SBC™ RESEARCH INSTITUTE

A Whole New Bag of Tricks

by Molly E. Butz & Kirk Grundahl, P.E.

"One test is worth 1000 expert opinions." –Tinius Olsen

As time progresses, building codes, engineering and design programs and construction materials are becoming more complicated and more sophisticated. And although structural building components have more than 50 years of tried and true performance behind them, they are still very new in the grand scheme of construction materials and there is still much for us to understand about their performance.

This is one of the reasons that the June 2007 opening of the SBC Research Institute (SBCRI), a 5,730 sq. ft. testing facility, was a monumental event. Developed to facilitate critical testing projects, SBCRI is helping our industry acquire more comprehensive knowledge about many complicated structure-related concepts, from how systems of building materials work together in a structure to how loads flow through these structures.

SBCRI is helping us simplify many of these concepts. For instance, Figure 1 illustrates a concept that has never been thoroughly understood by the construction community. That's right—for almost 60 years now, we have been engaged in what you might call a flow of loads guessing game.

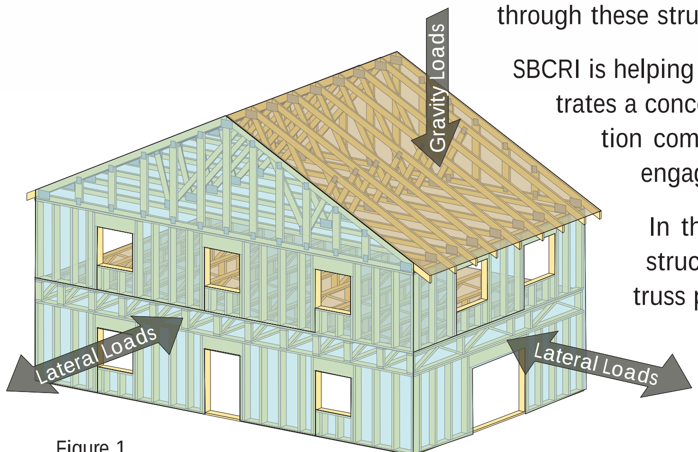

Figure 1.

In the past, engineers have tested smaller elements to understand structural performance: one lumber member, one nailed joint, one truss plate, one truss joint, one steel member, one wall or one header. This information was then combined into an engineering model that applied the data derived from this small scale testing performance into a much broader array of engineering design capabilities. This led to standardized tables developed from theoretical equations that were intended to make selecting the appropriately designed member a 30-second procedure for building professionals. A good example of these "tables" are the catalog truss design drawings of the 1960s and '70s, I-joist-sized selection tables, the IRC joist and rafter tables and the AISI steel beam tables. Soon the equations making up these tables made their way into Excel spreadsheets, making them easier to use and provide for greater accuracy. However, this new portable technology still relied on the same, previously established, simplified assumptions.

SBCRI provides a way for our industry to go beyond the simplified assumptions based primarily on single element testing information. Full-scale, whole system testing will provide a far better understanding of the real flow of loads through any structural system, with less guessing. Until we understand exactly how loads flow through an entire structure, it will be impossible to precisely provide the optimal resistance to the real flow of loads. (See sidebar on page 36 for more details about flow of loads.)

at a glance

- The vast resources of SBCRI have the ability to give us more answers than ever before about the nature of structural performance.
- In one case, SBCRI helped provide a timely and cost-effective solution to a structural problem that benefited everyone.
- In this situation, the analysis done at SBCRI allowed the building to remain open to the public while a structurally sound solution was executed.

Putting SBCRI to the Test

On December 21, 2007, an interesting "flow of loads" situation presented itself to SBCRI, just in time for the holidays. Until SBCRI opened, this sort of dilemma left industry professionals with limited alternatives, often followed by costly and risk averse engineering solutions.

Continued on page 32

SBCRI: A Whole New Bag of Tricks

Continued from page 30

Photo 1. Buckled top chords of supporting trusses in piggyback system resulting from a failure to install diagonal bracing in top chord plane.

Photo 2. Bottom chords of "cap" trusses are deformed to same general shape as the top chords of the supporting trusses.

Photo 3. Broken top chord joint in one of the trusses. The diagonal brace attached to the web at this joint kept the webs from moving laterally with the top chord.

