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Why Evaluate the *IRC, IBC, SDPWS* and *WFCM* Braced Wall Panel Engineering?

Why Evaluate the *IRC, IBC, SDPWS* and *WFCM* Braced Wall Panel Engineering?

1. Wall bracing seems very complicated.
2. A good understanding of load path makes it easier to apply our engineering knowledge.
3. Increased data and knowledge leads to better engineering judgments and more accurate BWP in BWL designs.
4. Product advancement and innovation cannot and will not happen without a good technical foundation and level playing field.

Why Evaluate Lateral Braced Wall Design?

The March/April 2011 Edition of AWC's *Impact* provides a compelling reason to undertake a fresh evaluation.

From: Merriman, Lacey [mailto:LMerriman@awc.org] **On Behalf Of** AWC Impact
Sent: Thursday, May 12, 2011 2:55 PM
To: undisclosed-recipients
Subject: AWC Impact March-April 2011- AWC receives ANSI accreditation!

AMERICAN WOOD COUNCIL

Impact

A Bi-Monthly Report on Building Codes and Standards Issues from the American Wood Council

Vol. 23 No. 2
March/April 2011

In This Issue:

ASCE 7-10 Seismic Exemption for Wood. A vote to include in *ASCE 7-10* an expanded exemption for wood frame buildings designed in accordance with the *IRC* and *IBC* section 2308 failed. The PUC (and BSSC Membership) overwhelmingly voted to approve this language last cycle based on the rationale that *IRC* and *IBC* prescriptive provisions were equivalent to those contained in *2009 NEHRP* Provisions. **During this meeting, several PUC members were critical of *IRC* and *IBC* 2308 prescriptive bracing provisions and raised questions about what is contained in those code documents** and how it relates to *2009 NEHRP* conventional construction provisions.

Why Evaluate Lateral Braced Wall Design?

The engineering foundation of the *IRC* is best described by the fact that the ICC's Ad Hoc Committee on Wall Bracing recognized a need to provide implicit design values for braced wall panel (BWP) resistance.

The committee goal – to reconcile engineering theory with proven residential building construction.

This was done through a consensus of the committee. Crandell-Martin provide the following insight:

> "Balancing wind load demand and wall bracing capacity served as the logical basis of the analysis framework developed by the Dolan-AHWB Committee. By far, the greatest challenge was reaching agreement on the capacity, or strength, of conventional wall bracing segments because such segments do not have explicit overturning restraint (i.e., hold-down brackets) conducive to use of accepted engineering analysis methods. Thus, expert opinions about appropriate design strength for braced wall segments varied widely. After several years of committee work and review of all of the available and relevant testing, a logical and simple framework to determine load demand and wall bracing capacity was agreed upon as:
>
> **Braced wall capacity = (fully restrained shear wall capacity) x (net adjustment factor)**
>
> Shear wall capacity is based on code-recognized values or testing in the absence of relevant code recognized values. The net adjustment factor was taken as the product of a partial restraint factor and a whole-building factor, which was simplified to a value of 1.2 for all cases for reasons explained later. The actual values of the separate terms were not specifically agreed upon by either committee. As such, the net adjustment factor could be grossly characterized as a "calibration factor" to bring results in line with historic bracing requirements for 1950s or 1960s era 1,500 ft.2 or less, two story or less, conventionally constructed houses.

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Why Evaluate Lateral Braced Wall Design?

Professor Dan Dolan of the ICC Ad-Hoc Committee on Wall Bracing (AHC-WB) elegantly states several good reasons to more fully understand restrained vs. unrestrained braced wall panel (BWP) behavior in his "Dolan-Toothman Report."

SUMMARY

A total of 45 walls were tested under monotonic loading using ASTM E564 and under cyclic loading using ASTM E2126. All of the walls were 1.2 x 2.4m (4 x 8ft), and to be conservative, there were no gravity loads applied to the walls. The intent of the test was to investigate the effect of combining Gypsum Wallboard (GWB) with 3 other typical light-frame sheathing materials (Oriented Strandboard (OSB), Hardboard, and Fiberboard.) Replicates of 2 were used throughout the investigation, with each of the sheathing types tested as single sided walls and then GWB was added to walls sheathed on one with one of the other three sheathing materials. Comparisons are made between each of the material types as well as the effect of GWB on the various performance parameters (i.e., peak load, yield load, stiffness, energy dissipation, etc.)

The results indicate that the monotonic and cyclic response of all of the walls were similar in stiffness and load up to a displacement of approximately 50 mm (2 in). GWB was effective in increasing the peak load for walls with hold-down connections, and was close to being linearly additive for walls tested monotonically. GWB was not as effective for walls with hold-down connections that were tested cyclically. GWB was not effective in changing the peak load for walls without hold-down connections.

Wall specimens using hold-down connections had higher peak load and stiffness values than walls without these connections. The walls with hold-down connections also had a higher toughness, in that the displacement capacity and energy dissipation characteristics were significantly improved. This performance improvement is due to the more distributed resistance of the sheathing nails in walls with hold-down connections. Walls without hold-down connections concentrated the resistance at the bottom row of nails into the bottom plate. These nails had to resist both the shear and overturning forces when the hold-down connections were not present.

ACKNOWLEDGEMENTS

The authors would like to thank American Forest and Paper Association for funding this research through research grant number 032-433796. We would also like to thank the Hardboard Association for their donation of sheathing materials used in fabrication of the walls.

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Why Evaluate Lateral Braced Wall Design?

The *IBC* and *IRC* have, by definition, incorporated into the design of BWPs the following core concepts:

1. Fully restrained (using hold-down connectors) BWP nominal unit shear capacity (NUSC) values used also in anchor bolt applications.
   – NUSC values are provided in *SDPWS* and the *IBC* and are similar/identical.
2. A hold-down (fully restrained) to anchor bolt (partially restrained) factor of some kind is used in the *IBC* and *IRC*.
3. The following factors are also implied within the code requirements:
   – An anchor bolt system effect factor
   – An E72/E564/E2126 test assembly boundary condition effect factor
   – A traditional performance effect factor

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Why Evaluate Lateral Braced Wall Design?

