RESEARCH & TECHNOLOGY

AN ARGUMENT FOR FULLY ENGINEERED POST-FRAME BUILDINGS

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On December 16, 2010, I met 66-year old dairy farmer Cyril Myren. He was sitting in an armchair in his house. He could barely move. Four days earlier he suffered two cracked ribs and lots of bruising when a portion of his two-year old post-frame dairy freestall barn collapsed on top of him.

Cyril's son Todd, 33, received a gash in the back of the head and other injuries in the same collapse. Both were working to get animals out of a portion of the building that had already collapsed when additional building bays came down on top of them. Todd was trapped until freed by police and fire department personnel. He'd lost a considerable amount of blood. In Cyril's words, they were both lucky to be alive. Some of their animals were not as fortunate.

Engineering gone missing

I was meeting with Cyril just after I had inspected his partially collapsed building. I explained to him his building had several major weaknesses due to a lack of engineering. Cyril's response was one of frustration and anger. He truly believed he had purchased a properly engineered building.

A properly engineered building in Cyril's mind is what I refer to as a fully engineered building. A fully engineered building is developed by following three structural design steps. Step 1: Calculate all loads and load combinations to which the building will be subjected. Step 2: Determine how loads from Step 1 are distributed to building elements (this step is known as structural analysis). Step 3: Select components and connections capable of handling the forces to which they will be subjected. In practice, selections made in Step 3 will influence structural analysis (Step 2) and this makes structural design an iterative process.

It follows that a fully engineered building is a building in which the interaction of all structural components is properly accounted for during structural analyses, and forces resulting from these analyses are used to size all components. By contrast, the design process of a non-engineered building does not account for component loads or actual component strengths. A partially engineered building lies somewhere between these two extremes.

The collapse of the Myren freestall barn, like that of five other collapsed buildings I inspected the same day, was triggered by unbalanced snow loads (i.e., drift and sliding snow loads) that each of the structures should have easily withstood. In all six cases, it was obvious the building was not fully engineered.

This lack of engineering can be attributed to the fact many companies involved in agricultural building construction do not employ engineers, nor do they hire an engineer to perform structural engineering calculations for the agricultural buildings they construct. Each year this results in the construction of numerous agriculture buildings that contain multiple components not sized to handle the loads the building is expected to experience.

Myriad problems

Companies that erect non-engineered buildings generally try to emulate designs they have seen elsewhere. This causes a myriad of problems.

Simply copying, altering and/or scaling up an existing design completely ignores the fact that loads like wind and snow are highly dependent on the size, shape, orientation and location of a building as well as characteristics of the local topography and the size, shape and orientation of attached and surrounding structures. Additionally, snow, wind and other structural loads act in a variety of combinations and a building must be designed to handle all load combinations to which it could be subjected. Total ignorance of applicable loads and load combinations is a hallmark of non-engineered building design and explains why so many agricultural buildings are damaged by wind and unbalanced snow loads that would not damage a fully engineered agricultural building.

Extremely weak connections between components is another hallmark of non-engineered structures. The stresses that surround mechanical fasteners (bolts, screws, nails) are complex and control fastener size, spacing and placement relative to the ends and edges of the components they connect. These conditions are seldom realized by builders attempting to mirror the design of another building. Improperly assembled connections trigger and/or contribute to many building failures.

Figure 1: Buckling of a nail-laminated post due to improper design. Also visible is the buckling of the compression web chords due to improper bracing.

Many building companies are established by individuals who begin erecting buildings for a company that employs engineers and sells fully engineered packages. While I applaud the entrepreneurialism of anyone starting their own

continued on page: 30

continued from page: 29

RESEARCH & TECHNOLOGY

building company, it is indeed scary when some of these individuals start erecting non-engineered buildings. Participating in the erection of engineered buildings does not make one an expert in building design, no more than designing a building makes one an expert in safe and efficient building construction.

Very few builders, architects, code officials and nonstructural engineers understand the true complexity of a fully engineered post-frame building system. Several building elements perform multiple functions not apparent or understood by those not actively engaged in post-frame building engineering. In addition to having no idea of the loads to which a component is subjected, builders are not familiar with all methods available to resist applied loads and they do not have the expertise needed to determine the proper size, support system and connection designs for a building component.

