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What Causes Poor Construction? The Answer Is in the Details by W. T. "Dusty" Yaxley, P.E.

Editor's note: This article defines quite well why our industry took on the development of our design responsibilities document and is heavily involved as a Director within the NAHB Research Foundation's "Certified Trade Contractor Program." Our goal with this is to help everyone in the construction process do it correctly the first time and eliminate costly problems.

Who is to blame when unacceptable construction practices prevail? The answer is no one and everyone. Sometimes, one team member does not take his or her responsibility seriously and allows issues to be overlooked.

In other instances, it is simply a communication or cooperation difficulty among team members. To have the project run smoothly, everyone must do his or her respective jobs responsibly and intelligently. The engineer must specify items correctly, the contractor must buy and distribute the items appropriately, and the trades must install the items properly. Any weak links in the chain will lead to poor construction.

This article briefly addresses each member's responsibilities on a residential project and discusses some of the specific problems that I commonly see as a consulting forensic engineer. It also discusses what a structural engineer can do to ensure that what he or she designed is what is actually built.

THE DEVELOPER'S RESPONSIBILITY

The developer has the ability to control the quality of drawings that the engineer produces and to determine whether the engineer observes construction. Although it is in the best interest of the future owner to have quality drawings and jobsite observation, it is not always in the best interest of the developer.

Oftentimes, the developer or owner requests that the engineer only produce a minimal set of plans just to "get the permit." In this situation, the developer wants the flexibility to build the project to meet the local inspectors' minimum requirements so that the engineer does not tie him or her to specific conditions. For example, if the engineer does not specify which connector is required, the builder will install the cheapest connector he can find without regard to the load carrying capacity of the connector. If the plans do not designate the connections, how would the inspector know or have the power to insist on certain connections? How should the inspector resolve the note on the plans to use a certain manufacturer and connection designation when "or equal" is noted?

Whether to pay the engineer for site observation is also left to the developer's discretion. Jobsite observation is an added expense and, again, it limits the developer's ability to control construction. Unfortunately, without jobsite observation, there is no chance of finding and correcting errors or misinterpretations in the plans. This is a difficult situation for the developer because he or she wants to do the right thing but must also stay competitive.

THE ENGINEER'S RESPONSIBILITY

Engineers are required to hold the health and safety of the public as a paramount consideration while designing any structure or building.

An engineer needs to design a building to carry the minimum loads specified in the applicable code. If the structure is required to resist 110 mph winds, the code and all calculations assume the structure will be safe at 110 mph—not in eminent danger of collapse. Safety factors and load factors have been carefully tested and designated to assure the structure will safely carry the calculated loads. Material strengths are factored according to their predictability of performance. If a controlled, manufactured material such as steel is used, the safety factor will be considerably smaller than visually-graded wood lumber that may vary in strength due to species, growth rate, and defects.

The engineer's input is required on a good portion of the details on a project. If it was adequate for the engineer to simply state on the drawings, “build to all applicable codes,” he or she wouldn't be needed at all. Unfortunately, it is a common occurrence for a set of plans to include that note. The engineer must be hoping to avoid a lawsuit if the building design failed to meet any part of the building code that he or she overlooked during the design.

Needless to say, that argument will be short-lived in litigation if the engineer were negligent. Negligence is defined in **Black's Law Dictionary** in part as “the failure to use such care as a reasonably prudent and careful person would use under similar circumstances.” Granted, the accusation of negligence is complicated and subject to many considerations, but the basic measurement for negligence is what is customary and accepted in a similar situation by competent professionals in that field. When an engineer specifies a certain size and material on the plans, it is the engineer's responsibility to interpret the code and select the correct size, material, and connections for the conditions.

Let's use an extreme example to illustrate the principle of reasonable responsibility. If a floor requires a 40 psf live load plus dead load, the engineer is expected to calculate and specify the appropriate size and grade of material to provide the required capacity. Assume the span is 25 feet and the engineer specified 2x4 - #2 spruce floor joists spaced at two feet on center. This would be an obvious mistake, and all involved would recognize it as such.

Others might also bear some responsibility to correct the mistake. The plan examiner, contractor, carpenter, and others involved would immediately realize that 2x4s would not carry even a minimal load at that span. But instead, let's assume the engineer specified an engineered composite wood I-joist that was only adequate for the dead load plus 39 pounds per square foot live load.