The goal of the work being performed is to provide a:

1. Enhance existing knowledge with respect to BWP and BWL engineering fundamentals.
2. Provide a clearer and deeper understanding of the IBC and IRC BWP code provisions.
3. Evaluate past test data and current state-of-the-art full-scale building testing to help provide a fundamental understanding of the actual performance characteristics of BWPs.
4. Offer a roadmap for better understanding of the engineering judgments that need to be made when using IBC Section 2308.2 Limitations, IBC Section 2308.9 Wall Framing, IRC Section R602.10 Wall Bracing, SDPWS Section 4.3 Wood-Frame Shear Walls and the WFCM and their specific and implied BWP in a BWL design methodology.
5. Clarify the BWP design values that are currently used, the assumptions made in their use, and the design value adjustment factors implicitly and explicitly defined by the codes and standards as written and implemented.
6. Provide a technically solid foundation upon which to make sound engineering judgments when using generally accepted engineering methods in concert with BWL design and code compliance requirements as defined within the current IRC, IBC, SDPWS and WFCM.
7. Facilitate a level playing field, allowing for fair and understandable BWP and BWL product development.

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Why Evaluate Lateral Braced Wall Design?

The following data serves as the technical foundation for this analysis:

1. Seaders
2. Dolan & Toothman
3. APA
4. Ph.D. Thesis under development
5. SBCRI OSB and Proprietary Testing

It appears the strength of OSB BWP performance is **NOT** as fully correlated to the following factors as the *NDS, SDPWS* and *IBC* assume:

1. OSB panel thickness (i.e., $^{3}/_{8}$", $^{7}/_{16}$", or $^{15}/_{32}$")
2. OSB grade (i.e., Structural I, sheathing, etc.)
3. Lumber stud type (size, grade or species)
4. Fastener type (i.e., 6d, 8d, etc.)

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Testing & Technical Substance Behind our Evaluation of Lateral Braced Wall Design?

Two hundred and eight (208) 12' x 30' single-story full building monotonic tests using ASTM E564 techniques built in accordance with the building code, including:

- Isolated 4 x 8 BWPs with and without hold- down connectors (a.k.a. “hold-down brackets”),
- Isolated 8 x 8 BWPs with and without hold- down connectors,
- 30' fully sheathed with and without gypsum wallboard (GWB),
- 6:1 and 9.6:1 narrow aspect ratio isolated panels;
- Roughly 9' opening portal frames, and
- 30' perforated shear wall with an effective braced wall length in the 14' range (48% perforated).

This testing includes:

- 168 proprietary walls tested (84 - 12' x 30' buildings with 2 BWLs tested per building).
- 248 Qualtim/SBCRI walls tested (124 - 12' x 30' buildings with 2 BWLs tested per building using $^{3}/_{8}$" and $^{7}/_{16}$" OSB code based applications).

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Testing & Technical Substance Behind our Evaluation of Lateral Braced Wall Design?

Sixty-eight (68) 4 x 8 single element station BWP tests using ASTM E72/E564 techniques to assess the lateral resistance with vertical connections using:

- Hold-down connectors,
- Anchor bolts with no axial applied load,
- Anchor bolts with 1,100 lbs of axial applied load,
- Anchor bolts with 2,200 lbs of axial applied load,
- Anchor bolts with 3,300 lbs of axial applied load,
- Anchor bolts with 4,400 lbs of axial applied load, and
- Anchor bolts with 5,500 lbs of axial applied load.

This testing includes data from:

- Ph.D. student testing ($^{15}/_{32}$" OSB)
- Proprietary BWP tests
- Supplemental Qualtim/SBCRI to fill in gaps ($^{3}/_{8}$" OSB)
- One QuickTie™ test as an alternative hold-down connection

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Testing & Technical Substance Behind our Evaluation of Lateral Braced Wall Design?

Sixteen (16) 12' x 30' full building cyclic tests using ASTM E2126 CUREE protocol techniques built in accordance with the building code, including:

- Isolated 4 x 8 BWPs without hold-down connectors,
- 30' fully sheathed with and without GWB, and
- Our 30' perforated shear wall (52% perforated).

This testing includes:

- 9 proprietary walls tested (18 – 12' x 30' buildings with 2 BWLs tested per building).
- 8 Qualtim/SBCRI walls tested (16 – 12' x 30' buildings with 2 BWLs tested per building using $^{3}/_{8}$" OSB code based applications).
- Sixteen (16) "E2126 failed" 12' x 30' full building monotonic tests using ASTM E564 techniques.
  - The same assembly was tested immediately after the 12' x 30' full building cyclic tests using ASTM E2126 CUREE techniques to assess residual capacity after the cyclic test.

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Testing & Technical Substance Behind our Evaluation of Lateral Braced Wall Design?

- Qualtim/SBCRI testing uses the standardized testing procedure techniques of ASTM E2126, E564 and E72 as appropriate in our full building testing.
- A comprehensive set of non-proprietary data and BWP/BWL analysis provided courtesy of Qualtim is available at:
  - sbcri.info/bcters.php
  - sbcri.info/ibcirc.php

Nominal Unit Shear Capacity Design Values Assumed Today per *IRC*, *IBC* & *SDPWS*

IRC

Sheathing	Fastener	Fastener Spacing	Nominal Unit Shear Capacity (PLF) SPF Studs at 16" o.c.	AHC-WB Net Adjustment Factor	*IRC* Effective Nominal Unit Shear Capacity (PLF)
3/8" WSP (sheathing)	2" x 0.113" nail	6:12	500 (515 PLF in SDPWS)	1.2	600
1/2" GWB (gypsum wallboard)	5d cooler nail (1-5/8" x 0.089") Type W or S screw 1" long (gypsum)	8:8 Nail 16:16 Screw	200 (200 PLF in SDPWS)	1.2	240
Combined 3/8" WSP and 1/2" GWB	As above	As above	700	1.2	840

Table 3: Summary of Nominal Unit Shear Capacity Values Used to Tabulate the Bracing Lengths Required by *IRC* Table R602.10.1.2(1)
APA provides data that forms the basis of these nominal unit shear capacity values also applying to 7/16" OSB.

TER No. 1101-03.5: *Defining the "IRC Net Adjustment Factor – WSP" and the "IRC Net Adjustment Factor – WSP+GWB" Used in the IRC Based on the Minimum IRC Requirements* provides the *IRC* nominal unit shear capacity value background.