This brings to mind a critical concern: What happens when a structural situation presents itself for which there are no previously defined prescriptive methods for solving the problem, or worse, the prescriptive methods of the past aren't an option? Let's take a look at how SBCRI is providing our industry with better information and a whole new supply of engineering options; truly accurate solutions that go beyond the old tricks of the trade.

Early last December, the staff at a ten-year-old commercial building contacted the building's contractor stating that the room dividing partitions in one area of their facility were stuck in their tracks and couldn't be moved into position. While attempting to correct the facility's issues by adjusting the upper tracks from inside the roof, the contractor realized that the cause of the partitions' performance problems likely stemmed from a much bigger issue.

After a brief inspection by the contractor, it was clear that numerous long-span piggyback trusses had been improperly installed in the large, middle section of the building. The portion of the supporting trusses directly beneath the cap trusses, essentially 12' tall x 40' long parallel chord trusses, had been installed without any permanent diagonal bracing in the top chord plane and insufficient continuous lateral restraint and diagonal bracing in the web member plane. In turn, this lack of diagonal bracing had allowed the top chords of the supporting trusses to buckle in the classic "S" shape. The top chords had buckled 7" out of plane on one side of the "S" and 5" out of plane on the other. (See photos 1-3.)

On December 19, the contractor, original component manufacturer and the building designer met at the site to assess the damage. Later in the week the component manufacturer called in a structural engineer to investigate the facility and analyze its structural integrity. It was uncertain what should happen next, but the outlook was grim.

The engineer's immediate recommendation was to close off the affected areas of the facility and begin working on a plan to straighten and properly restrain and brace the compromised trusses. This plan, as explained to the general contractor, would involve supporting the trusses from below and taking off of them as much load as possible. Then each buckled truss would need to be straightened back into plane, while replacing or repairing any truss that was, or would be, damaged through this process. All of the engineer's calculations indicated that the current trusses' S-curved top chords jeopardized the facility's safety and needed to be restored.

Both the contractor and the component manufacturer felt there had to be another way. In this case, at least, asking the owners of the commercial building to close down this critical area of their facility was going to be a huge financial liability. They pushed for alternatives to remedy the situation; could

Photos 4 & 5. In order to make this testing possible, once the foundation was set, each truss was manually distorted into an "S" shape to imitate the trusses installed in the building, and then braced to retain that shape.

anything be done with the original buckled trusses? Enter SBCRI.

On Christmas Eve Day, just three days after the engineer's inspection, the decision was made to use SBCRI to test a series of six trusses, constructed to simulate the trusses in the field, in order to find a better solution. In the meantime, an interim bracing plan was executed in the commercial building to keep the trusses from further deforming. With the cooperation of the original component manufacturer, the trusses were built and delivered to SBCRI by Thursday of Christmas week.

In the week following the New Year, the truss set-up, test fixturing, load cells, string pots and data acquisition were put in place and tested before the structure testing began. This can be a more difficult task than you might imagine and, for this project, was further complicated by the fact that the testing involved "S" buckled trusses. In order to make this testing possible, once the foundation was set, each truss was manually distorted into an "S" shape to imitate the trusses installed in the building, and then braced to retain that shape. (See photos 4 and 5.)

It's important to point out that there were differences between the actual components installed in the field and the trusses tested at SBCRI. However, the staff felt that they could replicate the field conditions adequately and conservatively using only the 40' truss length that was buckled, rather than reproducing the entire roof structure.

Once set up, manually-buckled and braced in the facility, the same "interim bracing plan" was implemented to mimic the field installation and testing began. SBCRI staff worked to determine the locations within the system that were most compromised by the buckled, out-of-plane configuration. Forces were applied through pneumatic actuators onto wiffle trees to evenly distribute the load; next, the loads coming into and going out of the structure were measured to ensure accuracy. Key deformations and lateral loads were evaluated along the way so the staff could fully understand how to best stabilize the six-truss test assembly. Essentially, the goal was to create a load-carrying system that would only deform vertically like a normal truss system deforms.

