SBCRI's Web Force Verification Device a Big Step for Bracing Tests

How the device evolved and why it can teach us a whole lot about bracing.

by Libby Maurer

Figure 1a. "Web brace" 1 is attached to a web with bolts. Two load cells (in blue) measure forces running through the web.

Some problems are best solved by working backward. The same holds true for some of the testing projects in SBCRI. This is how one small device has been developed that will soon yield big results for understanding truss web and chord member load paths and for bracing optimization.

One of the distinct advantages of the industry's testing lab is its capacity to conduct full-scale truss testing. Boiled down, SBCRI's immediate goal for this type of testing is simple. Take a truss assembly that is representative of one in the field, apply typical loads to it, measure how those loads flow through it, and identify areas that can be optimized. When those areas are identified, we can analyze:

- How the load path is functioning.
- The actual resistance taking place due to the applied load.
- The distribution of load through all the possible load paths.
- The stiffness of the connection systems and how it influences the path loads follow.
- How to develop recommendations on:
  a. Changes to the resistance required to manage the applied load.
  b. Influencing the direction of the load path.
  c. Design resistance specific to the actual load path found.
  d. Providing optimal strength of the load resisting system.

The long-range benefits could be significant to our industry, for instance optimizing web and chord bracing methods, or optimizing lumber sizes and/or grades. The staff of SBCRI has taken the first steps toward this testing.

What We Mean By "In Situ Testing"

We often refer to full-scale testing as "in situ," a Latin word meaning in place. In the context of building, it situ means as in the field. Now that we have the ability to test an assembly in conditions virtually identical to the field, we're taking the first steps to develop methods that can be used to accurately model and evaluate full-scale assembly performance. The International Building Code (IBC) uses this concept as the ultimate assurance that field performance exists to carry the expected loading conditions.

> **SECTION 1714 - IN-SITU LOAD TESTS - 1714.1 General.** Whenever there is a reasonable doubt as to the stability or load-bearing capacity of a completed building, structure or portion thereof for the expected loads, an engineering assessment shall be required. The engineering assessment shall involve either a structural analysis or an in-situ load test, or both. The structural analysis shall be based on actual material properties and other as-built conditions that affect stability or load-bearing capacity, and shall be conducted in accordance with the applicable design standard. If the structural assessment determines that the load-bearing capacity is less than that required by the code, load tests shall be conducted in accordance with Section 1714.2. If the building, structure or portion thereof is found to have inadequate stability or load-bearing capacity for the expected loads, modifications to ensure structural adequacy or the removal of the inadequate construction shall be required.

As they began to understand how to carry out accurate testing on full assemblies, however, the SBCRI team encountered situations that required working backward to deliver a solution for tracking loads flowing through webs or braces. Over the last year, SBCRI staff developed, tested, redeveloped and retested an exciting new testing device that will help us truly understand load paths internal to truss webs and chords, studs in walls, lateral restraint and diagonal bracing, and general load path performance of any components installed exactly as they would be in the field.

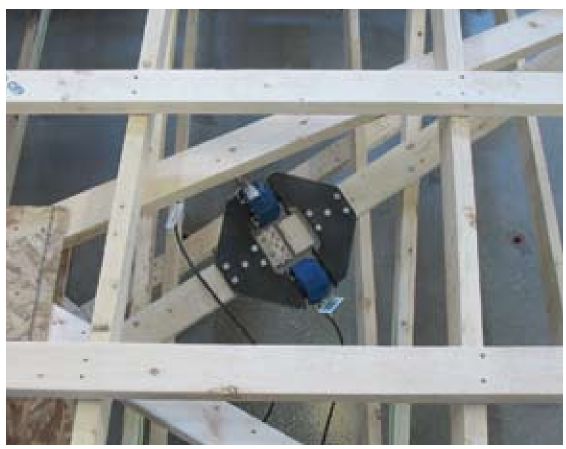

Figure 1b. View of WB1 looking down into the truss assembly.