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Nominal Unit Shear Capacity Design Values Assumed Today per *IRC*, *IBC* & *SDPWS*

IBC & *SDPWS*

WSP	Fastener	Fastener Spacing	Studs Spaced 16" o.c. Max.		Studs Spaced 24" o.c. Max	
			DF/SP Framing	SPF Framing	DF/SP Framing	SPF Framing
			IBC/SDPWS Nominal Unit Shear Capacity (PLF)		*IBC/SDPWS* Nominal Unit Shear Capacity (PLF)	
$^{3}/_{8}$" WSP (sheathing)	6d (2" x 0.113" nails)	6:12	560[4] / 560[5]	515[6] / 515[7]	560[8] / 560[9]	515[10] / 515[11]
	8d (2$^{1}/_{2}$" x 0.131" nails)		728[12] / 730[13]	670[14] / 672[15]	616[16] / 615[17]	567[18] / 566[19]
$^{3}/_{8}$" WSP (Structural 1 sheathing)			784[20] / 785[21]	721[22] / 722[23]	644[24] / 645[25]	592[26] / 593[27]

Table 1: Comparison of $^{3}/_{8}$" WSP Nominal Unit Shear Capacity Values with Shear Wall Panels Restrained from Overturning with the Use of Hold-Downs (Fully Restrained)

TER No. 1101-03.2: *Evaluation of the 2009 IBC Braced Wall Panel Provisions and Minimum Design Values Using $^{3}/_{8}$" Wood Structural Panels* provides the *IBC* nominal unit shear capacity value background.

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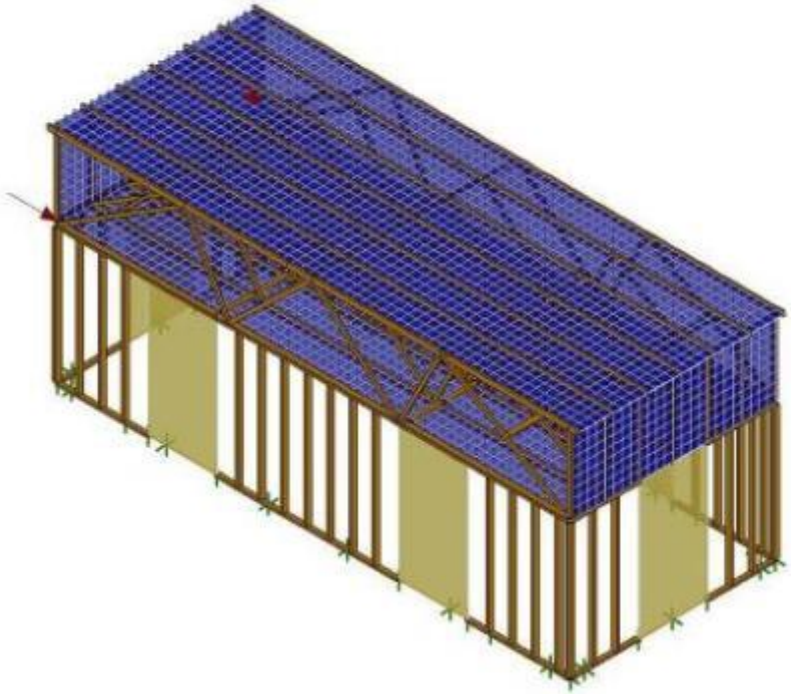
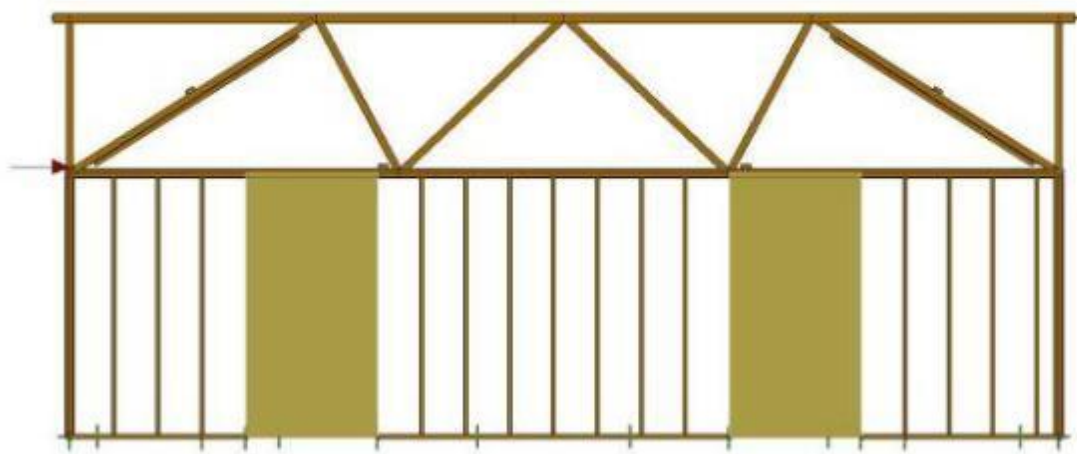
Known Test Limit States that Define Capacity for BWPs in BWL

- Lateral "OSB pull through" with respect to the sheathing at the bottom plate and lead stud nails – primarily in isolated BWPs.
  - OSB/nail capacity along the bottom plate is the general failure mode.
- Uplift of the stud at the anchor bolt due to applied lateral load rotating the BWP – primarily in isolated BWPs.
- Ability of hold-down connectors to hold the stud tight to the bottom plate – primarily in isolated BWPs.
- Gravity load holding the BWP lead stud down – positive PLF impact in isolated and non-isolated BWPs.
- Differential stiffness BWPs in a BWL are generally not additive. GWB is not purely additive.
- Isolated panels perform differently than fully sheathed BWL applications.
- Fully sheathed applications with GWB perform better as a composite than individually by themselves.
- Stiffness controls performance and load path to the foundation.

Modeling the Load Path from the Test Data



- Calibrate FEA Model to in situ tested performance.
- Most precise analytics.



