Strong Rail-Post Connections for Wooden Decks

by Joseph Loferski and Frank Woeste, P.E., with Dustin Albright and Ricky Caudill

Researchers at Virginia Tech applied measured loads to deck posts to see which connections could meet code. The tests were spawned in part by one author's observations of dangerously weak details on existing decks, as in the two examples below, where railing posts were simply toenailed into the decking. The post in the bottom photo was covered by a decorative plastic cover, which concealed the flimsy connection.

Where common connection details fail to meet code loads, prefab galvanized hold-down hardware passes the test

During the last several years, wood science researchers at Virginia Tech have scrutinized the structural connections commonly found in residential wood decks. This work resulted in the publication of the *Manual for the Inspection of Residential Wood Decks and Balconies* (Forest Products Society, Madison, Wis.) and the *JLC* article "Load-Tested Deck Ledger Connections" (3/04).

For this article we turned our attention to residential deck railings — the guardrails intended to prevent people from accidentally falling off the edge. When decks rise more than a couple of feet off the ground, such accidents can be serious and even deadly, as news reports have corroborated. With many decks standing 8 feet or higher above grade, this is not an issue a builder can afford to ignore.

Tested Post Connections That Failed

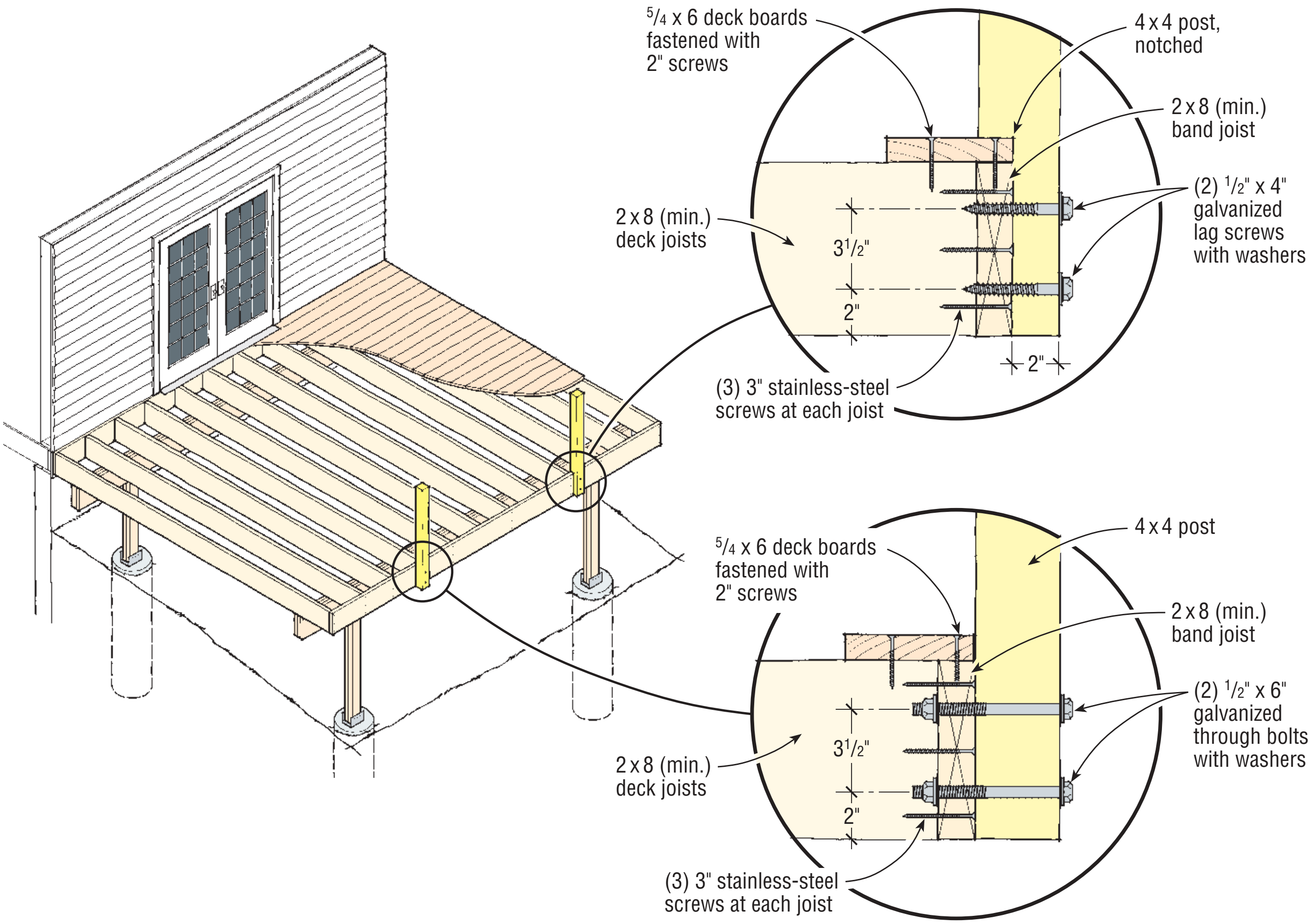


Figure 1. The authors first tested two post connections found commonly in their area, one where the 4x4 pressure-treated post is notched and lag-screwed to the band joist (top detail), and a second where the post is through-bolted to the deck band joist (bottom detail). Code requires that a rail post be able to withstand a 200-pound force applied in any direction. The researchers tested the worse-case scenario only, by pulling outward at the top of the post; they applied a 2.5-times safety factor, according to code-accepted test protocol.

The point was brought home to us when Frank was asked to inspect the railing on a friend's deck and found the rail posts toenailed into the decking (see photos on previous page), an unacceptably flimsy connection. Looking around our area of Virginia, we spotted other railing connections that made it clear that some deck builders, at least, aren't aware of code requirements for deck railings.