Now the obvious example of the 2x4 joists is not as apparent without a careful analysis. The plan examiner, contractor, or carpenter would not be expected to catch this slight overstress, but the engineer should know because of his or her training. A note on the plans to build according to all applicable codes will not help the engineer in the latter case.

This is an extreme example to show the range of problems, but the area between these extremes is gray, with each individual's responsibilities overlapping the other. Still, the engineer is considered to be in the best position to specify the correct size and connection for the material. If the engineer fails to specify the correct material and connections, and a collapse occurs, the courts will quickly explain what the engineer-of-record's responsibilities are.

THE CONTRACTOR'S RESPONSIBILITY

Neither the building inspector nor engineer should be responsible for quality control. Ultimately, it is the contractor's responsibility. With the thriving economy and decline of skilled construction workers, the contractor frequently waits for the engineer or inspector to catch any mistakes and the quality of the project suffers. A common excuse from the builder when a structure fails is, “it passed all the required inspections.” Many contractors depend on the inspection system to be the quality control rather than a procedure to resolve honest mistakes or conflicts in the drawings.

THE TRADE'S RESPONSIBILITY

A half-century and more ago, a carpenter would have had a good idea what size was required for floor joists and rafters in common buildings and how many nails were required to assure the proper connection. The tradesmen accumulated much of this knowledge through years of experience, and trial and error. This knowledge was then passed on to the apprentice tradesmen.

But today, no adequate apprenticeship programs exist on most multi-family building projects in this country. The custom on current projects is to train the worker to perform only the specific tasks needed for a particular project in a specific condition. If a project requires an application that is different from his experience, the worker's background may be inadequate for the new condition. And if the senior person was not trained to perform the task correctly for many different variations, how can he or she train his or her subordinates?

When an engineer points out the shortcomings of an installation, he or she is frequently met with resentment illustrated through statements such as, “I've been doing this for five years. Don't try to tell me how to do my job.”

A simple requirement by most manufacturers of connections is to “place a fastener in each hole provided.” When questioned by an engineer, the tradesman often states, “That is all we ever used and I've been doing this for five years,” or “The strap was misplaced by the concrete contractor, and those were the only holes that lined up with the structure.”

Because the installation is performed by tradesman with little or no supervision, this gap in knowledge and authority often results in improper installation. This problem is exaggerated by the fact that installers are paid by the job, not by the quality of the work.

Often, the engineer-of-record is “not needed” to observe construction, and the building inspector cannot be expected to know all the detail requirements for approving alternate connectors. With this relaxed attitude from the installer, it is difficult to obtain a high-quality final product.

In the example cited, the connection will only be tested in an extreme situation such as a hurricane, and at that point, it is too late.

Many examples of poorly-connected materials were verified after Hurricane Andrew. For example, roof sheathing was often found with as few as four nails in a 4x8 sheet of plywood. Concrete tile roofs contributed dead load to hold the sheathing in place until a strong wind blew off the roof tiles and the sheathing. The condition shown in Figure 1 was from another hurricane in the Northern Gulf of Mexico. The photograph proves that the roof sheathing was poorly nailed.

COMMON MISTAKE #1: NOT READING THE CONNECTION MANUALS

Each manufacturer presents general notes differently, but all of them list the conditions that must be met to qualify for the loads listed in the tables. These conditions are usually ignored when the contractor decides to buy substitute connectors from another manufacturer or at the local lumber supply store. The following are some of the issues discussed in the general notes that must be considered.

Most manufacturers base their loads on Group II wood, and the loads must be adjusted if a different wood group is used. A note (see Figure 5) is usually included that states that Group II lumber was used to certify the loads—or in this case, a specific gravity of 0.50 (a Group II wood). The designer must recognize and adjust the connector selection to the proper capacity connector if using a weaker wood. This note limits the table values to Group II woods; these include fir and southern yellow pine. The loads would require downward adjustment for other framing wood.