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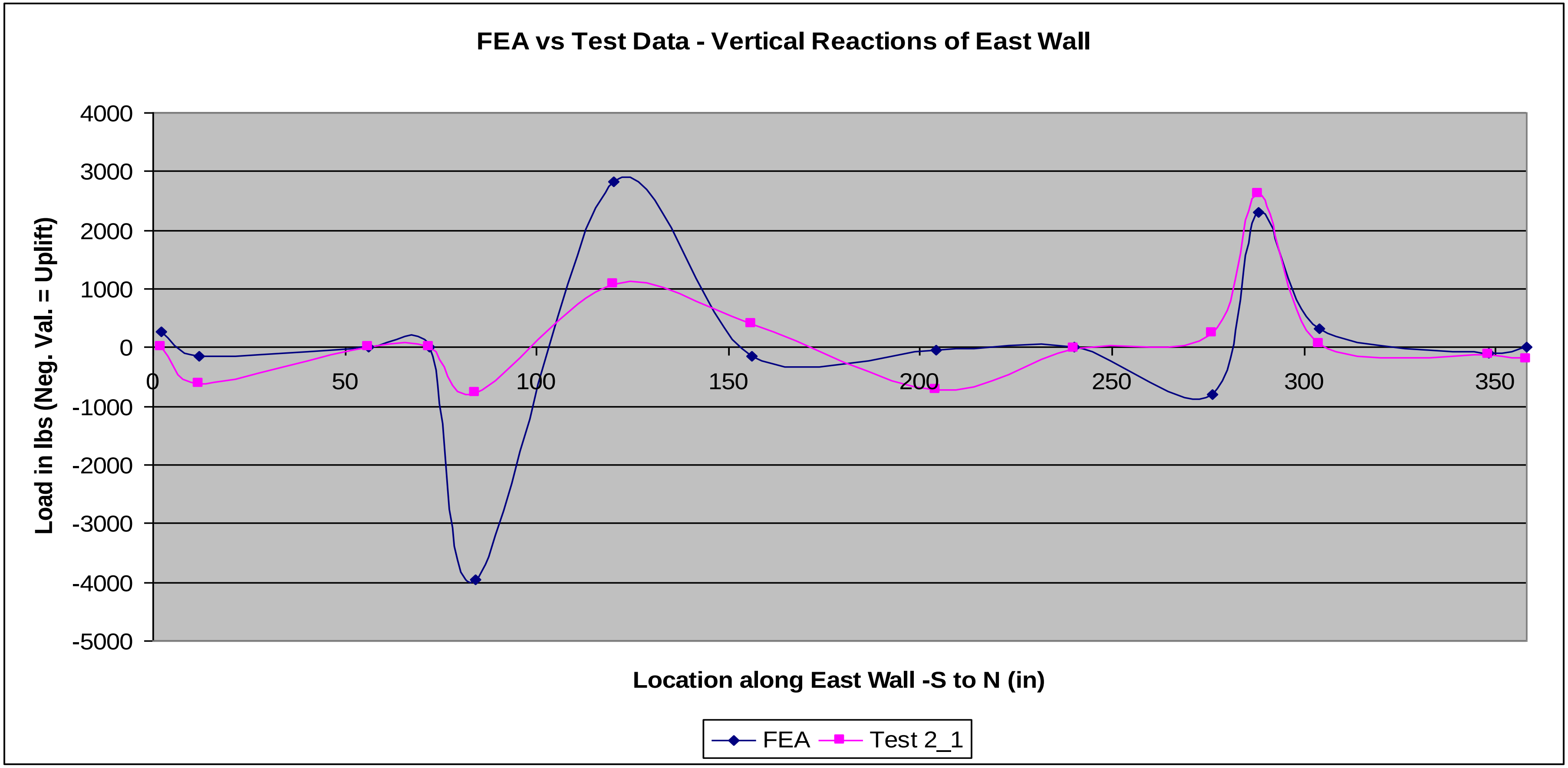
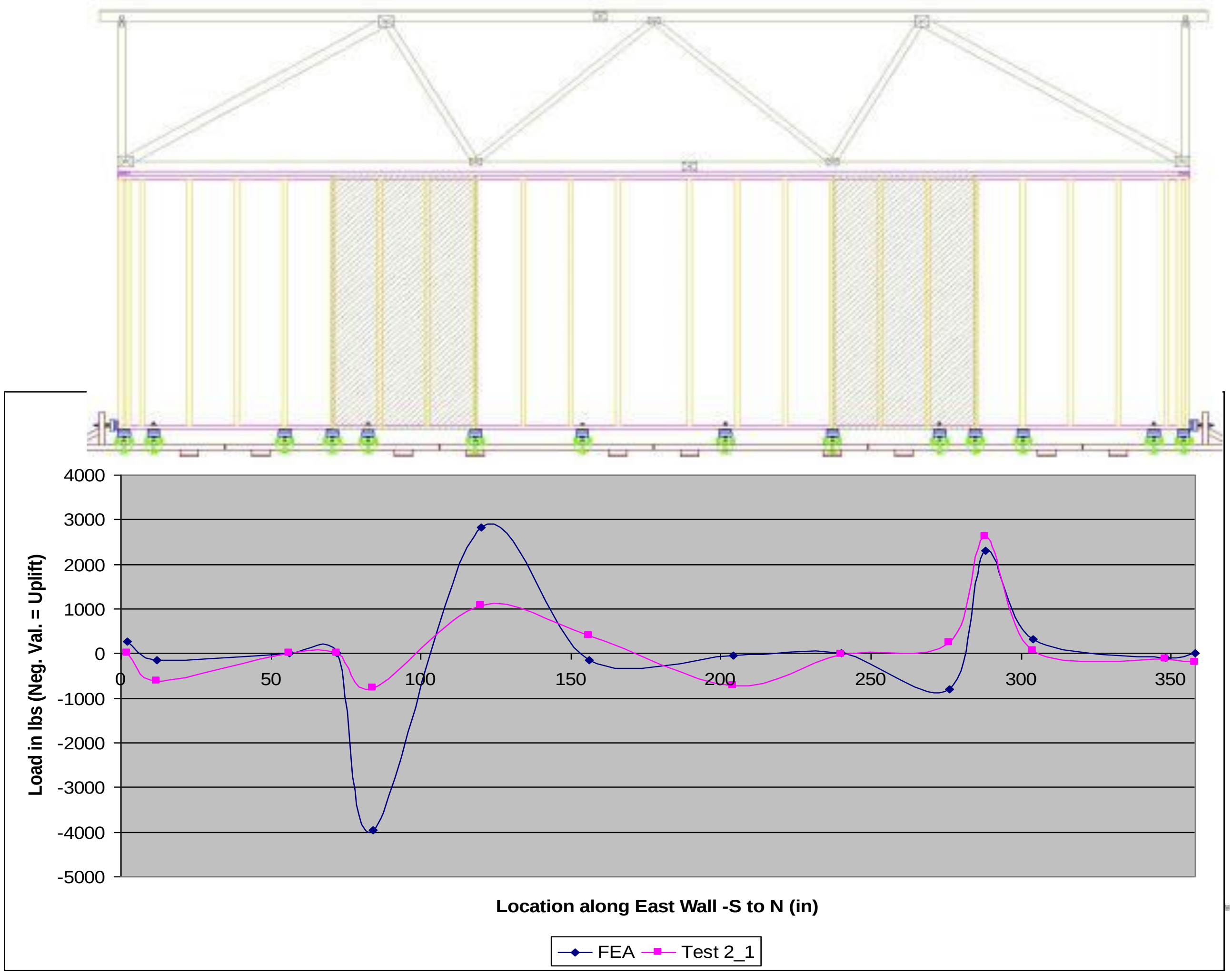
Correlate Actual vs. Predicted Load Path