Meet Prototype WB1

With the goal of measuring and analyzing the forces going through a truss when load is applied, the SBCRI team determined it would design a device that could be attached to a web. The initial considerations included using electronic strain or clip gauges to be attached the wood members or steel plates. They measure very small displacements that can be translated mathematically into member forces. After a few trials, this approach seemed more complicated and provided much more detail than was desired.

The SBCRI staff began by developing a prototype called WB1 ("web brace"), which was designed to use load cells they already had in-house. It was made from two triangular pieces of angle iron ½" thick with a slot in its center for a stick of lumber. The "web," a 6' 2x4, was bolted to the device for stability. Shown in Figures 1a and 1b, two load cells were sandwiched in between the plates of WB1, one on each side of the board. Once in place, they cut the member (forming two separate pieces). This was necessary so that the forces would not flow through the member but force the load into the load cells.

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Figure 2. The web is sandwiched between steel plates.

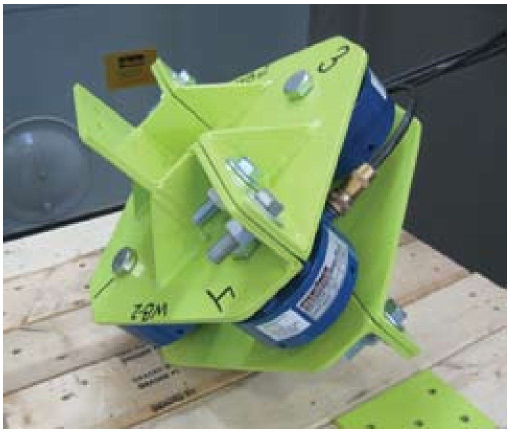

Figure 3. WB2 - Side View

Figure 4. Adding two load cells to WB2 allowed forces to be measured on the top and bottom axes.

Figure 5. Close-up of the top plate of WB2.

Once rigged up, the crew triggered a series of loading conditions and ran several tests on WB1. It quickly became clear that fastening only one axis of the web to WB1 caused bending to occur in an unwanted manner. Several additional tests made it clear that WB1 had to be adjusted to accurately measure the applied load.

WB2

The improvements to the second prototype, called WB2, had several goals. One was to decrease the bending about the weak axis, so WB2 became a multi-axis fixture.

The new design also allowed for two additional load cells (for a total of four) (see Figures 2-5. An axial force measuring model provided by ITW Building Components Group was used to help in the new design. Four cells meant forces could be tracked on both axes to give the team more data points to record forces traveling through the wood. Like WB1, bolts were used to secure the top and bottom plates to the board (see Figure 6 at right).

With WB2 attached to a web, it was secured to SBCRI's single element station or SES. This is SBCRI's version of a Tinius Olsen tension/compression testing machine meant to test webs, small joints or other single element components on a small scale. SES is capable of producing a constant rate of applied load and complies with the testing requirements and capabilities as defined in the Standard Practices for Force Verification of Testing Machines, ASTM E4. To recreate a true-to-life loading scenario, pure axial, uniform bending moment, combined bending moment and axial loading were simultaneously applied to the web through load cells attached at various points on the frame. The goal was to apply a given load and see if that same load would register in the load cells (meaning that was the amount of load running through the lumber member).

They tested WB2 within the SES (see Figure 7). This was critical because it allowed the team to understand the load path on the most fundamental level. "We really, really concentrated on knowing all the loads in and all the loads out of the piece tested. By developing this type of simplified set-up, we got a much better feel for the performance of the device," Director of Testing Keith Hershey said. Within the first few tests it was clear that they were getting accurate axial loads through the fixture. However, they also started seeing an unexpected result. "We were only looking at the axial force in the member, but we also started seeing bending moment induced loads. This was a huge finding as it would allow us to understand web buckling and bracing