What Code Says

The 2003 International Residential Code (IRC Table R301.5) specifies a minimum concentrated live load of 200 pounds for both guardrails and handrails. Footnote "d" defines the application of the 200-pound load as "a single concentrated load applied in any direction at any point along the top." Judging by what we were observing in the field, it seemed obvious that many deck railings would not pass this loading requirement.

A guardrail is really a system of components connected together and fastened to the deck, including posts, railings, and pickets (or balusters). Rather than look at the entire guardrail system, we decided to narrow our testing to post connections. There are many ways to attach deck posts, so for practical reasons we decided to limit the possibilities to methods frequently used by carpenters in our geographic area.

What's being built. By far the most common details we found locally were the cases shown in Figure 1, where the post attaches to a "band joist" at the outer edge of the deck structure. These posts are typically notched (see "Why Not Notch?" page 4), but not always, so we decided to test

Test Results: Lag Screws and Bolts

Post-to-Deck Connection Assembly	Average Test Load (lb.)	Range of Test Loads (lb.)	Average Deflection at 200 lb. (in.)	Average Test Load as Percentage of 500 lb.*
$1/2$-inch Lag Screws	178	146 to 211	NA	35%
$1/2$-inch Bolts	237	217 to 248	4.4	47%

*Must be greater than 100 percent to be considered code-conforming

Figure 2. Although the bolted and lagged connections appeared sturdy, neither type could come close to meeting the target 500-pound test load, as the table shows. The authors tested five samples of each connection, applying a horizontal force at the top of the post until the post detached from the joist structure or the band joist itself came off. A piece of $5/4$ decking nailed to the simulated joists and band joist did little to prevent failure.

the connections both ways.

While many of the post connections we observed were obviously loose and allowed us to shake the railing, some of the posts seemed strong. But the question we wanted to answer was whether these connections would stand up to a code-protocol test load.