Map Load Path Performance Characteristics

- Applied Lateral Load Left to Right
- Blue line is Existing “Woodworks” Finite Element Analysis Prediction
- Red line is as tested load path.
- “-4000” is uplift



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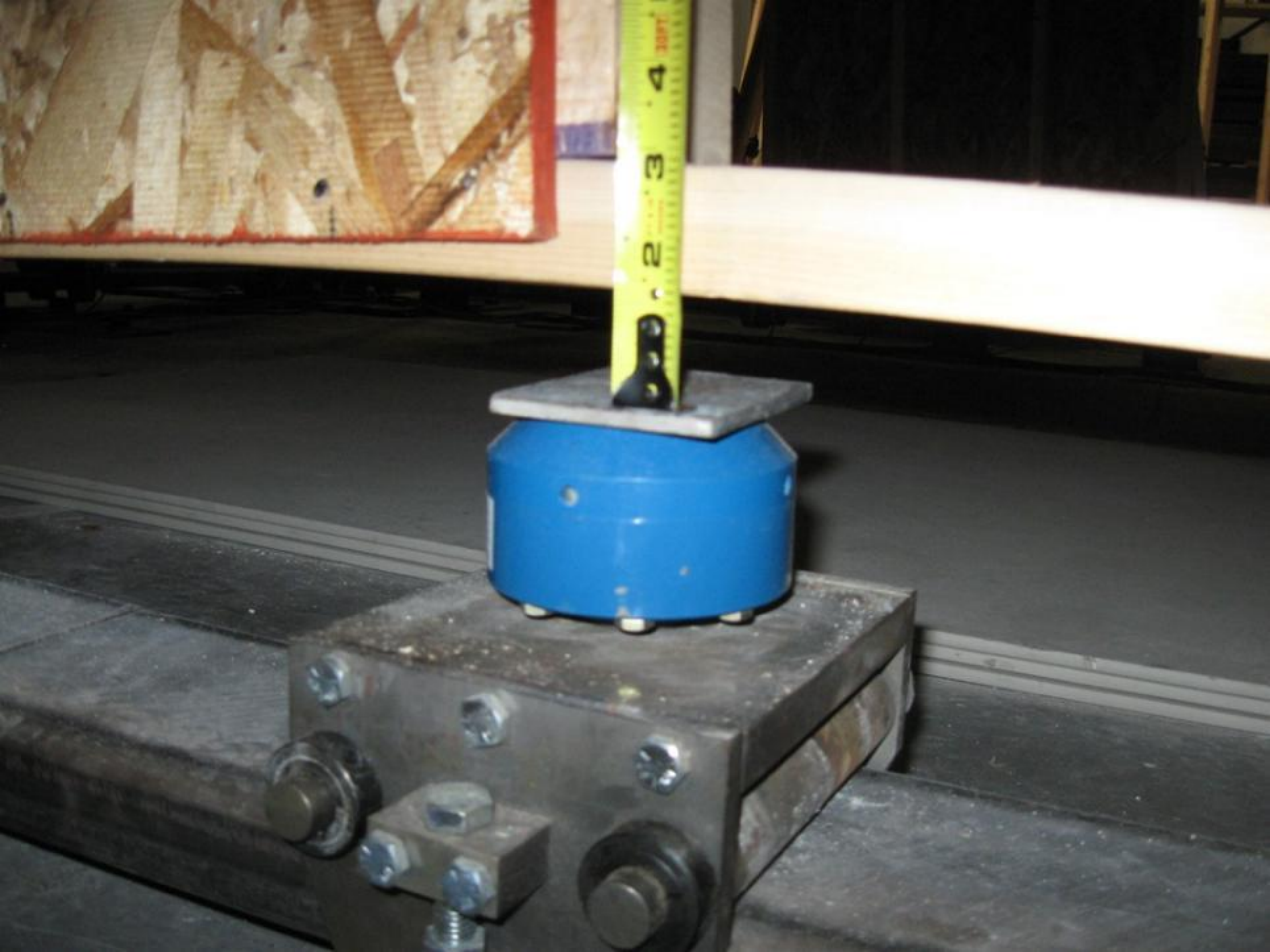
7/16" OSB Testing, 8d Nails, 6/12

