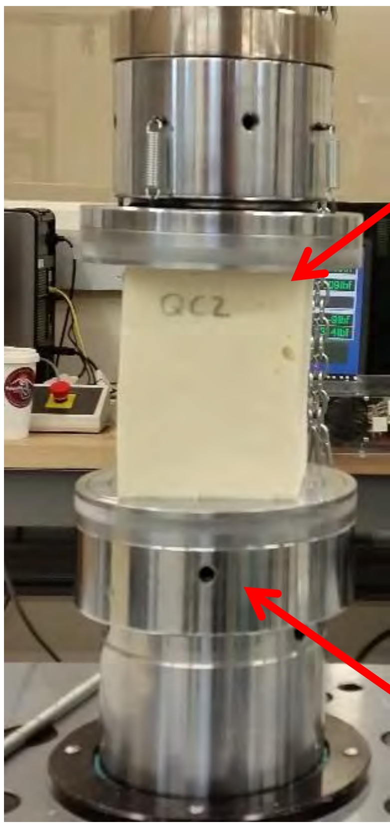
Quasi-Static Shear Results

Ultimate Strength: 28.2 psi (COV = 2%)

Ultimate Strain: 0.241 in/in (COV = 8%)



Quasi-static Compression Test

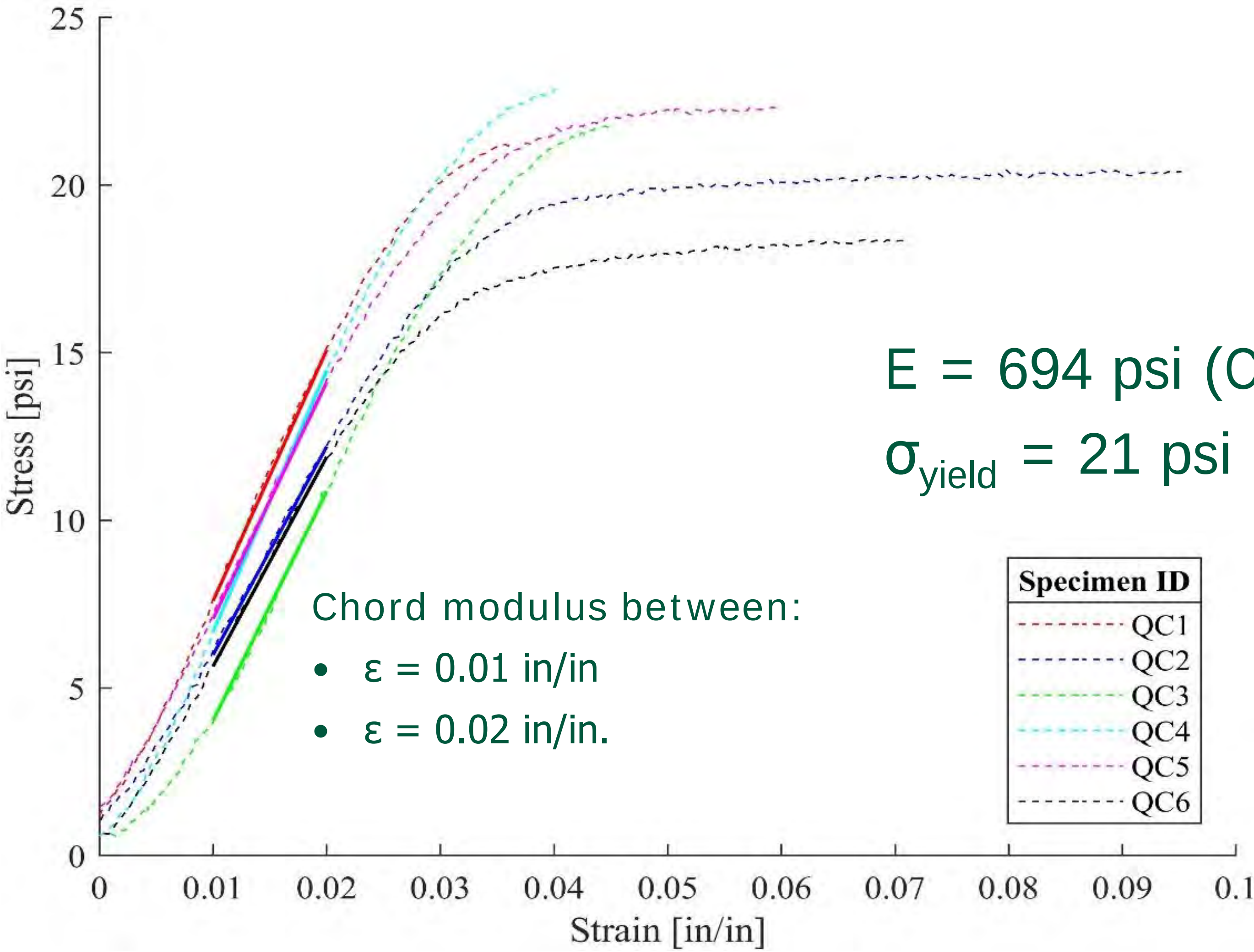


PUR Specimen

Loading Platen

- **ASTM C365 –** Standard Test Method for Flatwise Compressive Properties of Sandwich Cores
- **Eight Specimens Tested, Six Analyzed**
  - Two specimens to calibrate loading rate.
  - 4” (wide) x 4” (thickness) x 5¼” (height)

Quasi-static Compression Results



Chord modulus between:

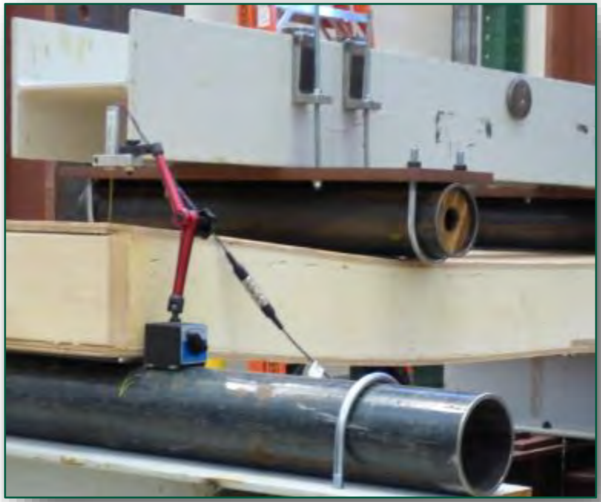
- ε = 0.01 in/in
- ε = 0.02 in/in.