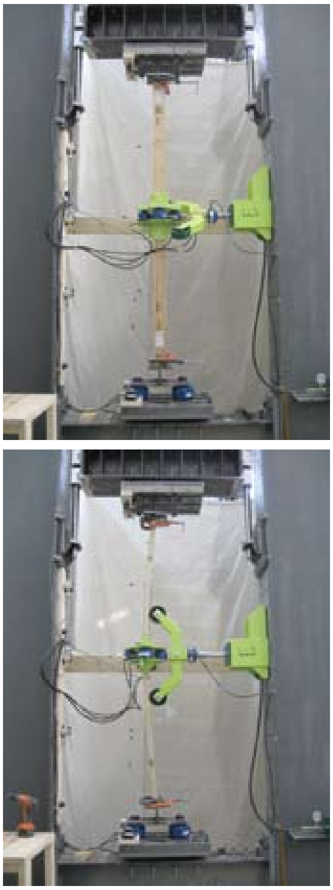

Figure 7. WB2 is tested in the SES.

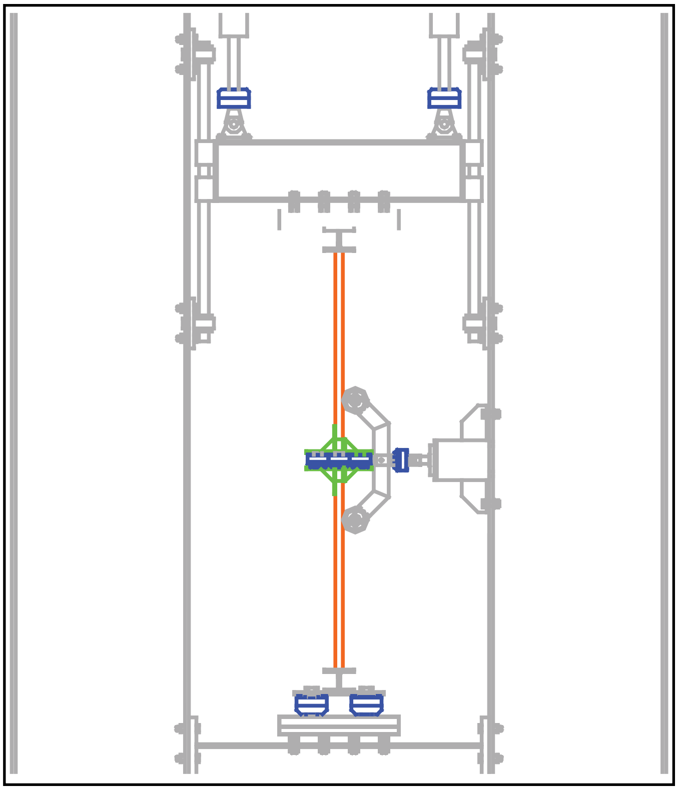

Figure 6: SBCRI's Single Element Hydraulic Station

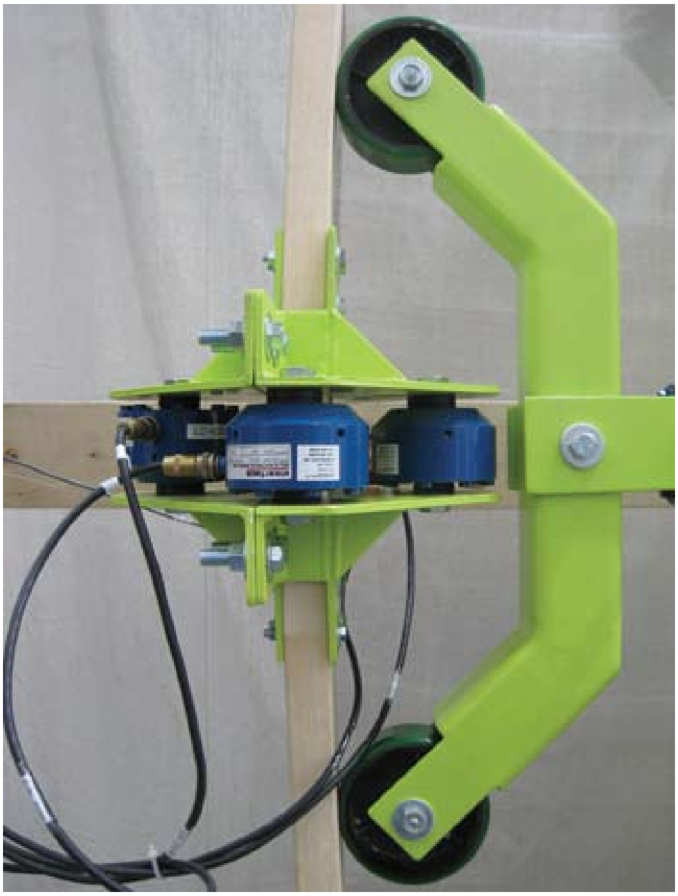

Figure 8. Close-up of WB2 being tested in the SES.

requirements from loading conditions that induced buckling," he explained. (See Figure 8 at right.)

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This discovery caused the team to change the testing plan to not just include axial force measurement, but to also measure forced bending moments through both offset/eccentric loads and the addition of a two-point bending moment loading apparatus. Initial testing was performed using a 6' SPF 2x4 as the specimen. Each specimen went through the same series of ten steps to maintain a consistent testing approach, and to benchmark the test data instantly. While it was an improvement, WB2 was still picking up too much load on the strong axis of the fixture, so the team decided to revise it again.

WB3 Gets Tested in a Full Scale Assembly