Constructed IRC/IBC Compliant



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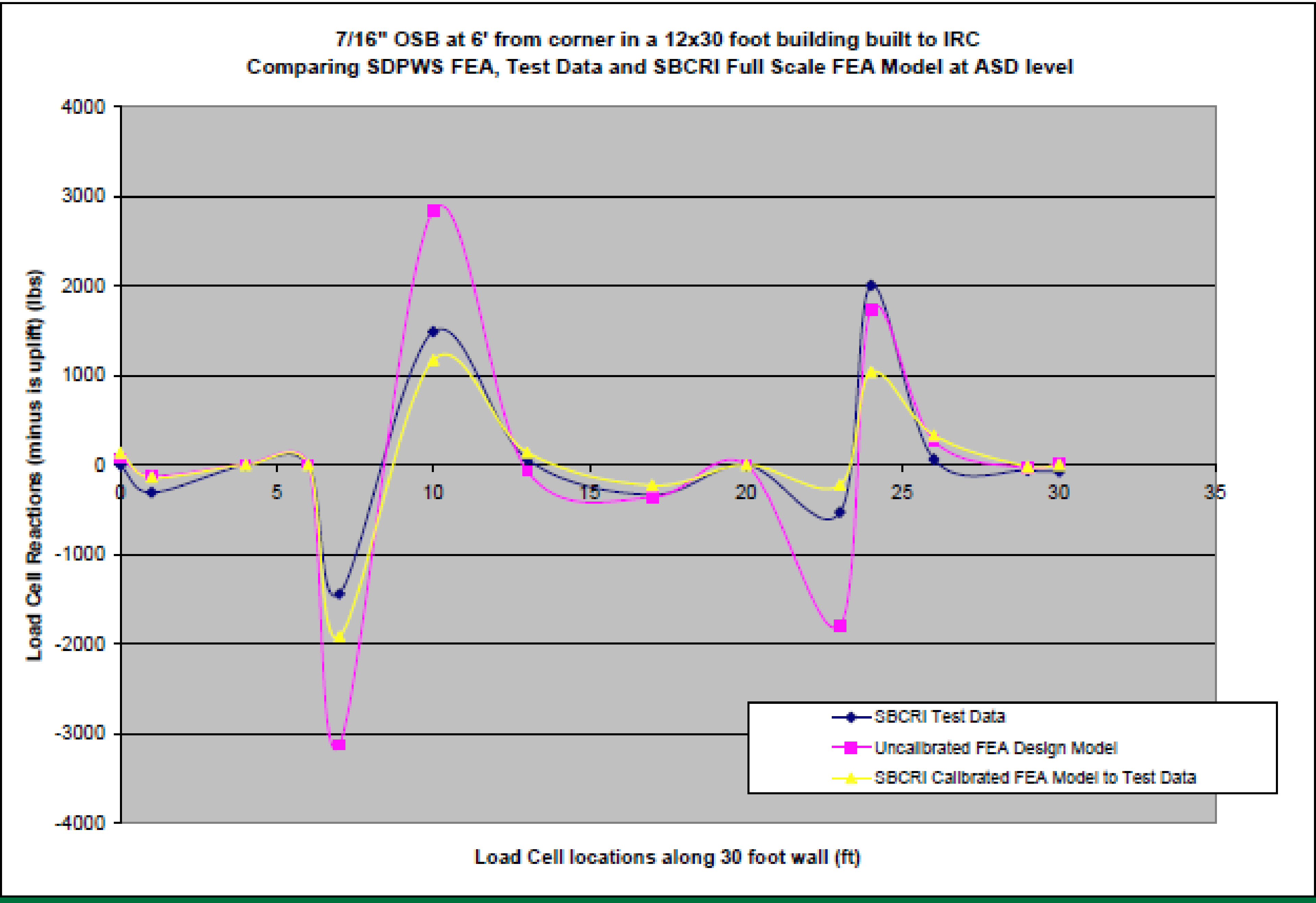
Load Path for 7/16” OSB Placed 6’ in from Each Corner as Shown in Previous Photos

Constructed IRC/IBC Compliant


7/16" OSB at 6' from corner in a 12x30 foot building built to IRC
Comparing SDPWS FEA, Test Data and SBCRI Full Scale FEA Model at ASD level
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
0
5
10
15
20
25
30
35
Load Cell Reactions (minus is uplift) (lbs)
Load Cell locations along 30 foot wall (ft)
SBCRI Test Data
Uncalibrated FEA Design Model
SBCRI Calibrated FEA Model to Test Data

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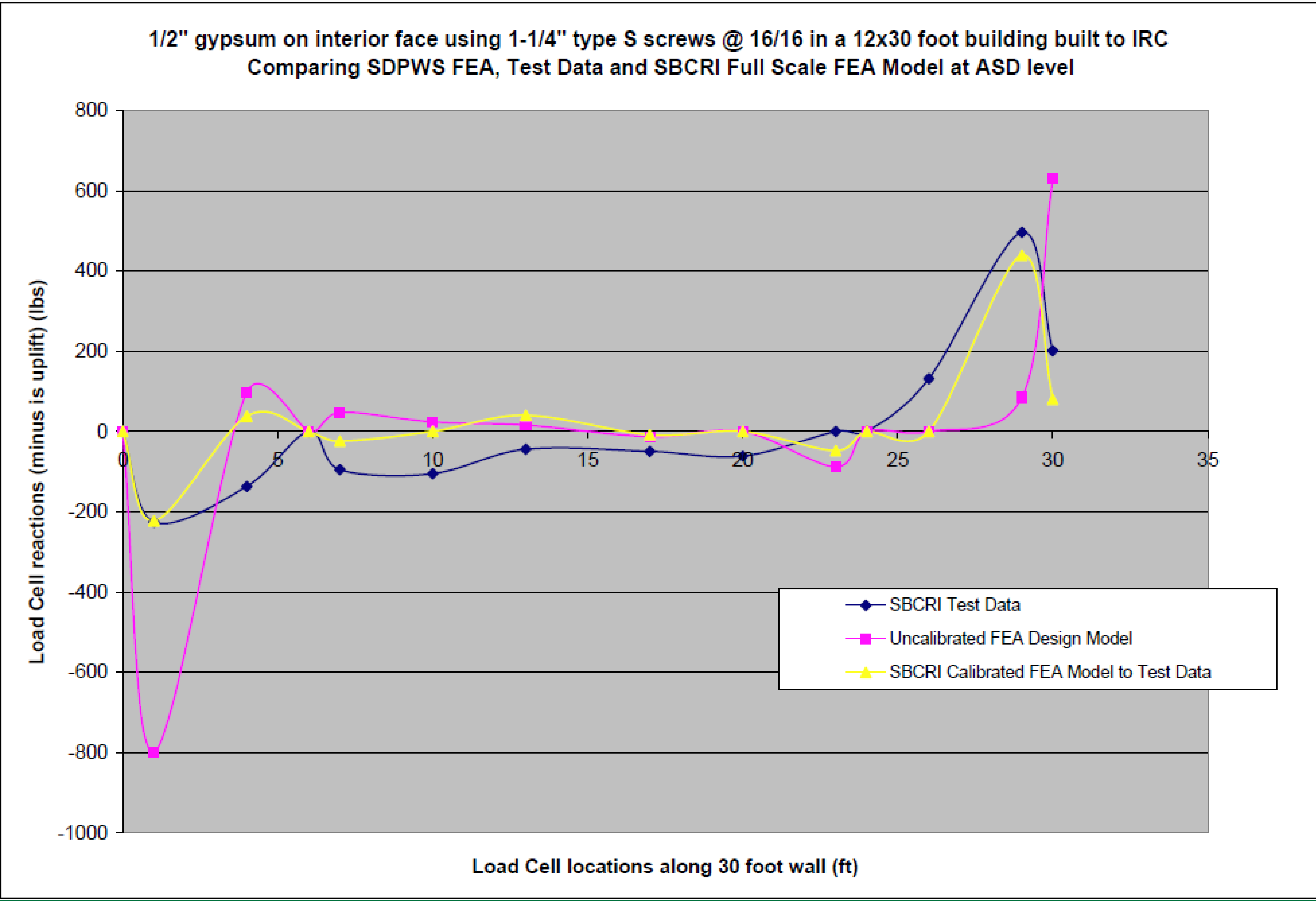
Load Path for 30’ of Gypsum Wall Board