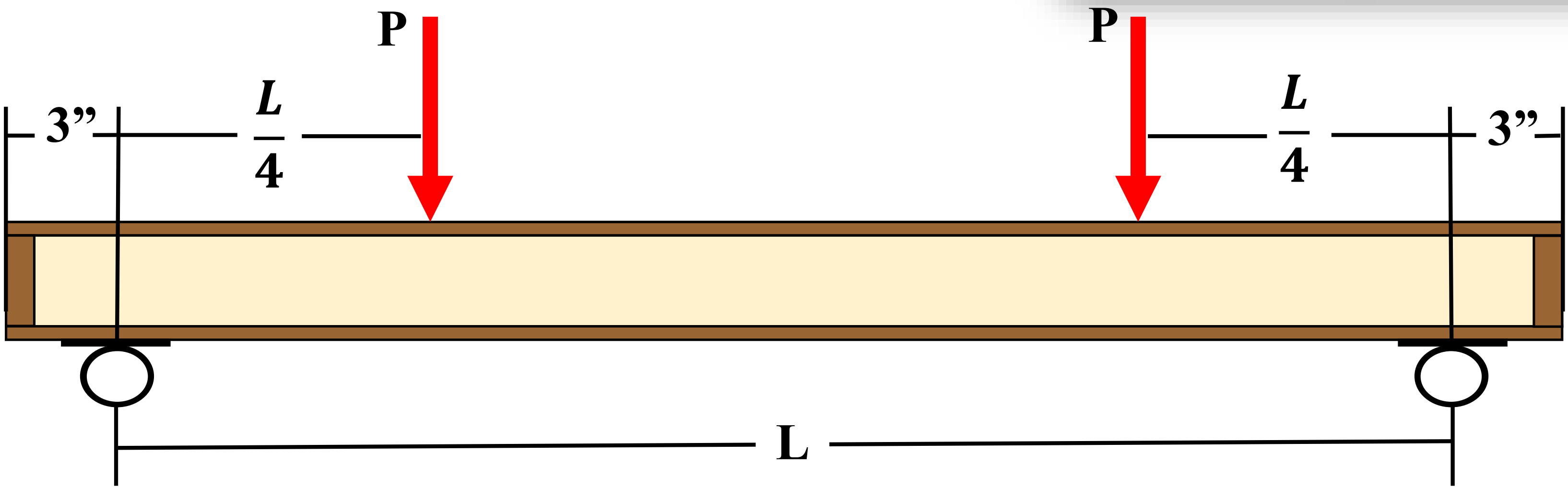
E = 694 psi (COV = 9.3%)

σ_{yield} = 21 psi (COV = 7.5%)

