Modeling TRUSSES in SBC Research Institute

by SBCRI Staff

Recently we've updated you on some exciting new testing happening in the Structural Building Components Research Institute (SBCRI). Our latest work involves using computer modeling software to show how a truss or system of trusses will behave under given loading conditions and comparing it to the system test data we are generating. This article is a review of three different set-ups tested in SBCRI and modeled using finite element analysis (FEA) software.

Why Model?

Using an off-the-shelf FEA modeling and research-oriented FEA program that we have been working with, the user inputs the details of a truss assembly into the software, and a 3D image drawn to scale is created. When various loads are "applied," the software outputs force, deflections and reactions at designated points along the assembly.

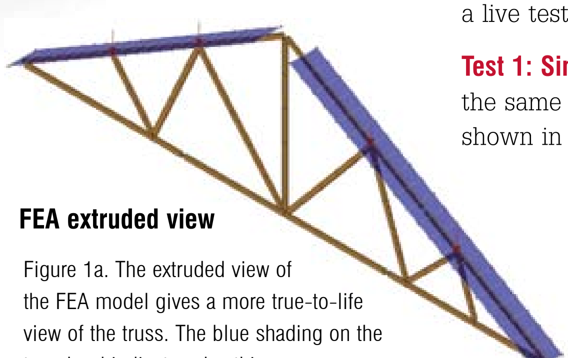
Why are we investing the resources and time to establish this FEA modeling approach when assemblies could just as easily be subjected to *real* SBCRI tests? In three words, flexibility and cost savings. Through modeling, our goal is to streamline test set-ups, define aspects of component assembly performance, expand our test design capabilities and model the load through an accurate assessment of stiffness and resistance. This takes a great deal of effort because we've discovered that very little calibration between engineering models and real world performance has been done in light frame construction. A good example of this is our tests of IRC shear wall performance on a 12'x30' building in SBCRI. We believe we can define the "judgment factor"[1] that the IRC Ad Hoc Wall Bracing (ICC-AHWB) Committee used to arrive at IRC braced wall panel design values. (Watch for an article on this topic in a future issue of ***SBC***.)

In the future when our modeling becomes more precise, it will reduce the need for conducting live tests in SBCRI. Of course, there will always be the need for calibration testing as materials change and as we modify current models. In the short-term, the value of the FEA modeling will be optimizing the bracing recommendations in BCSI. Manually testing each assembly within BCSI would be cost-prohibitive. The modeling knowledge we develop today will greatly benefit tomorrow's BCSI bracing recommendations. Eventually we hope to replace temporary restraint/bracing with permanent restraint/bracing, which will reduce framing labor and material costs.

Modeling Approach

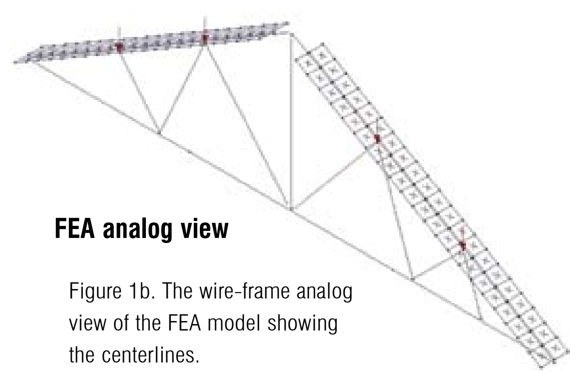
The approach we've taken is to compare FEA data to that of a live test. The idea is to refine FEA calibrations by testing, modeling, then testing and modeling over and over again. A model is said to be accurate when the error rates (when compared to a live test) are consistent across multiple tests.

Test 1: Single Truss Set-Up — Test 1 compared data from a live single truss test to the same single truss test conducted in FEA. The truss was a 39' common truss as shown in Figures 1a and 1b (below).