Constructed IRC/IBC Compliant


1/2" gypsum on interior face using 1-1/4" type S screws @ 16/16 in a 12x30 foot building built to IRC
Comparing SDPWS FEA, Test Data and SBCRI Full Scale FEA Model at ASD level
800
600
400
200
0
-200
-400
-600
-800
-1000
0
5
10
15
20
25
30
35
Load Cell reactions (minus is uplift) (lbs)
Load Cell locations along 30 foot wall (ft)
SBCRI Test Data
Uncalibrated FEA Design Model
SBCRI Calibrated FEA Model to Test Data

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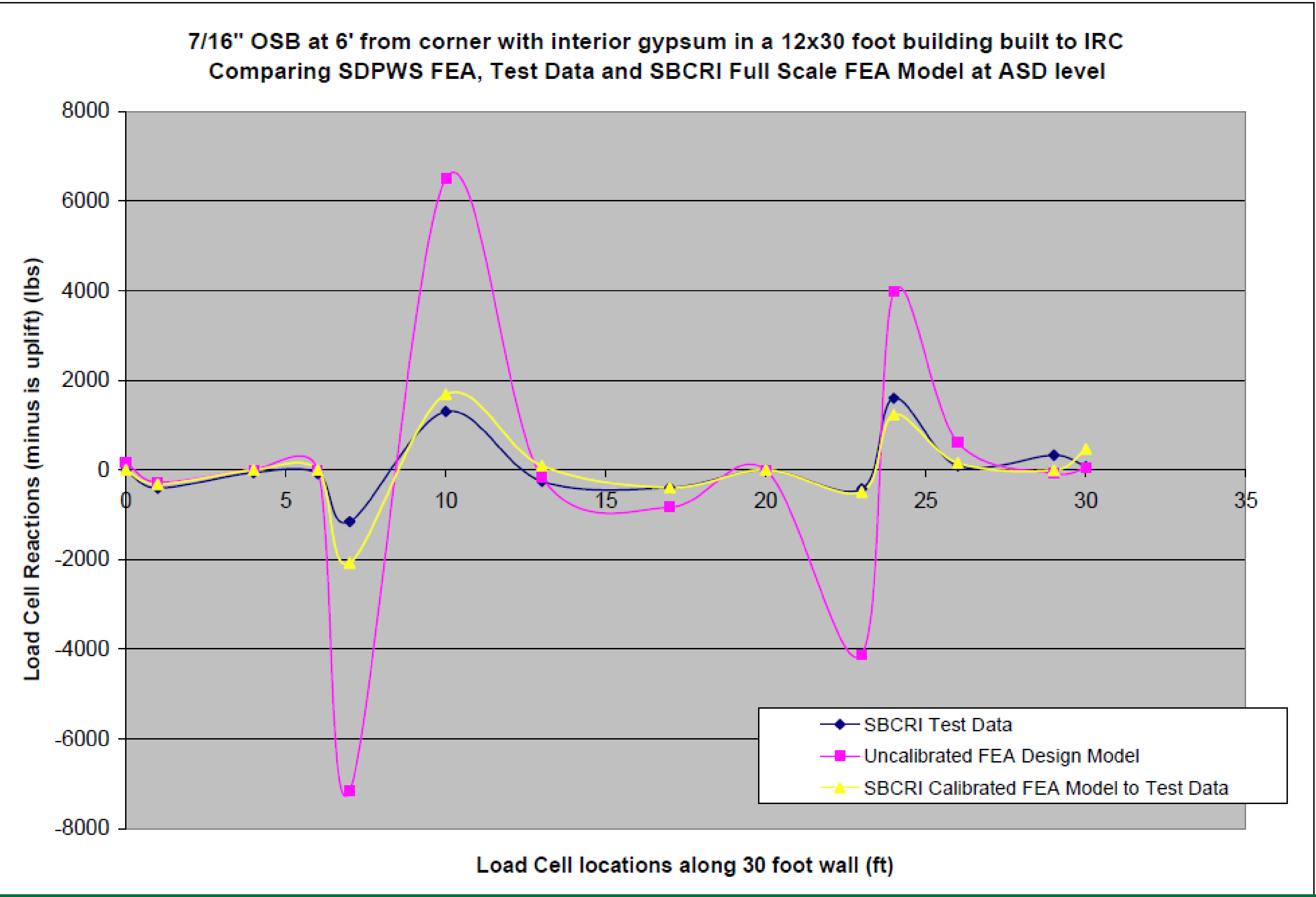
Load Path for 7/16” OSB Placed 6’ in from Each Corner and 30’ of Gypsum Wallboard