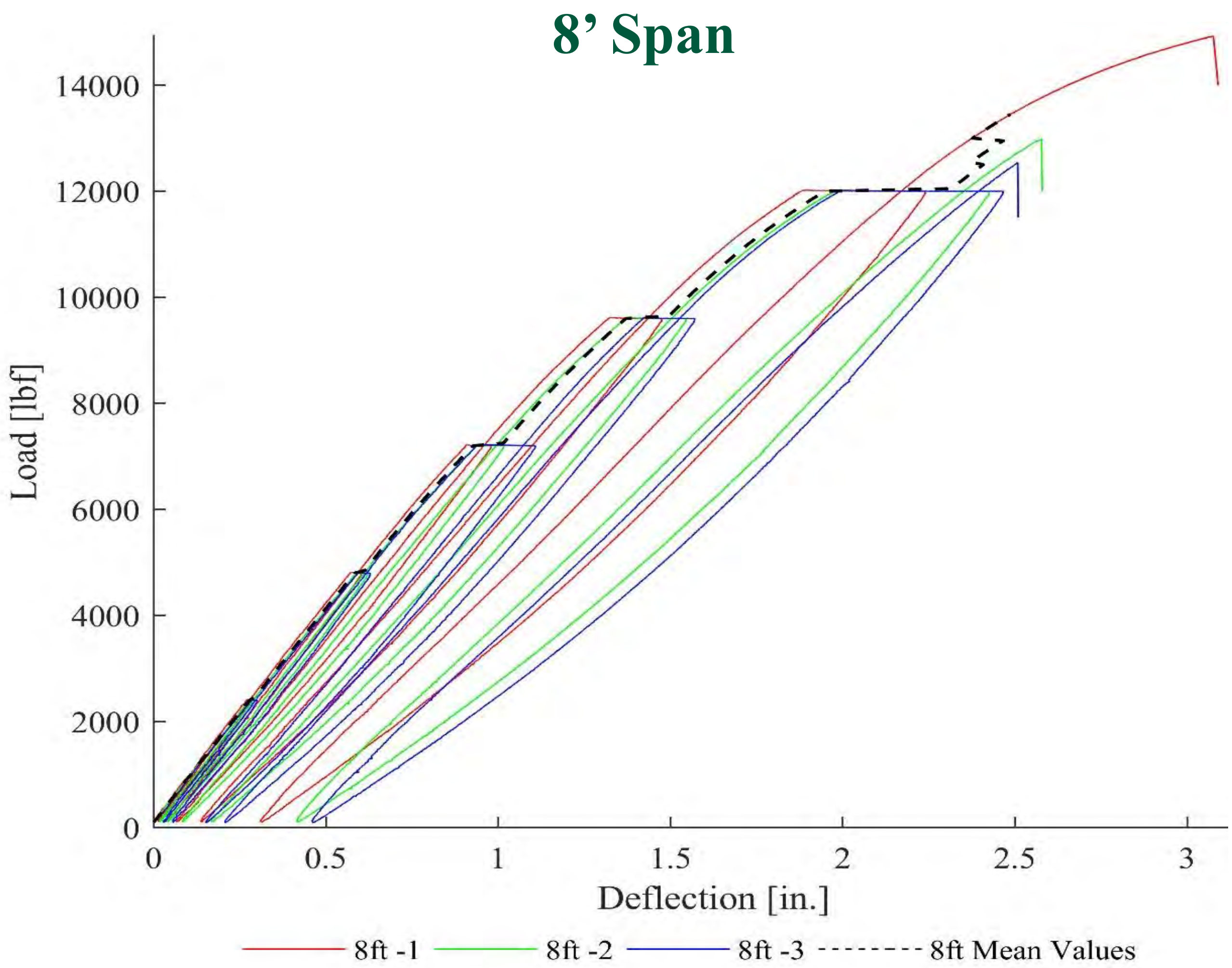
Full-Scale SIP Transverse Bending Tests

- **ASTM E72** – Standard Test Methods of Conducting Strength Tests of Panels for Building Construction
- Simply-supported, quarter-point loaded
  - Not monotonic testing.
  - Incremental loadings of 2,400 lbf.





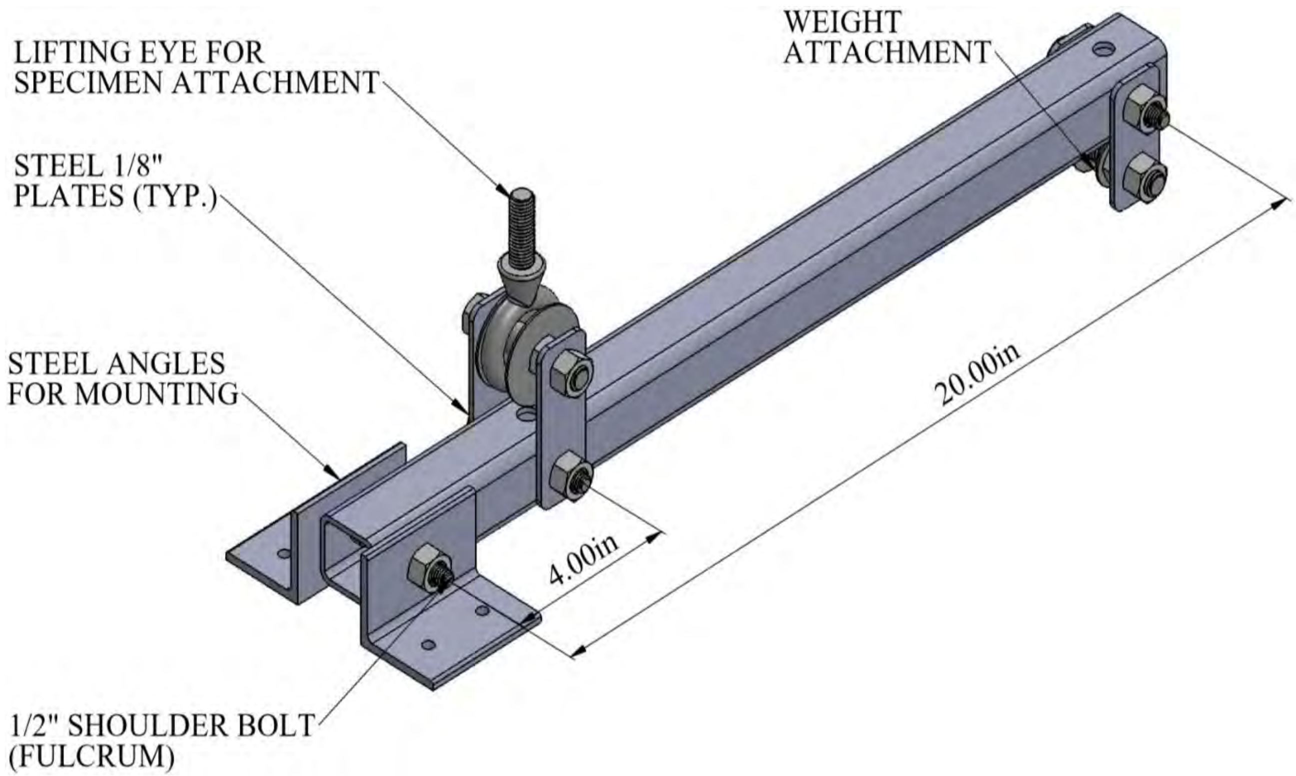
Full-Scale SIP Transverse Bending Results