A prime example of the problems this causes was on full display in Myren's freestall barn and the other five failed buildings I visited the same day. Many of these buildings had seriously under-designed interior columns. As constructed, most of these columns would have an allowable axial design load of zero (0) which explains the classic buckling observed (figure 1). Other major deficiencies included no column sideway control at connections between interior columns and trusses, no accounting for additional loads induced by drifting snow and improper truss web bracing. With respect to the latter, all buildings I inspected with roof trusses utilized continuous lateral restraint (CLR) systems to brace longer compressive web members. Unfortunately, every CLR system was improperly installed, as none of them included diagonal bracing to prevent CLR shifting. This resulted in web buckling (figure 2) and subsequent truss failure.

In my view, the more major concern is not that the CLR systems were improperly installed in these buildings, but that they were used in the first place. In buildings with trusses 6 feet or more on-center, all compression web chords should be T- or L-braced. The use by builders of CLR systems (instead of L- or Tbracing) results from plans

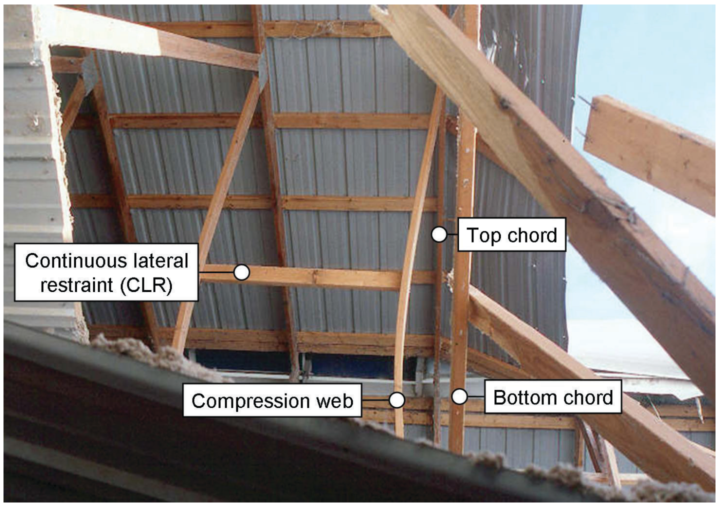

Figure 2: Shifting of the CLR enables the compression web to buckle out of the plane of the truss. All trusses to the right of the one labeled here failed in a progressive manner.

produced with software developed for trusses spaced less than 4 feet on center (e.g. residential trusses). Using Land/or T-bracing not only saves lumber and provides greater stability, such braces are also easier to install (they can be attached on the ground) and do not cause progressive collapses.

With a CLR system, when one truss fails, the lateral restraint attached to that truss pulls on the similarly buckled webs of the two adjacent trusses (i.e., the trusses located on each side of the failed truss). The truss on one side of the failed truss is helped by this action and does not fail (as its bowed compressive web is somewhat straightened out).

Conversely, the truss on the other side of the failed truss becomes more compromised as its buckled web is pulled further out of alignment. This almost always snaps the web of that truss, resulting in its collapse. The collapse of this second truss brings down the next truss in a similar fashion. In a dominolike fashion, trusses continue to fail until there are no more trusses to pull down. This entire failure process explains why this mode of failure is characterized by a partial roof collapse that ends at a wall.

Misled consumers

During my investigation of agricultural building failures, it has become quite apparent that a vast majority of farmers are under the impression they

continued on page: 32

continued from page: 30

have purchased a properly engineered building, when in fact they have not. In some cases, these farmers are intentionally misled which is highly unethical if not criminal.

Frequently, farmers are quoted a "balanced design snow load" (generally in pounds force per square foot) that was used as an input to a truss design program by an employee of the local lumber yard. Given this number, the farmer assumes they are getting a fully engineered building. This could not be further from the truth. Trusses so designed seldom account for all loads to which the trusses are subjected, nor do they account for the exact manner in which the trusses will be connected to other components, receive loads from other components, and/or be braced by other components. Furthermore, a truss is only one element in an extensive building system and each of these elements must be properly engineered with special attention given to unique interactions between elements.

But codes exempt agricultural buildings

The International Building Code is the primary non-residential model building code in the United States. Although the IBC: (1) covers agricultural buildings, and (2) has been adopted to varying degrees in all 50 states, most agricultural buildings are not designed in accordance with its provisions. This is because most state and local governments that adopt the IBC exempt "buildings used exclusively for farming purposes" from all building code provisions.

Because of this special agricultural exemption many builders are quick to tell farmers they do not need to have their agricultural buildings engineered. While this is absolutely true, it is something you would be foolish to do, especially if you are building a freestall barn or other large structure, a storage building for expensive equipment or a facility in which you or your employees will be spending measurable time.