The changes to the third iteration of the WB device were made so that it had as little impact on how the web would perform as possible. For instance, the team found that WB2 added quite a bit of stiffness to the board, causing inaccurate moment calculations and increasing the board's bending capacity inappropriately. In WB3, changes were made to improve the load transfer to the load cells through the web so that the axial loads could be measured accurately with minimum impact from the fixture. Additionally, bolting the fixture to the web was eliminated. Instead, WB3 was clamped to the board (see Figure 9).

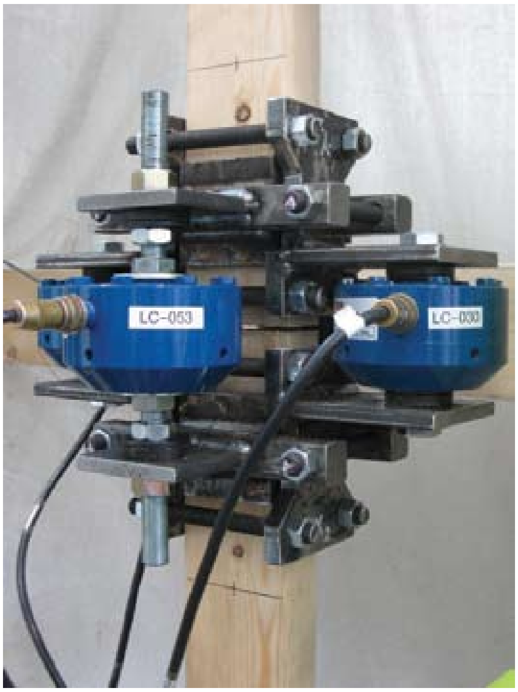

Figure 9. Changes made to WB3 were intended to stabilize the web and improve load transfer.

The team used the same testing matrix as they used for WB2 so that results could be compared easily. It was clear from the first specimen tested in the SES (see Figure 10) that WB3 solved the majority of the problems identified in WB1 and WB2. Axial load measurements internal to the 2x4 member were still very accurate, while the bending moment was predictable.