Practically limitless options meant that a large variety of tests could be run, from light 100-lb loads to a full design load of 18,315 lbs. Twenty-seven tests were performed in all, some 20- and 40-minute tests, others three- or six-hour shifts. Some

Continued on page 34

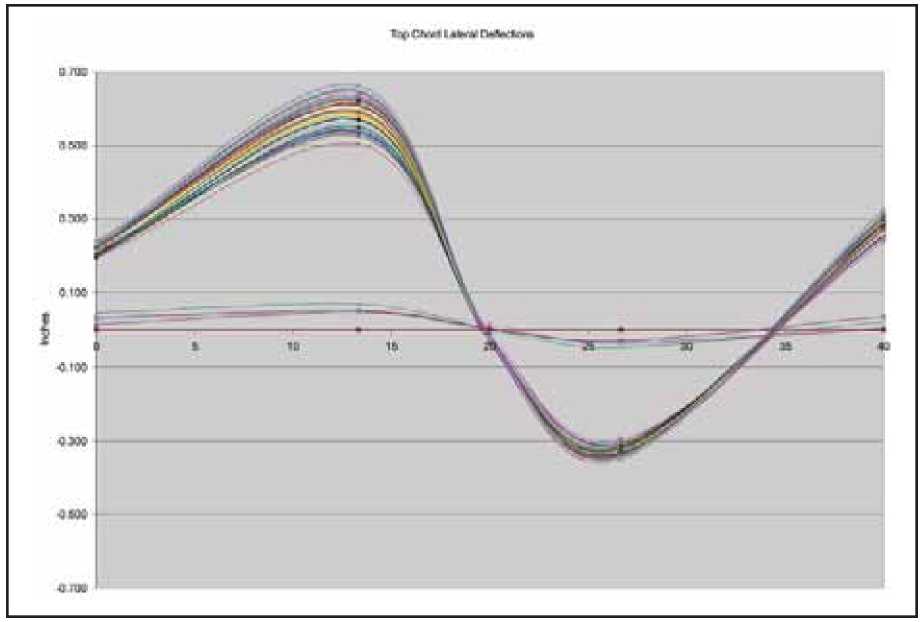

Figure 2. This chart shows the monitoring that was done of the deformations of the top chord of the truss at the deformation acquisition points of 0', 13.5', 20', 26.5' and 40'. This deformation was recorded multiple times during full design load applications over a total of more than 25 hours of load application when accumulated. The width of the series of lines is the range of deformation that this assembly experienced during the series of loading events over the 25 hours of load.

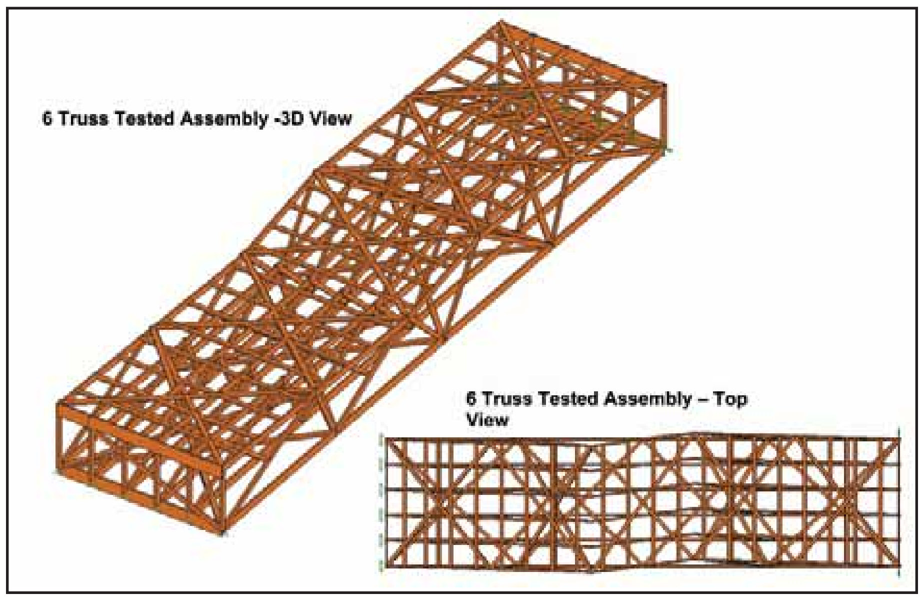

Figure 3. Top chord and web member plane bracing.

SBCRI: A Whole New Bag of Tricks

Continued from page 33

tests added small increments of weight every few minutes, while others held large amounts of load on the trusses over time.

It became clear, after the first series of testing, that the interim bracing plan was not going to be sufficient for maintaining long-term, sound, structural performance. The first in a series of new lateral restraint and diagonal bracing concepts was developed based on the load and deformation data gathered, and then another and so forth, each time refining the resistance to the loads and deformations that were being seen. The ultimate goal was to provide lateral restraint and diagonal bracing that would stabilize the truss system in its current state while being easy to implement inside the roof. To accomplish this, over the next three weeks the lateral restraint and diagonal bracing thought process was revised, re-installed and tested twelve times. Once the final bracing plan was decided upon, the remainder of the testing focused on long-term hold tests to validate the final plan.