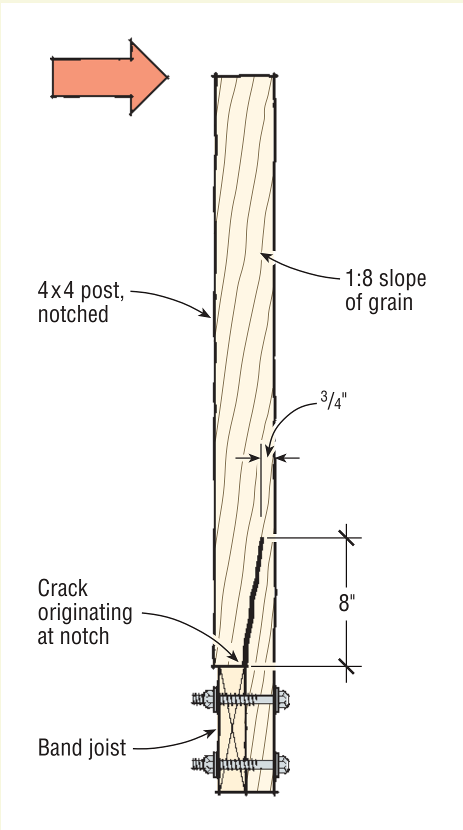
Setting Up the Test

A load “applied in any direction” includes people leaning against the railing or sitting on top of it. But it also means that the railing should be able to resist a load applied from the outside — for instance, a tree that falls against it. We decided to limit our testing to the worst-case scenario — that of a 200-pound load applied from the deck side perpendicular to the very top of the post. Making a connection to resist this force at the base of the post is harder than you might think, because of the lever-arm effect (force x distance): The magnification of this 200-pound horizontal force produces a couple of thousand pounds of load at the base of the post (see “Forces in a Typical Guardrail Post,” page 5).

We assumed that the top of the railing was 36 inches above the deck surface (the minimum height allowed by the IRC) and that the deck boards in an actual application are at most 1.5 inches thick. Thus, the horizontal test load was applied to the post 37.5 inches above the top of the simulated deck joists.

Our test machine applied a measured force, using a roller chain and pulley to redirect its vertical motion to a horizontal force at the top of the post. The post was attached to a simulated deck framing system that included two joists and a band joist with the post attached to the band joist with bolts or lag screws,

Why Not Notch?



Cracks will typically develop from the corner of a notch (photo, right). As a crack develops, a steep "slope of grain" can critically reduce the section of the post, as the drawing shows.

Several of the 4x4 posts we tested were notched around the band joist — a common detail in the field. While you might expect the notch to be the weak point in the connection, in fact none of the test posts failed at the notch. Even so, notching should be avoided, because it does substantially reduce the strength of the post. Here's why:

Many years of observation have proved that moisture cycles will typically cause cracks to develop and propagate, parallel to the grain, from the corner of the notch. This may not be apparent when the post is first installed, but it happens gradually over time.

According to the grading rules for lumber, a piece of 4x4 No. 2 southern pine can have a "slope of grain" of up to 1:8 (or 1 inch in 8 inches). If a 4x4 with a slope of grain of 1:8 is notched 1.75 inches deep, a crack propagated along the grain will reduce the 1.75-inch-thick section at the notch to only 3/4 inch at 8 inches above the corner of the notch — not something you'd want to bet your life on.

just as in a real deck. We secured the deck joists to the concrete floor of the lab, and attached a transducer to the joist near the post location to verify that the test assembly didn't move. We also attached a transducer to the post 37.5 inches above the joist to measure how much it deflected during the test.

Safety factor. The code requirement says that the post must be able to withstand a 200-pound load. But when a structural assembly is tested in a lab, the load gets multiplied by an appropriate safety factor, which is intended to allow for the uncertainties of field installation and the fact that the connections may degrade in service from repeated loading and weathering (but not rot).