In the Southeast, most of the lumber used for framing is southern yellow pine. Calculations confirm that Group III woods, such as lodgepole pine, are good for only 85 percent of the values

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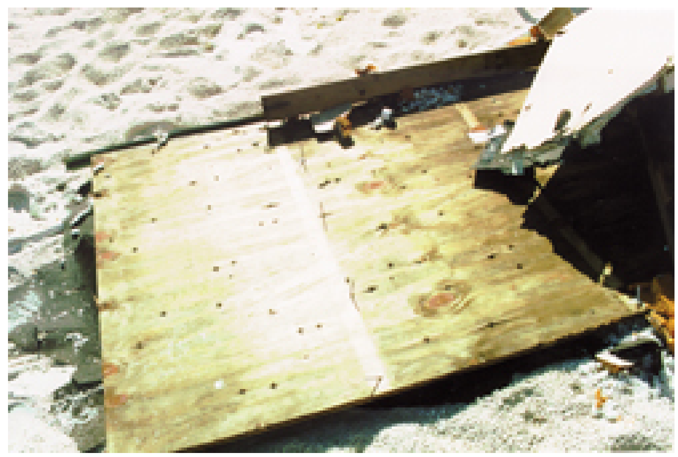

Figure 1. I found this nailing condition in many sheathing boards at the site of the collapse. Note that of the four nails visible, three completely missed the truss below. This was not an isolated example for this site; many roof sheathing boards looked similar. This building was only four years old.

listed in the table for Group II woods. If using Group IV woods that include northern white cedar, a common framing lumber in many areas, the table values must be reduced to 65 percent of the value listed in the table for Group II woods.

Providing a complete load path is another item frequently ignored. For example, if a heavy framing anchor bolts into vertical studs, those studs must be fastened together to act as one piece without splitting (see Figure 6). Figure 2 shows four studs that are grouped together beside a window. This group of studs have minimal nails—about five nails per stud—to transfer the shear. This anchor was listed in the catalog as transferring 4,000 pounds.

First of all, the 4,000-pound capacity is based on Group II wood, and this building had Group IV wood. This anchor was also depending on the shear transfer from all the studs as a unit. Not enough nails were provided to have the studs act as a unit. Furthermore, this anchor specifically limits the horizontal holes to be less than 1/16 inch larger than the bolts. The holes were 1/8 inch oversized for ease of installing the horizontal bolts. Shrinkage of the wood further enlarged the hole.

The catalog specifically states that the "anchors should be retightened after shrinkage." No attempt was made to tighten the bolts initially, and they surely weren't tightened later after shrinkage. With the violations to the manufacturer's requirements, this anchor was probably useful for less than half of the load listed in the catalog.

COMMON MISTAKE #2: IGNORING LATERAL BRACING

The Standard Building Code (SBC) includes a reference to tables in the American Forest and Paper Association's (AF&PA) Span Tables for Joists and Rafters as a guide to the engineer or tradesman to size and space these members.

Figure 2. This connection has several problems. The four studs were not nailed together to act as a unit, and the horizontal bolts were loose due to oversized holes.

Figure 3. These 4x2 floor trusses were not fastened properly. The vertical anchor from the tie beam was misplaced, and only a few nails hit the wood. The strap was misplaced by three inches and was bent down onto the tie beam and up at the truss.

New products like wood I-joists require propriety software and design furnished by product manufacturers. These propriety designs adequately lead to the correct design for a particular product, but the overall concept of the building continuity is repeatedly lost. An example of this shortcoming is in the metal plate connected wood truss industry. Wood trusses are probably the best engineered and controlled product in a modern building project, but a lack of communication can often lead to problems.

Wood truss designers design wood trusses as individual components and clearly state on their drawings that the engineer-of-record must provide overall system bracing. For example, the lateral bracing is specified on the truss drawings, but must be adequately diagonally-braced to provide stability for the wood truss system. Improper attachment of the lateral bracing system is not unusual. Figure 4 shows a lateral bracing system that was toe-nailed to the drywall firestop, a condition was prevalent throughout that building.

Figure 4. This photo illustrates a typical condition for this building. The lateral braces for the truss system was nailed into the drywall fire break. The fire wall is useless because of the lack of framing to secure the drywall. This building was only four years old.

e. Unless otherwise noted, allowable loads are for use with Douglas FirLarch No. 2 or better (based on 625 psi) under continuously dry conditions. Allowable loads for other species or conditions must be adjusted according to the code. Specific gravity is 0.50 for Doug Fir–Larch.