On January 28, 2008, the component manufacturer, along with the building contractor, made the trip to SBCRI to meet with staff and go over the results. Per the outcome of the numerous tests, the new plan would meet the goals, yet require significant diagonal bracing of the top chord and web member plane in groups of six truss sets similar to the test set-up in the facility. (See Figure 3.)

For all parties involved, SBCRI provided some eye-opening results, and as the reports were finalized in mid-February, less than two months after the initial discovery, it became clear how valuable our industry testing facility will be in the future. This isn't the first time a real-world situation like this has presented itself, but in this case the tools available in SBCRI helped to present a long-term solution that would not have been an easy or optimal option in the past. Before we had the ability to perform the evaluation needed through real-life testing, our industry professionals were limited to equations with simplified assumptions. For this unique scenario, SBCRI provided a recommendation that wrapped an accommodating and economically reasonable engineering solution around a potentially expensive and time-consuming repair.

Had these trusses been discovered a year ago without the advantage of SBCRI's testing, the most likely, best case scenario would have involved the engineer's major roof overhaul. In comparison, salvaging the original trusses saved time and money in a number of areas. SBCRI's flexible facility and staff's fast response time reduced what could have cost a small fortune to a minimum. When presented with a real life situation that raised numerous questions and concerns about how to fix an installation error in the field, SBCRI gave our industry the opportunity to put together a much better plan with a whole new bag of tricks. SBC

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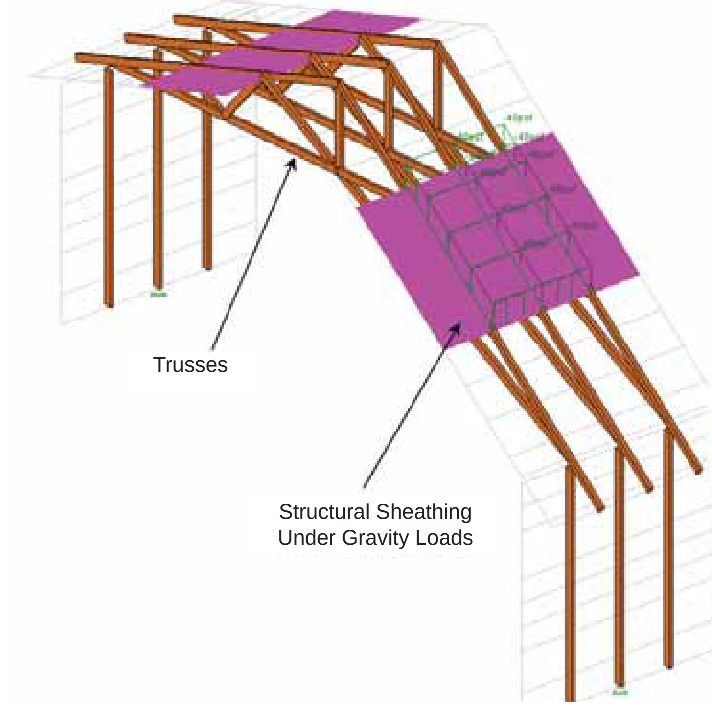
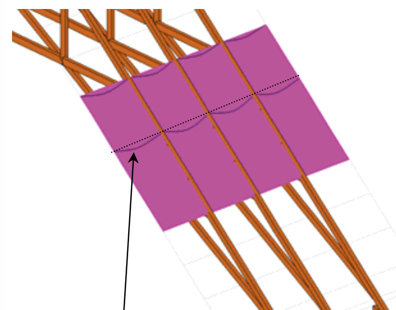
Understanding Flow of Loads

By Kirk Grundahl, P.E.