FEA extruded view

Figure 1a. The extruded view of the FEA model gives a more true-to-life view of the truss. The blue shading on the top chord indicates sheathing.



FEA analog view

Figure 1b. The wire-frame analog view of the FEA model showing the centerlines.

[1] From the article at The Story Behind the 2009 IRC Wall Bracing Provisions (Part: 2: New Wind Bracing Requirements) Jay H Crandell, P. E, and Zeno Martin, P. E Spring 2009 *Wood Design Focus*.

Load was applied through four defined joints, and the FEA and live tests each measured the reactions at each end of the truss (in pounds) and deflection from axial forces (in inches). Table 1a shows the left and right end reactions. Comparing the FEA model to the live test, you can see that the reactions are very similar. We interpret this to mean that the material properties for both the truss plates and the lumber are accurate.

	Point Load	Right End Reaction	Left End Reaction
Test Average	375 lbs	749 lbs	752 lbs
FEA Model	375 lbs	753 lbs	747 lbs

Table 1a: Total point load and end reactions for the single truss test.

Figures 1c and 1d depict FEA models showing the axial forces and the resultant deflection, respectively. Table 1b reports the deflection measured at each of four joints. The % Error column shows that the error rate for the test conducted on the FEA model compared to the live test.

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FEA extruded view

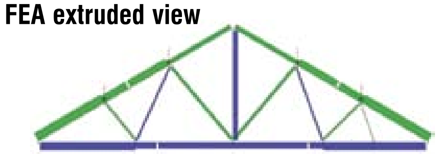

Figure 1c. The extruded view shows compression and tension forces.

FEA analog view

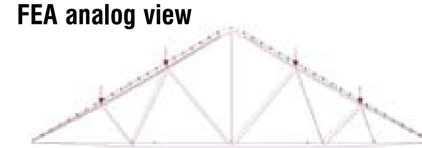

Figure 1d. The analog view shows actual deflection.

	JT 1 Deflection	% Error	JT 2 Deflection	% Error	JT 3 Deflection	% Error	JT 3 Deflection	% Error
Test Average	-0.110 in	-	-0.151 in	-	-0.151 in	-	-0.131 in	-
FEA Model	-0.101 in	8.4%	-0.138 in	8.5%	-0.145 in	3.8%	-0.136 in	-3.9%

Table 1b: Deflection at each of four joints and the percent error between the live and FEA tests.

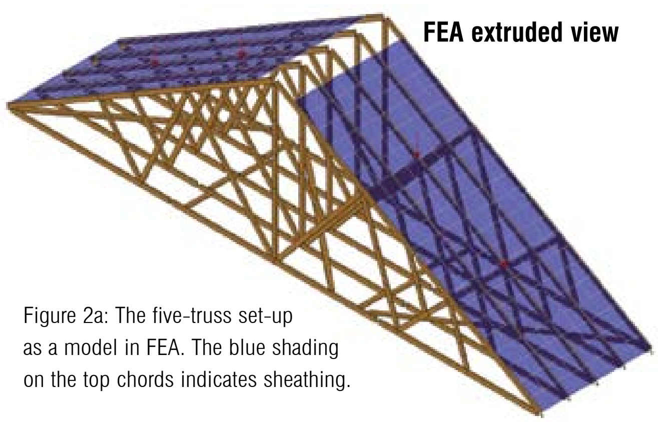

Figure 2a: The five-truss set-up as a model in FEA. The blue shading on the top chords indicates sheathing.