Time-Dependent Coupon Testing

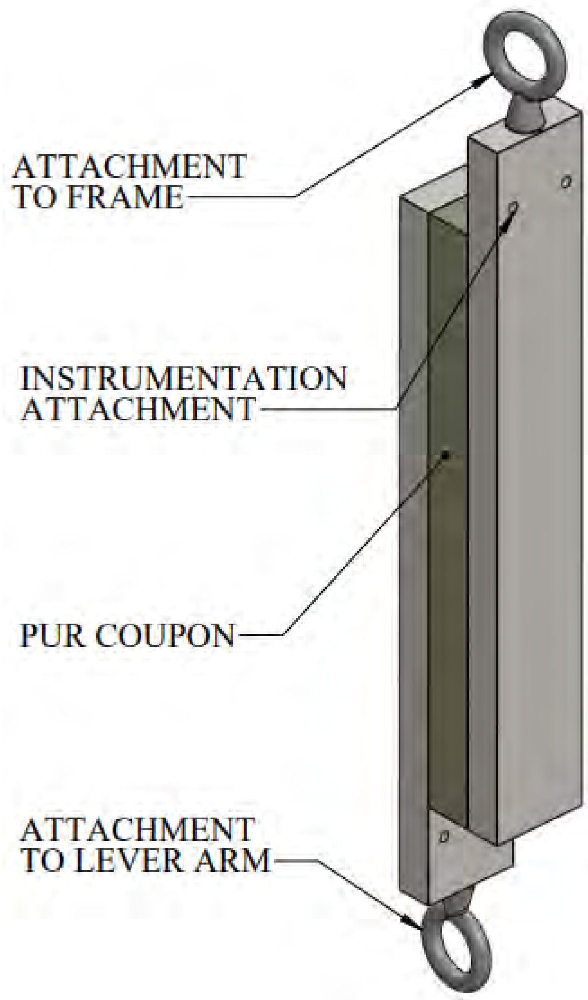
1000-hour creep tests

- Room temperature and humidity

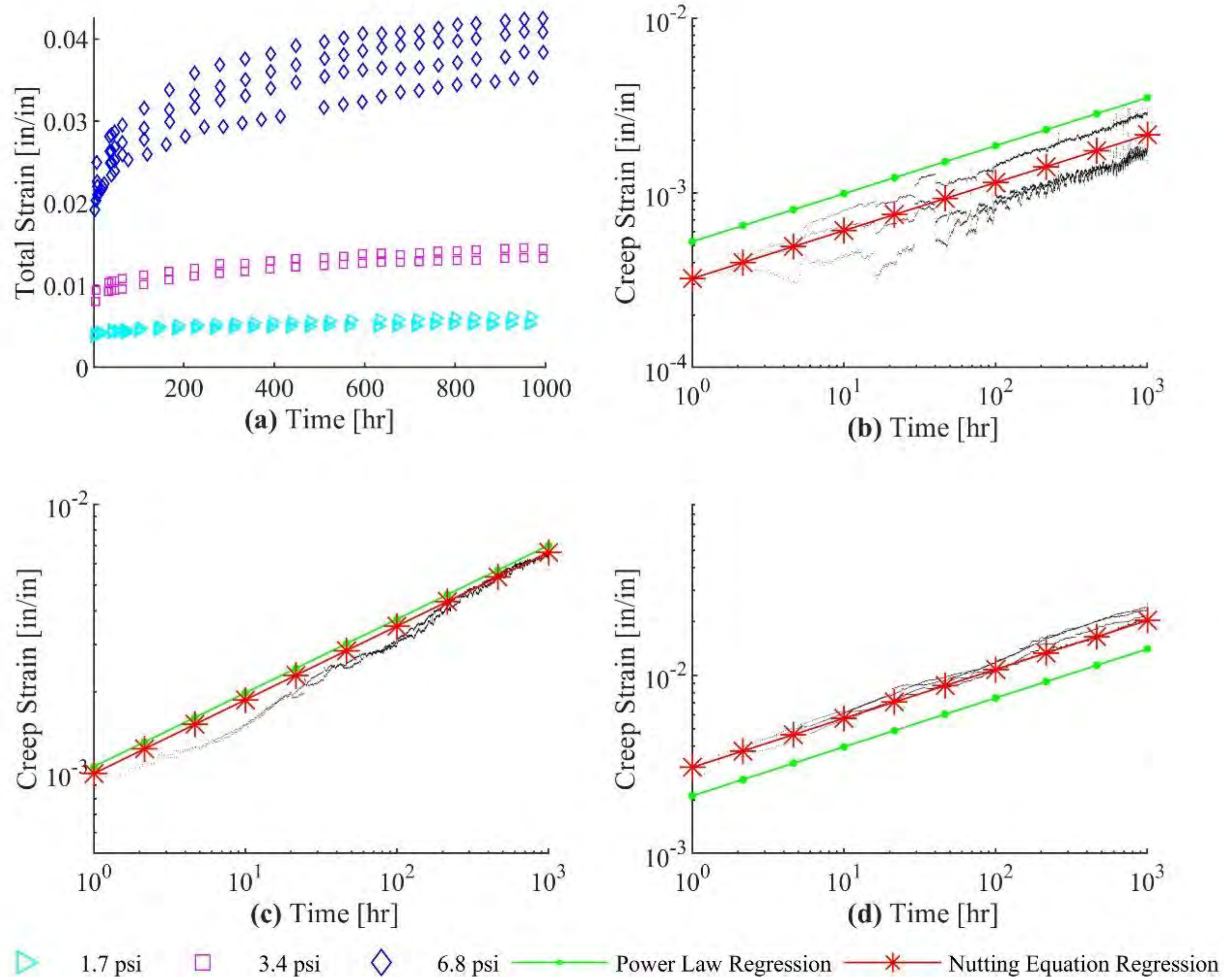


Time-Dependent Shear Testing

Group No.	Load Applied [lbf.]	Percentage of Ultimate	Specimens Tested
1	40.6	5.3%	3
2	81.1	10.6%	4
3	162.3	21.2%	4