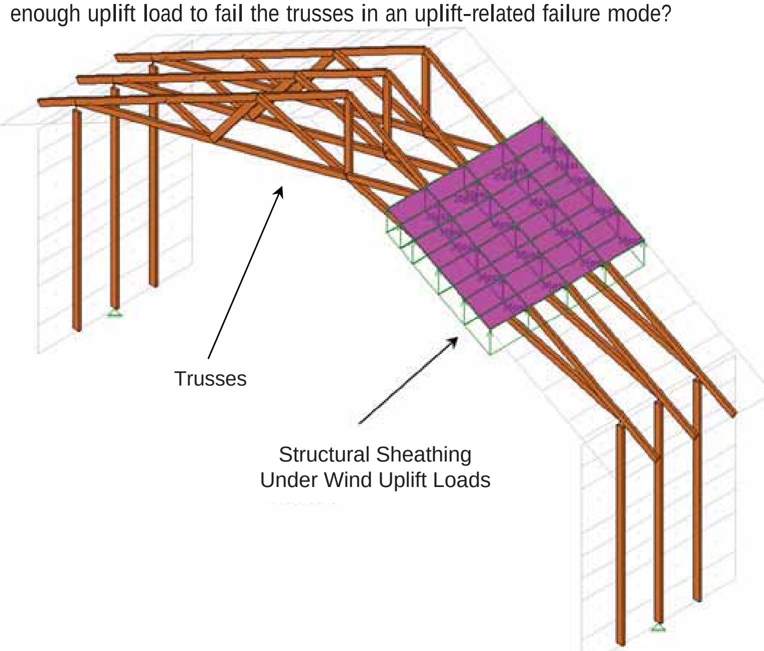
For those of us close to the SBCRI testing, there has been a metamorphosis in the way we think about engineering, especially as it relates to how loads flow through structures. The best way to understand this change is for each of you to consider the following questions:

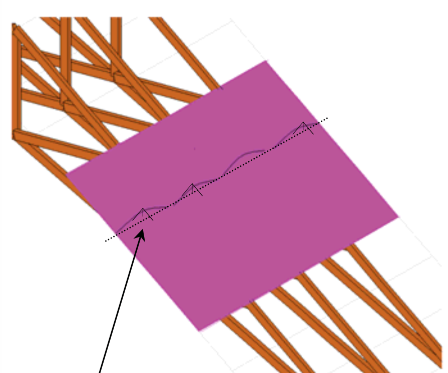
A. Do you believe that 7/16" OSB roof sheathing is strong enough to adequately transfer environmental loads (e.g. snow) so that the trusses will reach and exceed their ultimate load carrying capacity? In other words, will the load carrying capacity of the OSB sheathing be able to transfer enough load to define the ultimate capacity of the trusses?



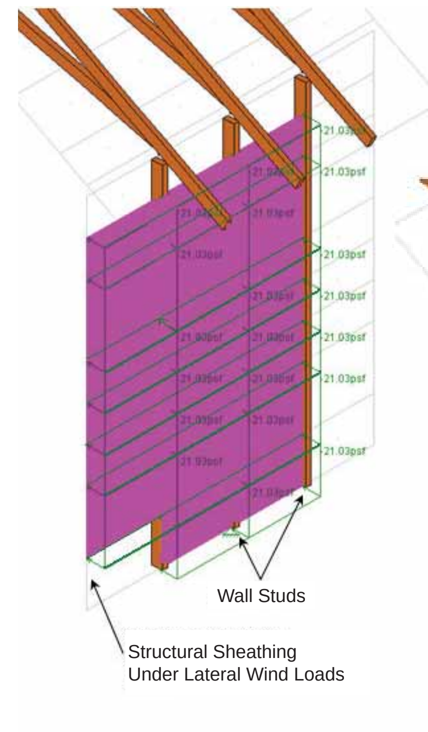


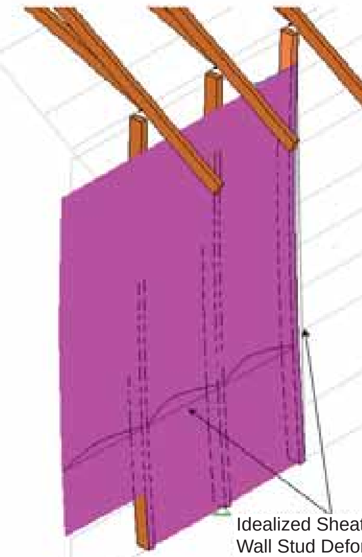
B. Do you believe that 7/16" OSB roof sheathing and its attachment is strong enough to fully transfer the uplift loads that are needed to be applied to it to load trusses to their uplift capacity? In other words, will the wind suction that is applied to the sheathing be able to transfer enough uplift load to fail the trusses in an uplift-related failure mode?