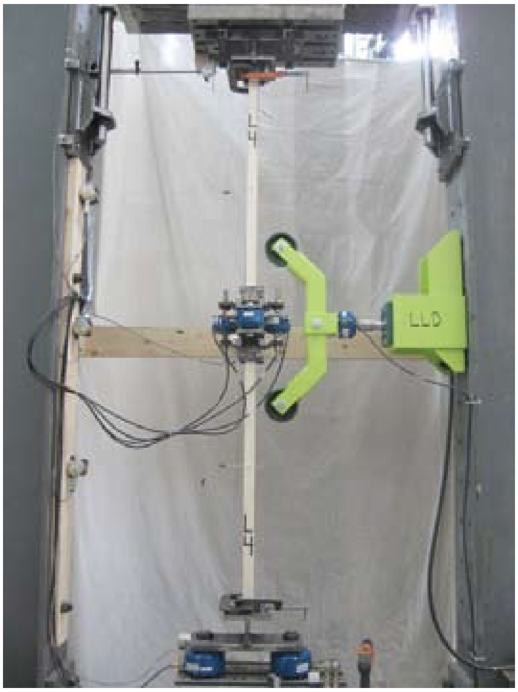

Figure 10. WB3 during a test in the SES.

With the data from the single element station suggesting WB3 was working well and actually better than predicted, it was time to move forward and use the device to measure the forces in a real truss web member, as shown in Figures 11 and 12 on facing page.

Figures 11 & 12. WB3 is used to test the forces through a web in a full-scale assembly.

Why is Accuracy in Measuring Loads So Important?

Accurate measurement of forces within the members of a truss, wall panel or bracing system is important to the evaluation of the load path in the element, as well as through an entire assembly. Armed with this knowledge it is much easier to create mathematical models that predict load movement and then define accurate resistance for the load path.

Wood members present an increased degree of difficulty in capturing these loads due to their variable fibrous composition and orthotropic properties. The testing method SBCRI created with the WB devices provides the ability to accurately measure the real forces within a single member. This will give us much greater knowledge that will lead to much more accurate engineering modeling through calibration.

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Following tests done in the full truss assembly, the team compared the new data to a truss design drawing (with predicted forces). They found the following results as shown in Table 1.

WB4

WB4 is the team's fourth and (hopefully) final prototype. They hope to reduce the weight of the device by one-third by using lighter housing material for holding the load cells like aluminum. They also plan to serrate the inside of the plates to provide more resistance when holding the board in place using a lower clamping force. With these minor changes and the data above, it is clear that SBCRI's WB device will add to our knowledge of load paths through trusses, walls and entire structures. SBC

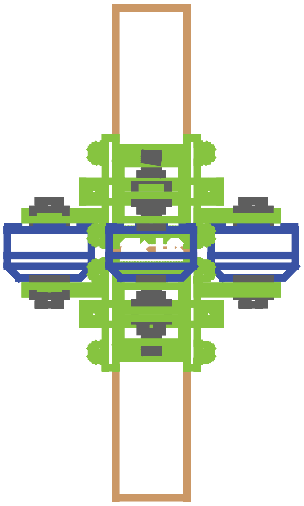

Figure 13. CAD drawing of the WB3 prototype.