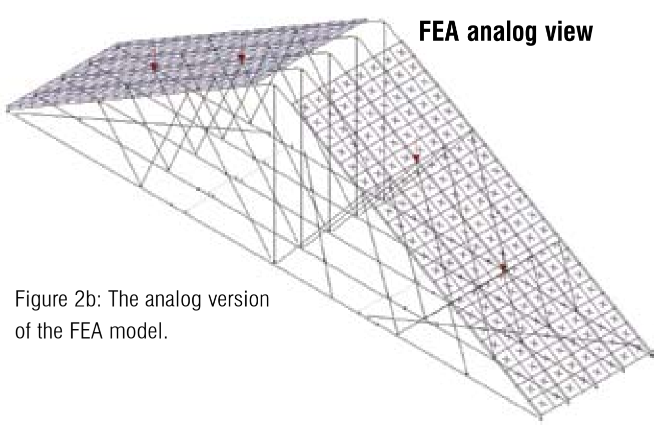

Figure 2b: The analog version of the FEA model.

Modeling Trusses in SBCRI

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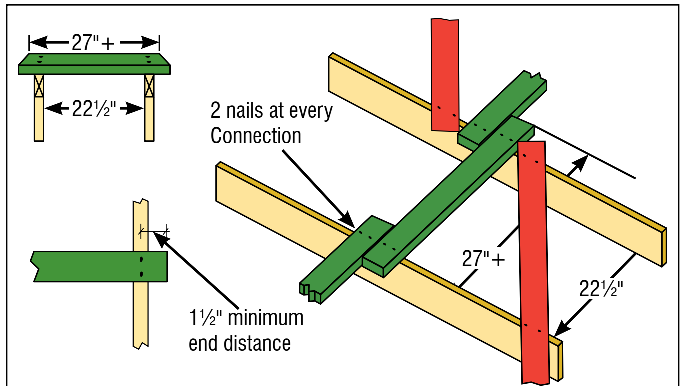
As shown in Table 1b on page 13, the FEA model predicts performance within 10%. Given that the raw material variability we are working with can be up to 15% or more, this is a very good foundation to work from. We plan to further refine it even more in the future.

Test 2: 5-Truss Setup – BCSI Bracing — In Test 2, we worked with a full-scale truss assembly. The five-truss assembly measured 39' and was sheathed with 15/32" OSB. The purpose of this test was to begin our assessment of the bracing methods recommended in BCSI-B2. Only the center truss in the assembly was loaded at each of four joints per the loads noted in Table 2a. The bottom chord had lateral restraint bracing (see detail below), at 1/3 the span or 13-foot spacing. Three diagonals were placed between the lateral bracing.



Option 1 Detail Short Member Temporary Lateral Restraint Installed on Top of Trusses from the BCSI booklet, Figure B2-25, p. 24.

Figure 2a is the FEA model for the five-truss assembly with OSB sheathing applied. Figure 2b is the analog view of the same system. As in Test 1, the FEA and live tests measured the reactions at each end of the assembly and the axial force deflection. The right and left end reactions are captured in Tables 2b and 2c respectively. Note the discrepancies in both tables between the FEA and live tests.

Joint 1 Load	Joint 2 Load	Joint 3 Load	Joint 4 Load
376	389	382	353

Table 2a. Point loads at each of 4 given joints.

	TR-1	TR-2	TR-3	TR-4	TR-5
Test Average	130	146	187	166	119
FEA Model	66	23	571	17	69

Table 2b. End reactions at the **right end** of each of the five trusses.

	TR-1	TR-2	TR-3	TR-4	TR-5
Test Average	134	156	177	156	132
FEA Model	-27	2	808	-2	-25

Table 2c. End reactions at the **left end** of each of the five trusses.

We have identified two reasons for this result. The sheathing provides great stiffness at the heel of the truss and allows load distribution across the entire heel. The FEA model is not calibrated to predict this load distribution. The bottom plate that the trusses sit on is also a load distribution device that spreads load to the right and left, again something the FEA model is not calibrated to predict.

Hence our task becomes understanding how to isolate each individual element of stiffness that is causing this distribution and figure out how to incorporate the stiffness-induced load path into the model without distorting the successful modeling outcomes for the single truss above. Simple in concept, a challenge to do in practice. But this work is important because the model must predict well if we expect it to predict BCSI bracing optimization well.