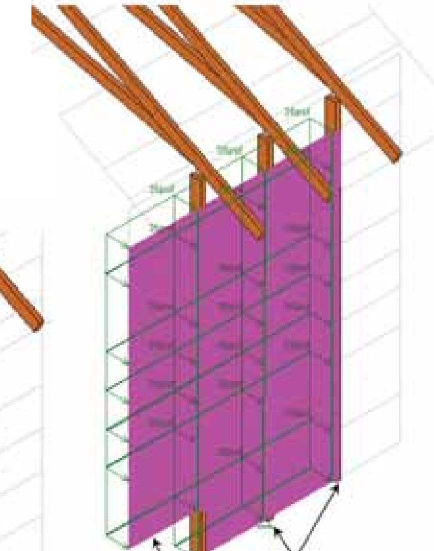


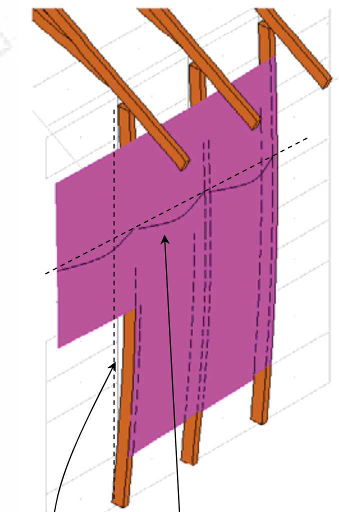


C. Do you believe that typical wall sheathing/siding is strong enough to fully transfer the wind loads so that the wall studs can be loaded to their ultimate capacity? In other words, will the load carrying capacity of the OSB sheathing be able to transfer enough load to define the ultimate capacity of the studs?

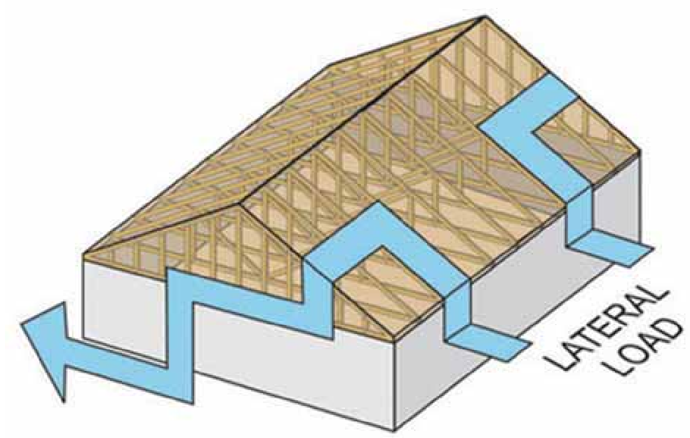




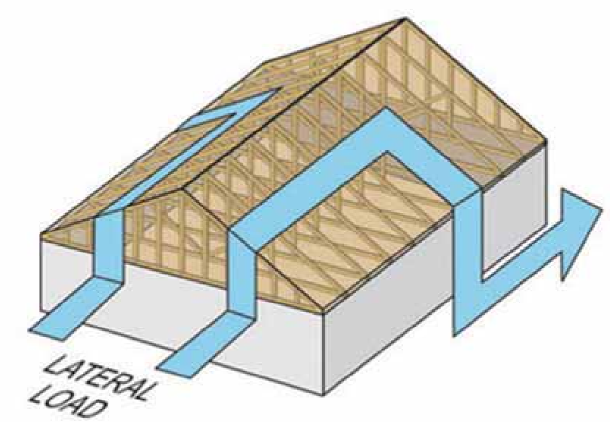




D. Finally, do you believe that roof trusses placed on top of the walls will have no bearing on the ability of those walls and related connection hardware to resist the lateral loads that are applied to those walls by wind?



Lateral loads acting on the side wall



Lateral loads acting on the gable end wall

As you can imagine, this is just the beginning of a long list of questions that can be asked with respect to the flow of loads through the real-life building system. The answers generally make good common sense, yet the engineering we perform today does not generally look at the flow of loads in a global and comprehensive manner. At SBCRI we are excited about the future because we have learned so much in such a short period of time. Stay tuned and visit us often. SBC

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Truss Publications, Inc.

6300 Enterprise Lane • Suite 200 • Madison, WI 53719
608/310-6706 phone • 608/271-7006 fax
www.sbcmag.info • admgr@sbcmag.info