Figure 5. The note above is found in the front of a manufacturer’s catalog. Group II wood also includes southern yellow pine.

• To tie double 2x members together, the designer must determine the fasteners required to bind members to act as one unit without splitting.

Figure 6. The note above requires that the studs be fastened together and act as a unit. Most building plans do not specifically address this.

Although required, the building designer rarely designates the system diagonal braces on a typical house or building. Many plans simply state “pre-engineered wood trusses,” even though the wood truss designer places a restriction on his plans stating that the system bracing must be designed by the engineer-of-record. If he or she doesn't designate the system diagonal bracing, the inspector cannot be expected to demand adequate diagonal bracing. Without the system being braced sufficiently, the individual roof trusses will not perform as designed, and therefore they will not meet the loads specified in the wood truss shop drawings or the applicable code. A knowledgeable investigator will quickly identify a lack of lateral bracing anchorage.

Another example illustrates a common lateral bracing failure. When two gable roofs intersect at 90 degrees, the most common solution is to run one set of simple trusses through in one direction. Trusses framed at 90 degrees will have over-framing on the lower trusses to form the valleys. The top chord of the lower trusses must still be laterally braced to provide stability. This lateral bracing on the top chord is usually accomplished by the roof sheathing. If the intersecting roof is of sufficient size, the sheathing is often incomplete on the under structure and therefore does not provide the lateral bracing to the top chord anticipated and required for the truss design.

If built without lateral bracing, the top chord of the bottom truss will deflect sideways severely due to the long compression chord that was not laterally braced sufficiently. Even if the top framing consisted of the normal partial truss with a lateral slope cut to fit the lower slope, the framing is usually only minimally attached to the lower trusses.

It is difficult for the carpenter in the field to understand the need to provide lateral bracing to the top chord of the lower truss that “has no load.” However, the top chord of the lower truss will deflect excessively with the dead load of the roof system. Any added wind load from a hurricane will likely fail the system.

COMMON MISTAKE #3: USING “OR EQUAL”

Connections of wood to wood or wood to concrete are often designated by the engineer-of-record by reference to the manufacturer's product number and capacity. To be practical and fair, the designer will specify the connection by product name, number, and load capacity, and state “or equal.” If the builder desires to use another manufacturer, he or she will change the connector and supposedly maintain the correct capacity with the substitute connector. What should the building inspector do when he or she notices the connector has been changed? Should the inspector cross-reference the connectors to assure the adequacy of the substituted connector? Should the building department require the engineer-of-record to designate the appropriate change in writing?

Timing on the job is usually critical. What is the contractor to do when the connector was not delivered to the jobsite for inclusion in the project? What should the contractor do when the connector specified is not available? Should the contractor wait to obtain a replacement specification for the connector from the engineer-of-record before proceeding? This describes the honest and conscientious contractor wanting to do the right thing. It is difficult for the job to proceed smoothly under these conditions.

What about the contractor who wants to get by as cheaply as possible? What is the chance of getting the project built properly? Connectors are often cheaper at the local lumber supply house than from the large, well-known manufacturer of connectors. Why are the connectors cheaper at the local building supply? They only stock the basic connectors, and they are often a lighter gage than required by the engineer-of-record. The building inspector cannot easily tell the difference between truss anchors from the local building supply store and the connector manufacturer. Usually, if an anchor looks good, the inspector doesn't have an easy way to identify a specified connector from a substitute connector. Also, keep in mind that the normal building inspector performs 20 to 30 inspections each day.

CONCLUSION

Structures that have more complete and more restrictive plans and specifications are usually built better. In the multi-family housing market, however, the developer is often the driving force and may insist that the engineer produce only a set of minimal plans with just enough details to obtain a building permit. This is a dangerous and sub-standard process for constructing a quality building.

The party with the least skill and knowledge about the building business—the buyer—is hurt the most by this process. The developer with latitude to skimp on certain conditions during the construction of the building can sell the units cheaper than the builder that produces a top-quality product. Ultimately, the consumer must insist on the project being built correctly and competently. Unfortunately, the buyer usually learns this lesson too late to recoup his or her investment. The professionals involved must be aware and insist that the contractor produce a quality building.

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