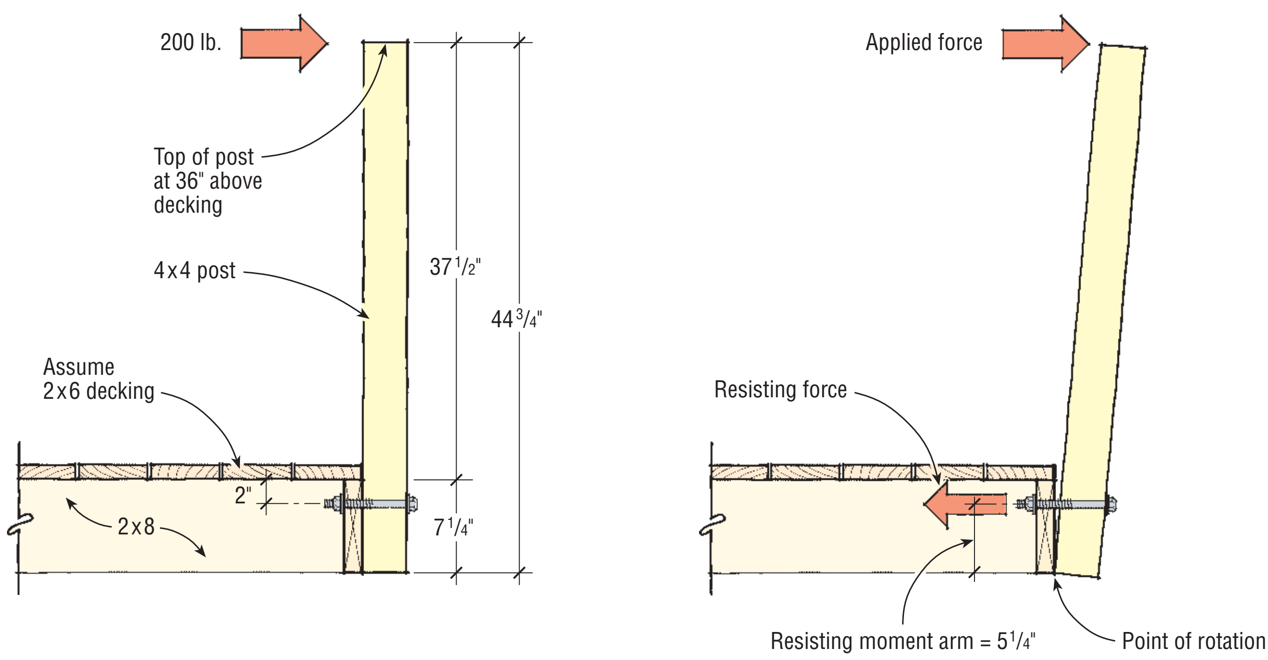
We used a safety factor of 2.5, a number that has been in the model codes for decades for testing structural assemblies. So, for our testing, we needed to apply a 500-pound load to determine whether the post connection could be considered "code-conforming."

Lumber grade and species. Because we were imitating local carpentry details, we used pressure-treated (ACQ or CA-B) 2x8 southern pine to simulate the joists and No. 2 southern pine 4x4 posts. Some of the tests included a PPT 5/4x6 radius-edge deck board attached to the joists and band joist. We bought the lumber in "wet" condition (moisture content greater than 19 percent) and kept it that way before the test so that we wouldn't have to apply an adjustment factor for "wet use" to our test data.

Test Results

We tested five samples each of the bolted and lag-screwed post connections shown in Figure 1. What became

Forces in a Typical Guardrail Post



Moment = force x distance
Applied moment = resisting moment

Applied moment = 200 lb. x 44.75 in.
= 8,950 inch-pounds at base of post

Resisting moment = ? lb. x 5.25 in.

(5.25 in. is the distance from bottom of joist to bolt centerline)

Resisting force = 8,950 inch-pounds / 5.25 in.

= 1,705 lb.

A guardrail post can behave like a lever: The force applied at the top gets multiplied by the length of the post — the lever arm — to produce a large moment, expressed in inch-pounds, at the base. The resisting force at the base, here represented by a single bolt, is also multiplied, but by a much shorter lever arm — 5 1/4 inches in this example. In the case shown here, representing a typical residential deck rail post 36 inches high, the bolt would have to provide nearly 2,000 pounds of resisting force. While the steel itself might be up to the task, the wood fibers under the washers would not be strong enough, as the authors' tests indicated.

obvious is that these standard details don't come close to meeting the code load requirement (Figure 2, page 3).