Constructed IRC/IBC Compliant


7/16" OSB at 6' from corner with interior gypsum in a 12x30 foot building built to IRC
Comparing SDPWS FEA, Test Data and SBCRI Full Scale FEA Model at ASD level
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
0
5
10
15
20
25
30
35
Load Cell Reactions (minus is uplift) (lbs)
Load Cell locations along 30 foot wall (ft)
SBCRI Test Data
Uncalibrated FEA Design Model
SBCRI Calibrated FEA Model to Test Data

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IRC PFH Test (Portal Frame Hold-down) Photos Showing Load Path Testing

Constructed IRC/IBC Compliant

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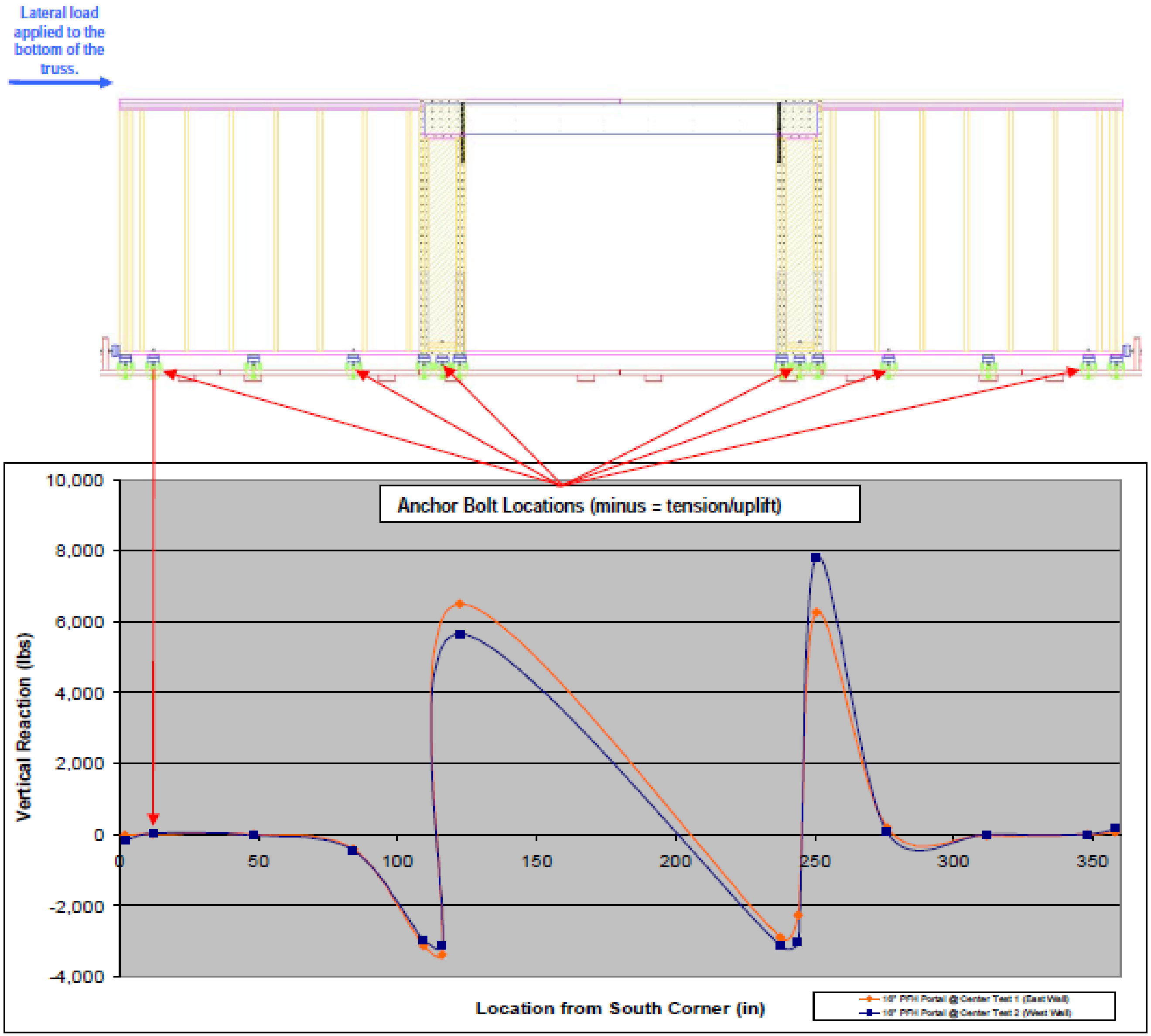

GRAPH 6: Combined Vertical Load Path to the Foundation – Reaction Loads at Test Applied Ultimate Load (P_u)

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Qualtim's Approach
Testing with FEA Engineering in Mind

Predicting Performance Through Modeling
Accurately Calibrating Performance
In Other Words Rocket Science without the Rockets!

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Examples of SBCRI ASTM E72/E564 Testing – Anchor Bolts


KELLER

Collaborating With

Examples of SBCRI ASTM E72/E564 Testing – HDU8 Hold Down


LC-064

Collaborating With

Examples of SBCRI ASTM E72/E564 Testing – 3,300 lbs. Axial Load


Life Guard

STANLEY
Life Guard


STANLEY
25ft

ft
25ft
in
1


LC-064


STANLEY
Life Guard


STANLEY
LC-064

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Examples of SBCRI 12' x 30' In-Situ Testing Assembly that uses ASTM E564 and E2126 Testing Techniques – 4x8 OSB Isolated Anchor Bolts

Collaborating With

Examples of SBCRI 12' x 30' In-Situ Testing Assembly that uses ASTM E564 and E2126 Testing Techniques – 8x8 OSB Isolated Anchor Bolts.


ZERO
GAIN

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Examples of SBCRI 12' x 30' In-Situ Testing Assembly that uses ASTM E564 and E2126 Testing Techniques – 4x8 OSB Isolated with HDU8 Hold Downs

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Fox Valley Metrology
ID SP-102
Cal By BS
CA271-56603-175
Date 09/28/2010
Due 09/28/2011

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Examples of SBCRI 12' x 30' In-Situ Testing Assembly that uses ASTM E564 and E2126 Testing Techniques – 8x8 OSB Isolated with HDU8 Hold Downs.

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