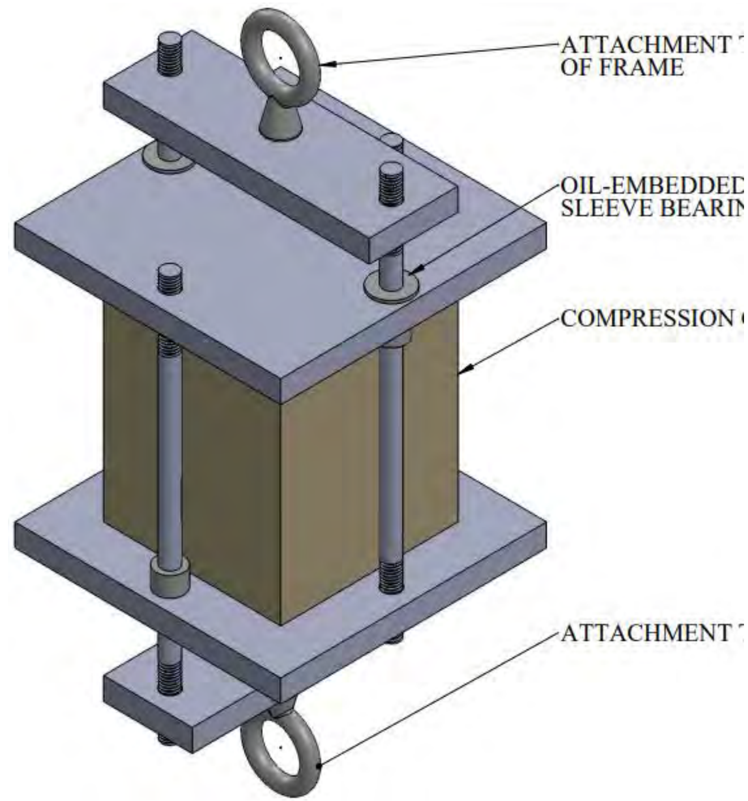


Shear Creep Results

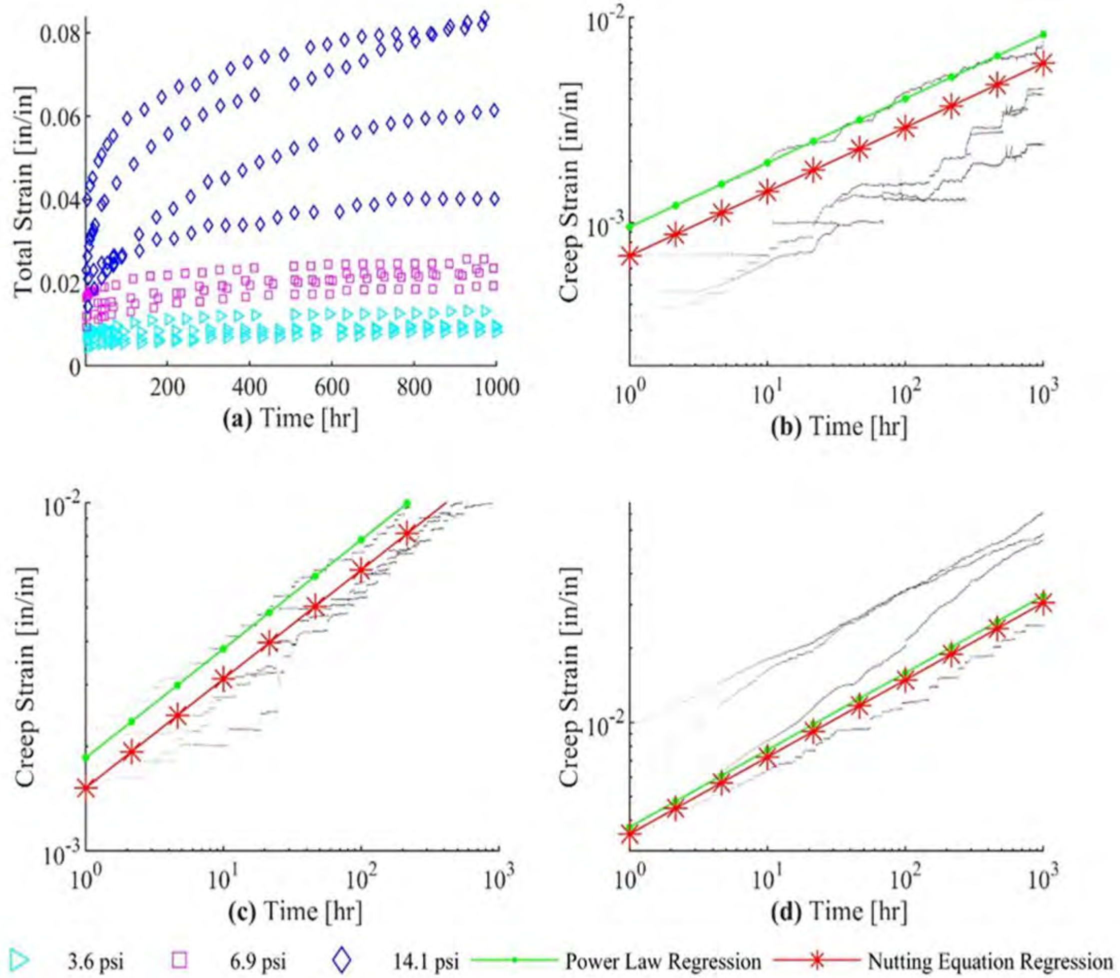


Time-Dependent Compression Testing

Group No.	Load Applied [lbf.]	Percentage of Yield	Specimens Tested
1	57.1	16.8%	4
2	110.9	32.5%	4
3	225.1	66.1%	5