The lag-screwed connection failed at less than 200 pounds when the lags pulled out of the band joist. The bolted connections failed at an average load of 237 pounds — barely surpassing the code design load but with almost no safety factor for the service life of the deck. The bolted samples typically failed when the band joist peeled away from the deck joists, as the screws attaching the band to the joists pulled out. The screws holding the 5/4 deck

Figure 3. After testing the bolted and lagged connections, the authors tried reinforcing the post with blocking in a variety of configurations. Each configuration they tried failed when the blocking split along the grain.

Post Connections That Passed

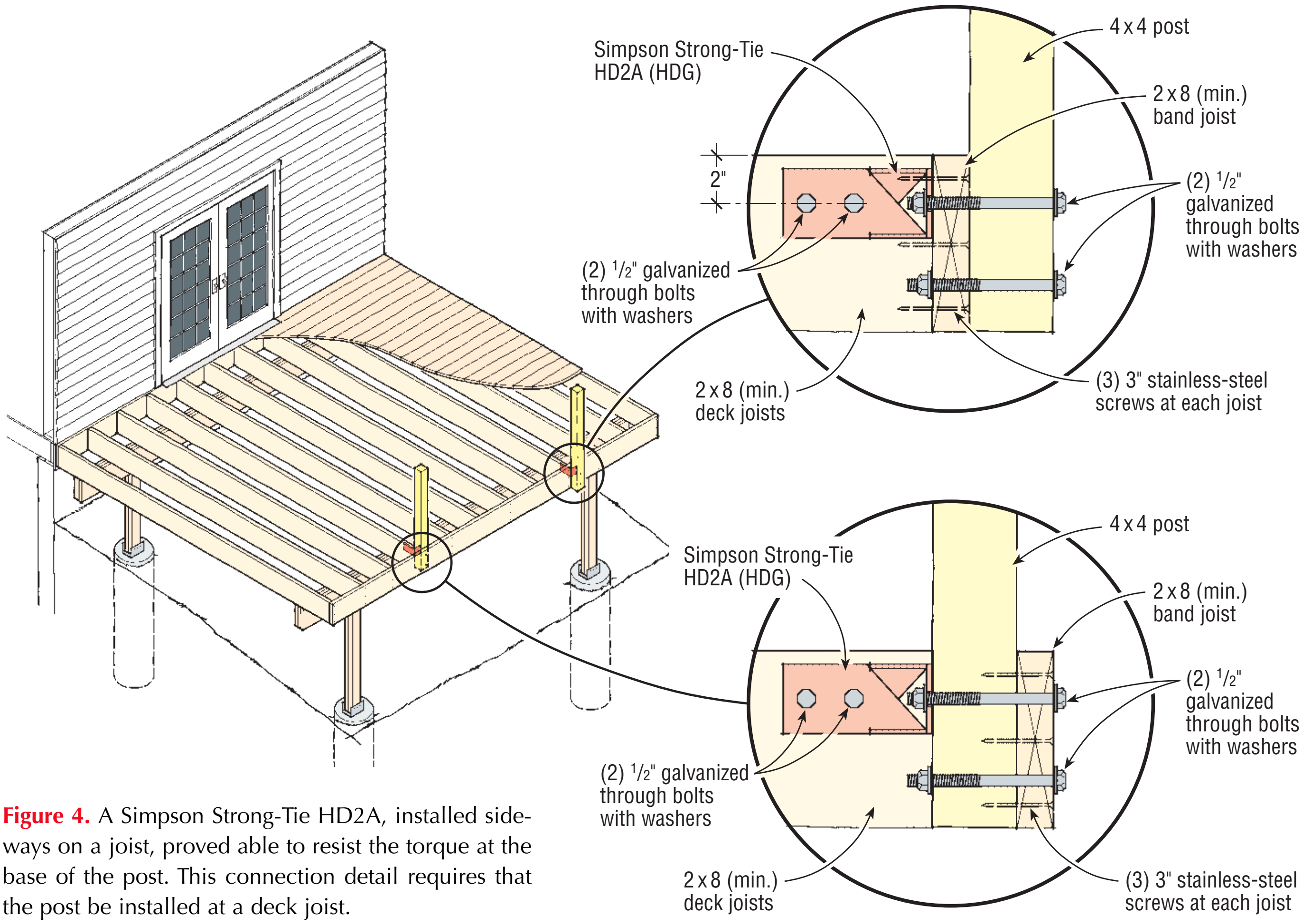


Figure 4. A Simpson Strong-Tie HD2A, installed sideways on a joist, proved able to resist the torque at the base of the post. This connection detail requires that the post be installed at a deck joist.

board to the joists and band joist failed early in the tests.