Similar to Test 1, Figures 2c and 2d depict FEA models showing the axial forces and the resultant deflection, respectively. Table 2d reports the deflection measured at each of four joints of the center truss. The % Error column shows that the error rate for the test conducted on the FEA model compared to the live test. Note that compared to the deflection measured in Test 1, the percent error in this test is far greater.

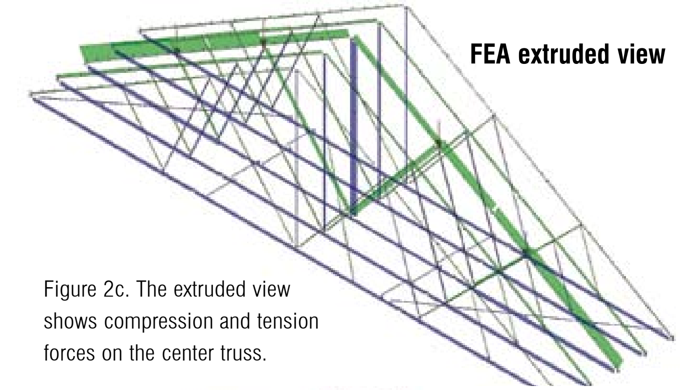


Figure 2c. The extruded view shows compression and tension forces on the center truss.

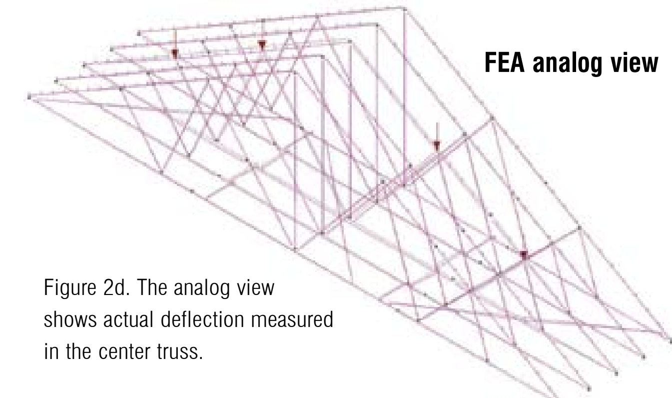


Figure 2d. The analog view shows actual deflection measured in the center truss.

TR-1 Deflection	% Error	TR-2 Deflection	% Error	TR-3 Deflection	% Error	TR-4 Deflection	% Error	TR-5 Deflection	% Error
-0.014	-	-0.027	-	-0.051	-	-0.022	-	-0.018	-
-0.017	-20.6%	-0.027	-1.9%	-0.057	-11.1%	-0.027	-24.4%	-0.017	6.6%

Table 2d. Deflection and error rate for each of the five trusses.

We have a very good sense for why the error rate is higher. For one, we have not calibrated single truss design models to system performance. To do this we need to understand sheathing stiffness properties and how the sheathing transfers load perpendicular to trusses. The same holds true for understanding how lateral restraints and diagonal bracing transfers load to trusses.

Each of these conditions need to be isolated and a generalized stiffness property created (i.e., for the nails, truss plates, sheathing, etc.) to calibrate our model to field performance. In the past we haven't had the data to do this; SBCRI is just now creating it for our industry.

Test 3: 5-Truss Setup – Web Bracing — The final test we'll report on measured web axial forces to understand more about our truss design models and web member bracing using the WB-3 device built in SBCRI. (For more information about WB-3, view p. 14 in the November 2009 issue of ***SBC***.) The assembly dimensions were identical to those in Test 2, and the assembly was fully sheathed with 15/32" OSB.

Load was applied to all five trusses at the four points on each truss as noted in Figures 3a and 3b on page 16. WB3 was attached to web 4 of the center truss as shown in Figure 3c, also on page 16.