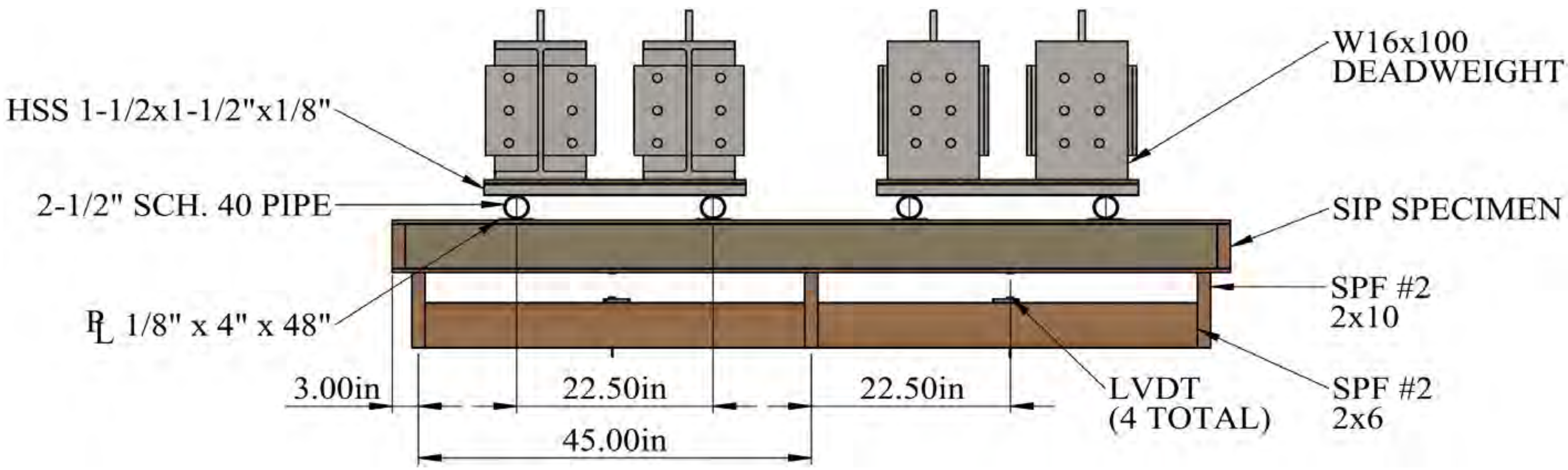


Compression Creep Results

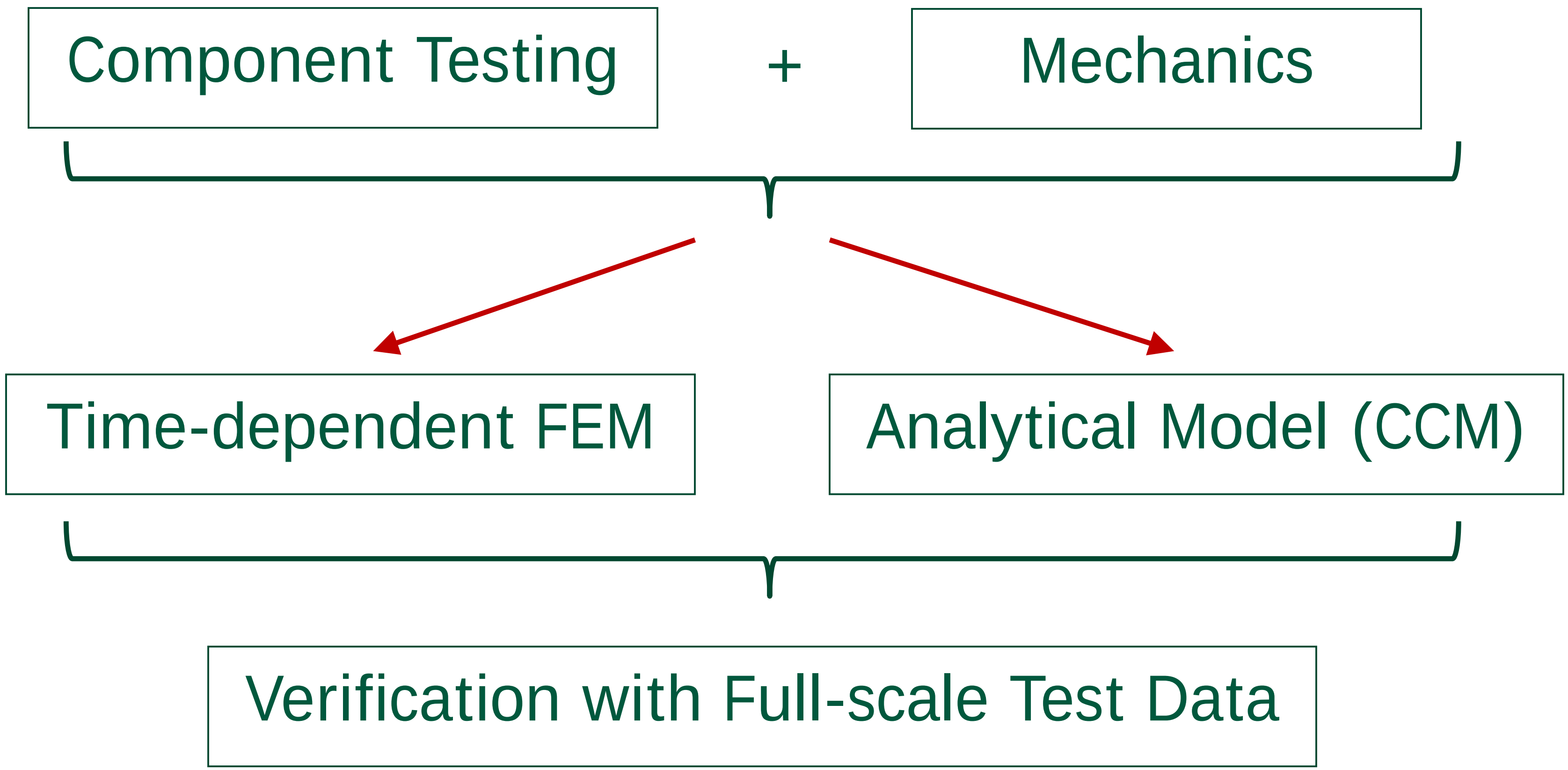


Full-scale Time-Dependent Transverse Bending

- Multispan creep test
- Total of 2,100 lbf. per specimen
- 4 specimens tested
- 1000-hour tests (~42 days)