Once it was clear these two common details were inadequate, we tried various ways of blocking around the post, attempting to distribute the load over many lag screws to reach the 500-pound test load. These attempts typically failed when the lumber split under perpendicular-to-grain loading — the kind of load exerted when you split wood with an axe (Figure 3, previous page).

A Different Approach

As the testing progressed, we realized that the high forces at the base of the post were not going to be resisted by fasteners loaded in withdrawal or by blocking loaded perpendicular to the grain. What we needed was a way to arrange the bolts so that the load from the post to the joist would be transferred in shear (lateral loading), because bolted connections are very strong when handling lateral, or shearing, loads.

We turned to a commercial steel connector — a Simpson Strong-Tie HD2A — which is designed to resist wind and earthquake loads in shear walls. By orienting the connector sideways along the joist, we were able to use it to secure the post (Figure 4). We installed the HD2A with three 1/2-inch-diameter bolts: The two bolts in the joist are loaded in shear, while the third bolt, passing through the post, the band, and the connector itself, is loaded in tension. As part of the tested design, we also installed another 1/2-inch bolt in the lower part of the post and the band joist. We applied at least 650 pounds to the top of the post; every specimen successfully resisted the load.

We tested the connection two ways — with the post located inside the band and on the outside. We observed different types of failure for the two cases as the load increased up to the maximum of about 650 pounds (Figure 5, next page).

When the post was mounted inside the band, the washers under the bolt head embedded into the wide face of the 2x8 band joist. When the post was located outside the band, the bolt head and washer pulled well into the 4x4 post, crushing the wood fibers beneath the washer.

Figure 5. The authors tested the HD2A connection with the post installed both inside and outside the band joist; both configurations withstood the full test load. At 200 pounds, the sample post shown above deflected but the connection held; at 650 pounds, with the post still holding, the test was ended so as not to damage the test machine.

Test Results: HD2A Anchors

Post-to-Deck Connection Assembly	Average Test Load (lb.)	Range of Test Loads (lb.)	Average Deflection at 200 lb. (in.)	Average Test Load as Percentage of 500 lb.*
HD2A Anchor (4x4 post inside band)	645	593 to 687**	2	129%
HD2A Anchor (4x4 post outside band)	686	653 to 713**	1.9	137%

* Must be greater than 100 percent to be considered code-conforming
**Tests stopped to protect test equipment

We used only one Simpson HD2A per post, placing the centerline of the connector 2 inches below the top edge of the 2x8 joist. If you use this detail in the field, it's important to maintain this centerline distance, because it helps to limit the forces involved in the connection. If you place the HD2A lower, you're reducing the resisting lever arm, which extends from the bottom of the band joist to the centerline of the connector. Losing even an inch of this resisting lever arm would greatly increase the forces in the connector.

We used a hot-dipped galvanized (HDG) HD2A connector for our tests. Because of the corrosive nature of the new lumber treatments, this is the version that should be used in practice. The $^1/_2$-inch bolts, washers, and nuts should also be hot-dipped galvanized.

Limitations of Test Results

We didn't test the HD2A connector post-to-deck assembly in the inward loading mode — that of the tree falling against the railing. In our judgment, the assembly as tested would not carry a 500-pound inward force. However, we believe that the assembly would carry 500 pounds in either direction if you were to install two HD2A connectors per post, one 2 inches from the bottom of the 2x8 band joist and one 2 inches from the top.

Our test also applies only to the grade and species of lumber that we used. Keep in mind that southern pine is denser than most other common framing species (specific gravity [SG] = 0.55), which affects its ability to hold fasteners. Pressure-treated hem-fir is commonly available in the Western states, but because hem-fir is less dense (SG=0.43) than southern pine, the same connections made with hem-fir lumber would probably fail at a lower load.

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