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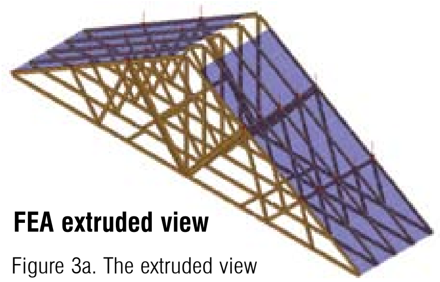
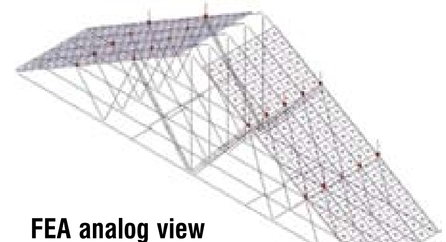


FEA extruded view

Figure 3a. The extruded view of the assembly.



FEA analog view

Figure 3b. The analog view clearly shows the point loads applied in each truss.

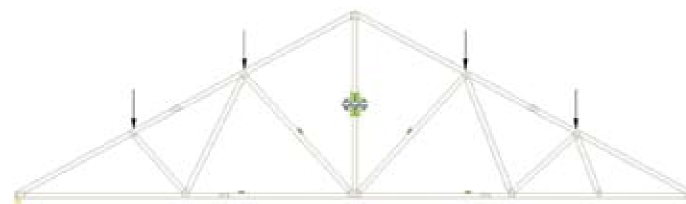


Figure 3c. The center truss with WB3 attached to web 4.

	TR-1	TR-2	TR-3	TR-4	TR-5
Test	822	785	697	683	894
FEA Model	700	861	778	750	828

Table 3a. End reactions at the **right end** of each of the five trusses.

	TR-1	TR-2	TR-3	TR-4	TR-5
Test	799	706	607	768	734
FEA Model	730	812	436	850	818

Table 3b. End reactions at the **left end** of each of the five trusses.

TR-1 Deflection	% Error	TR-2 Deflection	% Error	TR-3 Deflection	% Error	TR-4 Deflection	% Error	TR-5 Deflection	% Error
0.172	-	0.182	-	0.173	-	0.187	-	0.185	-
0.150	12.9%	0.149	18.0%	0.136	21.6%	0.150	19.8%	0.165	10.9%

Table 3c. Deflection and error rate for each of the five trusses.

Modeling Trusses in SBCRI

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As in Tests 1 and 2, the FEA and live tests measured the reactions at each end of the assembly and the axial force deflection. The right and left end reactions are captured in Tables 3a and 3b respectively. Table 3c reports the deflection measured at each of five trusses. Note the % Error column as compared to the results in Table 2d. Finally, Table 3d shows the results from the WB-3 device attached to the fourth web of the center truss. The FEA model under-predicted the axial force that was found in the WB3 by 35%. FEA also under-predicted the vertical deflection in the test by 20%.

The error of the web axial force estimate are for all the reasons defined above and also include the fact that we do not know very much about the behavior of truss plates as they transfer load through sheathing to the top chord through the joint and into the web member. As discussed above, each stiffness condition needs to be isolated and generalized stiffness properties created to calibrate our model to field performance.

SBCRI Staff Thoughts

The modeling and live tests presented in this article are just the beginning of our modeling work. Our goal is to refine these models using assembly tests similar to those shown here so that we are confident in their accuracy. Then we will begin to model and test the bracing recommendations in BCSI to optimize bracing practices.

While it has taken valuable time and resources to do this work, we firmly believe we need to have a good grasp of system testing, system/load path performance, the current state of model prediction of single trusses and truss systems.

We have derived a tremendous amount of knowledge about building performance through modeling work, which has been essential to our goal of advancing the industry. While there are many different testing approaches we could have taken, we have chosen the path that has exposed the big picture of building performance. **SBC**

	Web 4 Axial Force
Test Tension	994
FEA Tension	641
% Error	35.53%

Table 3d. Axial force measurements recorded with the WB-3 device fixed to web 4 of the center truss.

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