PU-Ply SIP Analysis (Cox)



PU-Ply SIP Analysis (Cox)

Component Testing + Mechanics

Time-dependent FEM

Analytical Model (CCM)

Complexities:

- Simplified creep models in Abaqus
- Shear-Compression Interaction
- Inability to account for fasteners
- Micro-cracking and other softening

Ful

Complexities:

- Indeterminacy
- "Elastic-Foundation" effects due to compression creep at supports
- Dimensional Lumber at Panel Ends

Proposed Design Code from SIPA

Methodologies

- ADT – Average Divided by Three
- ASD – Allowable Stress Design
- LRFD – Load Resistance Factor Design
- LSD – Limit States Design

Table 4.1.3-1: Reduction Factors for Flexural Tension

Safety Factor, Ω_{mt}		Resistance Factor, ϕ_{mt}	
ADT	**ASD**	**LRFD**	**LSD**
1.0	1.68	0.80	0.95

Limit States for Bending

- Limit States for Bending
  - Flexural Strength Limited by Facing Tension
  - Flexural Strength Limited by Facing Compression
  - Flexural Deflection
  - Shear Strength

Facing Strength

Tension

$$M_t = \lambda_t F_t S_t$$

where:

M_t = Nominal flexural strength limited by facing tensile strength (in.-lbf)
F_t = Facing tensile strength (psi)
S_t = SIP section modulus corresponding to facing in flexural tension ($in.^3$)
λ_t = Time effect factor from Table 4.1.3-2

Table 4.1.3-1: Reduction Factors for Flexural Tension

Safety Factor, Ω_{mt}		Resistance Factor, ϕ_{mt}	
ADT	ASD	LRFD	LSD
1.0	1.68	0.80	0.95

Table 4.1.3-2: Time-Effect Factors for Flexural Tension, λ_t

Load Duration	ADT λ_t	ASD λ_t	LRFD λ_t	LSD λ_t
Short	1.0	1.0	1.0	0.9
Normal	1.0	0.6	0.8	0.8
Permanent	0.5	0.55	0.6	0.5

Compression

$$M_c = \lambda_c F_c S_c$$

where:

M_c = Nominal flexural strength limited by facing compressive strength (in.-lbf)
F_c = Facing compressive strength (psi)
S_c = SIP section modulus corresponding to facing in flexural compression ($in.^3$)
λ_c = Time effect factor from Table 4.1.4-2

Table 4.1.4-1: Reduction Factors for Flexural Compression

Safety Factor, Ω_{mc}		Resistance Factor, ϕ_{mc}	
ADT	ASD	LRFD	LSD
1.0	1.50	0.90	0.80

Table 4.1.4-2: Time-Effect Factors for Flexural Compression, λ_c

Load Duration	ADT λ_c	ASD λ_c	LRFD λ_c	LSD λ_c
Short	1.0	1.0	1.0	0.9
Normal	1.0	0.6	0.8	0.8
Permanent	0.5	0.55	0.6	0.5

Flexural Deflection

- Deflection Expression

$$\Delta = \Delta_b + \Delta_v$$

where:

Δ_t = Total deflection attributed to loads of a single duration (in.)

Δ_b = Deflection due to bending effects determined using tabulated bending deflection formula (in.)

Δ_v = Deflection due to shear effects (in.)

- Simply Supported – Uniform Load

$$\Delta = \Delta_b + \Delta_v = \frac{5wL^4}{384E_tI} + \frac{wL^2}{8G_tA_v}$$

where:

$$E_t = \lambda_E E$$

$$G_t = \lambda_G G$$

Flexural Deflection

Table 4.2.2-1: Time-Effect Factors for Elastic Modulus, λ_E

Core Material	Load Duration	λ_E
Expanded Polystyrene (EPS)	Short	1.00
	Normal	0.40
	Permanent	0.30
Polyurethane	Short	1.00
	Normal	0.20
	Permanent	0.15

Table 4.2.3-1: Time-Effect Factors for Shear Stiffness, λ_G

Core Material	Load Duration	λ_G
EPS	Short	1.00
	Normal	0.40
	Permanent	0.30
Polyurethane	Short	1.00
	Normal	0.20
	Permanent	0.15

Conservative Code Assumptions

- Uses only "Permanent" (50 years) and "Normal" (10 years). No allowance for 2 month loads
- Uses Power Law (not stress dependent)
  - Overestimates creep for low stresses
  - Underestimates creep for high stresses
- Uses compression-only time-effects values (and applies them to shear

Code Calculation vs Test Data

Code vs Test

Multi-span test with 45-inch span, 100psf
6.5" PU SIP with 1/2" CDX Plywood Faces

$E := 694\ ksi$
$G := 300\ psi$

Neglect Plywood faces: $A_v := A_{core}$

$Load := 100\ psf$ $W := 100\ psf \cdot 12\ in$ $L := 45\ in$

$t_{40d} := 60 \cdot 1000 = 60000$ (1000 hour test)