Web Force Verification

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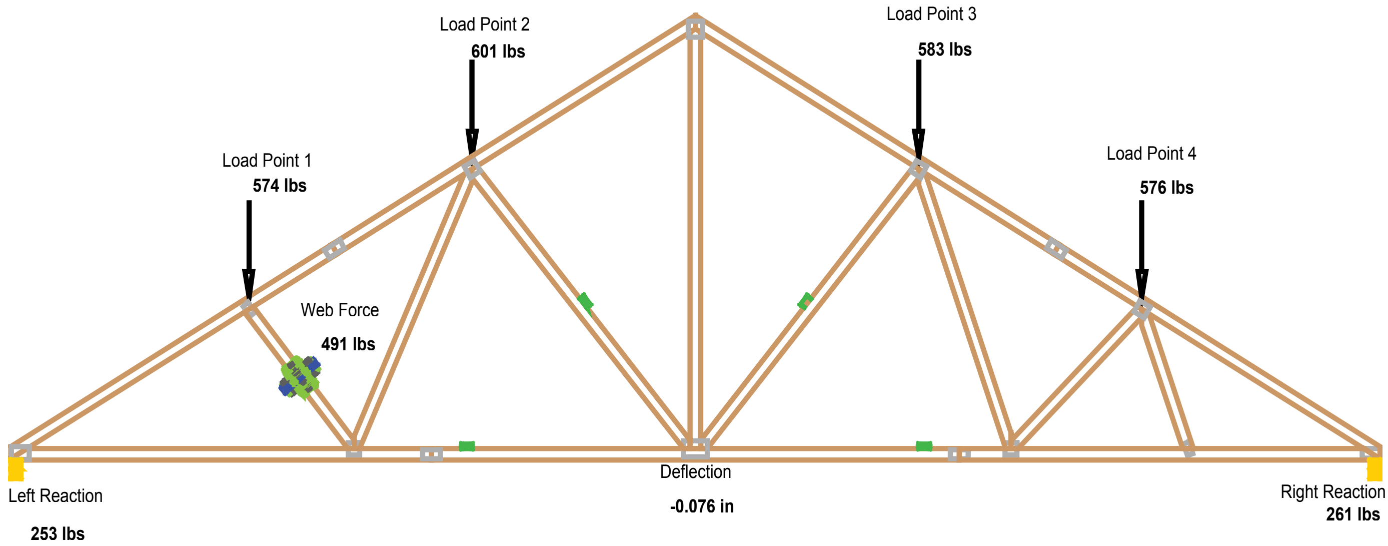

Load In = 2334 lbs

Load Out = 2294 lbs

Load In - Load Out = 40 lbs

Load In	Tested Web Force	TDD Web Force	% Difference	Left Reaction	Right Reaction	Load Point 1	Load Point 2	Load Point 3	Load Point 4	Deflection
752	223	187	15.97 %	79	81	189	196	184	176	-0.018
1124	285	262	8.19 %	119	122	280	289	280	268	-0.033
1500	351	338	3.64 %	161	165	373	387	374	366	-0.046
2252	478	490	-2.57 %	244	250	555	578	564	551	-0.073

Table 1. Sample data from a test using WB3 show the difference in forces predicted in a truss design drawing and actual forces measured in the web. The ability to produce this type of data will be critical in evaluating industry bracing recommendations.

Optimizing Bracing

Compared to fifty years ago, today we know infinitely more about truss bracing. The vast majority of our knowledge comes from bracing tests conducted on a single truss. This data was used to make a series of assumptions, based on engineering principles, about how that one truss was expected to perform inside a system on the jobsite. At the time, we didn't have the means to test the actual load paths through trusses as they would be installed in a building environment. The assumptions made were the best we could do with the technology at our disposal.

With the tools available in SBCRI, built environment testing is easy! Our goal, given SBCRI capabilities, is to understand as completely as possible the load paths and the loads that cause chord and web buckling.

How will the WB device help us evaluate bracing recommendations? First, the team must complete a set of exhaustive full-scale WB tests to ensure the results are accurate (and that the device is not adding undo stress to webs). These test results will be combined and analyzed. Then an exact replica of the truss system will be drawn in CAD and imported into special 3D modeling software. Next, the data from the WB tests will be applied to the replica within the modeling program. The model will indicate weakness in the web members according to the WB test findings. The software can even predict how a truss collapse will occur given these areas of weakness! Finally, "bracing" will be added to the weak members until the system model performs without buckling.

We firmly believe that the built environment is reacting differently than our current theory suggests—primarily because current theory is limited to single element thinking.

We now believe that the majority of temporary bracing can be done in the web and bottom chord plane. This would make the bracing process:

1. Safer, due to working inside the truss.
2. More efficient to install (because it is safer).
3. More efficient overall because temporary bracing will also become the permanent bracing of the structure.
4. Allow for fall protection.

If you have questions about the capabilities of SBCRI, please email editor@sbcmag.info.

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