Telling a consumer they do not need to have their building engineered if it is exempt from the building code is no different than telling a person they do not need to wear a seat belt or a bike helmet if the law doesn't require it. Inasmuch as it makes sense to wear a seat belt and a bike helmet regardless of the law, so is it wise to fully engineer a building regardless of whether it is or is not code exempt.

Many agricultural builders will tell you it costs more to construct a fully engineered building. While this may be true for smaller buildings, it is generally not true for larger buildings. Builders who sell you a large non-engineered building for less than the price of a fully engineered building are likely selling you a relatively dangerous building. This results from the fact non-engineered buildings are not balanced in terms of overall design.

Non-engineered structures generally contain components that are either not needed or are larger than needed and this unnecessarily drives up building cost. At the same time, non-engineered structures are frequently missing critical components and/or have numerous under-designed components and this places building occupants in grave danger.

Keep in mind building codes establish minimum performance levels for buildings. Virtually all engineers will design their agricultural buildings so they just meet these minimum performance levels. Consequently, any statement implying that engineered agriculture buildings are over-designed is just not true.

Figure 3: Relocated here are some of the 60 springing heifers killed in the partial collapse of a non-engineered post-frame building

Be ethical

I believe it is unethical to sell larger buildings that are not fully engineered. Not only does it needlessly endanger farmers, but a lack of building engineering is responsible for the deaths of numerous animals every year. I've been in buildings with thousands of crushed chickens. I've also seen my share of dead cattle (Figure 3).

With respect to the consumer, I highly recommend all farmers ask for written confirmation that their building has been designed to meet the structural performance criteria of the IBC. Demand this

continued on page: 33

written document be sealed by a qualified registered professional engineer (P.E.). If it's a post-frame building, ask that the document be sealed by a structural engineer that specializes in post-frame building design. Also, it never hurts to demand a sealed copy of the same structural calculations and plans that an engineer would have to provide for your building if it was not exempt from the building code.

Be extremely leery of builders who erect facilities designed and supplied by the local lumber yard. As I previously noted, the engineering of many such buildings is often quite limited. It is also important to understand that just because you may receive a nice set of drawings (i.e. plans) it does not mean that the building has been properly engineered.

Industry reputation on the line

Every time a large storm brings down a series of post-frame buildings, the reputation of the industry takes a hit as additional architects, code officials, insurance companies and consumers begin to question the integrity of the post-frame building system. Insurance premiums go up (even on fullyengineered structures) and the effectiveness of the time and money invested in the PFMI (Post Frame Marketing Initiative) is lowered.

What should be of major concern to the industry is the sheer number and steady increase in large agricultural building failures. That this is occurring should not surprise anyone. When you double the size of a structure, you double the number of components in the structure and this will approximately double the probability that the structure will experience a failure.

From a consumer safety perspective, large building failures are more of a concern than small building failures because there is generally a greater potential for loss of life in larger facilities. In response, some individuals have suggested code exemptions for agricultural buildings be terminated, at least for larger structures. Personally, I have waffled on this issue. While it would somewhat help solve a growing problem, I am not for more government intervention, and quite honestly, buildings are not failing because of a building code exemption, they are failing because they are not properly engineered and/or constructed.

Perhaps NFBA needs to institute a program in which fully engineered buildings receive an "engineering and construction (E&C) certification" after final engineering and construction have been determined by an independent, qualified professional to meet minimum industry-established criteria. To make this system pay, insurance companies would be asked to recognize certified buildings with lower rates — rates that could be determined by studying failures rates of existing structures. Farmers looking for a fully engineered structure would simply request E&C certification. Quality builders, insurance companies, the NFBA and farmers all win. The losers in this scenario are those individuals currently putting lives needlessly at risk.

Fully engineered post-frame buildings are awesome

Invariably, when the report of another non-engineered post-frame building failure surfaces, someone will exclaim "they sure don't build barns like they used to." If this is stated to me directly, I typically respond with something like "Be thankful, because pound for pound, agricultural buildings of past generations do not come close to the performance level of today's fully-engineered post-frame buildings."

The sheer size of many of today's buildings, the distances they clearspan and the loads they can withstand make them true engineering marvels. The low per square foot cost of post-frame buildings is a reflection of efficient material usage. This efficiency, when coupled with their durability makes the modern, fully engineering post-frame building one of the most, if not the most, environmentally friendly or "greenest" structures in the world.

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