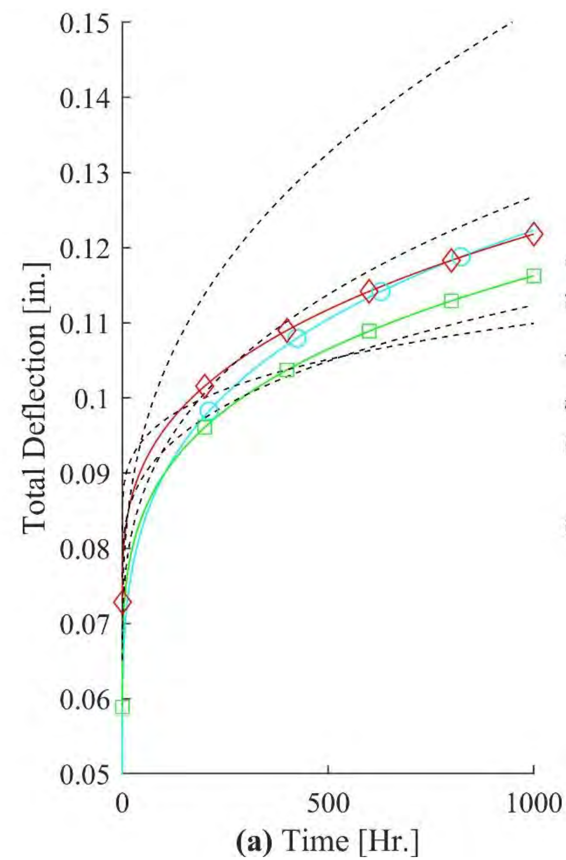
$$\lambda_{test} := \frac{1}{1 + 0.0197 \cdot t_{40d}^{\ 0.33}} = 0.57$$

SIPA Commentary

$E_t := \lambda_{test} \cdot E = 398\ ksi$ $G_t := \lambda_{test} \cdot G = 172\ psi$

$$\Delta_b := \frac{W \cdot L^4}{384 \cdot E_t \cdot I} = 0.002\ in \qquad \Delta_v := \frac{W \cdot L^2}{12\ A_v \cdot G_t} = 0.12\ in$$

$\Delta := \Delta_b + \Delta_v = 0.13\ in$ $\frac{L}{240} = 0.19\ in$



Code Deflection Example

Simple-span test with 32-inch span, 10psf Dead + 40psf Snow
6.5" PU SIP with 1/2" CDX Plywood Faces

$E := 694\ ksi$
$G := 300\ psi$

$L := 32\ in$ $\quad SL := 40\ psf$
$W := 12\ in$ $\quad DL := 10\ psf$

Using SIPA Chart Values: $\lambda_S := 0.2$
$\lambda_D := 0.15$

$E_{t\_S} := \lambda_S \cdot E = 139\ ksi$ $\quad E_{t\_D} := \lambda_D \cdot E = 104.1\ ksi$
$G_{t\_S} := \lambda_S \cdot G = 60\ psi$ $\quad G_{t\_D} := \lambda_D \cdot G = 45\ psi$

$$\Delta_{b\_S} := \frac{5 \cdot SL \cdot W \cdot L^4}{384 \cdot E_{t\_S} \cdot I} = 0.003\ in \qquad \Delta_{v\_S} := \frac{SL \cdot W \cdot L^2}{8\ A_v \cdot G_{t\_S}} = 0.11\ in$$

$$\Delta_{b\_D} := \frac{5 \cdot DL \cdot W \cdot L^4}{384 \cdot E_{t\_D} \cdot I} = 0.001\ in \qquad \Delta_{v\_D} := \frac{DL \cdot W \cdot L^2}{8\ A_v \cdot G_{t\_D}} = 0.04\ in$$

$$\Delta_S := \Delta_{b\_S} + \Delta_{v\_S} = 0.11\ in \qquad \frac{L_l}{240} = 0.12\ in$$

Table 1604.3 (2012 IBC)

$$\Delta_T := \Delta_S + \Delta_{b\_D} + \Delta_{v\_D} = 0.15\ in \qquad \frac{L_l}{180} = 0.16\ in$$

It works! (barely)

Code Deflection Example

Simple-span test with 32-inch span, 10psf Dead + 40psf Snow
6.5" PU SIP with 1/2" CDX Plywood Faces

$E := 694\ ksi$
$G := 300\ psi$

$L := 32\ in$ $\quad SL := 40\ psf$
$W := 12\ in$ $\quad DL := 10\ psf$

Using Creep equation from SIPA Commentary:

$$\lambda_{2m} := \frac{1}{1 + 0.0197 \cdot t_{2m}^{\ 0.33}} = 0.54 \qquad \lambda_{50y} := \frac{1}{1 + 0.0197 \cdot t_{50y}^{\ 0.33}} = 0.15$$

$E_{t\_S} := \lambda_{2m} \cdot E = 377\ ksi$ $\quad E_{t\_D} := \lambda_{50y} \cdot E = 106\ ksi$
$G_{t\_S} := \lambda_{2m} \cdot G = 163\ psi$ $\quad G_{t\_D} := \lambda_{50y} \cdot G = 46\ psi$

$$\Delta_{b\_S} := \frac{5 \cdot SL \cdot W \cdot L^4}{384 \cdot E_{t\_S} \cdot I} = 0.001\ in \qquad \Delta_{v\_S} := \frac{SL \cdot W \cdot L^2}{8\ A_v \cdot G_{t\_S}} = 0.04\ in$$

$$\Delta_{b\_D} := \frac{5 \cdot DL \cdot W \cdot L^4}{384 \cdot E_{t\_D} \cdot I} = 0.001\ in \qquad \Delta_{v\_D} := \frac{DL \cdot W \cdot L^2}{8\ A_v \cdot G_{t\_D}} = 0.04\ in$$

$\Delta_S := \Delta_{b\_S} + \Delta_{v\_S} = 0.04\ in$ $\quad \frac{L_l}{240} = 0.12\ in$ $\quad$ Table 1604.3 (2012 IBC)

$\Delta_T := \Delta_S + \Delta_{b\_D} + \Delta_{v\_D} = 0.08\ in$ $\quad \frac{L_l}{180} = 0.16\ in$ $\quad$ It works! (by a lot)

The Future…

Current and Ongoing Work

- R-value Tests
- Composite Action with joists
- Creep of Foundation Elements
- Seismic Evaluation

Proposals to Funding Agencies

- Wood Innovations – Early phases of commercial project that promotes Forest Products
- Charles Pankow Foundation – Creep and Seismic Evaluation
- Other Funding (NSF?) – Seismic Evaluation

Questions?