Tested Guardrail Post Connections for Residential Decks

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Abstract

Both the *International Residential Code (IRC)* and *International Building Code (IBC)* (ICC 2003a and 2003b) specify a minimum concentrated live load of 200 pounds for both guardrails and handrails. The *IRC* does not give prescriptive guidance on how to select a guardrail post and connect the post to the deck substructure such that a 200-pound load requirement will be met. Commonly used residential guardrail post connections were tested in the laboratory, and they did not carry the required load level for a load tested code-conforming assembly per the *IBC* (ICC 2003b). A commercially available connector typically used in shear wall construction was tested as a post-to-deck residential guardrail assembly. The connection passed a 500-pound load test based on code provisions for a "tested assembly".

Introduction

Guardrails are intended to prevent occupants from accidentally falling off of a deck and onto the ground. If the deck floor is even a few feet high, serious injuries can result from a fall. Today, many decks are more than 8 feet above the ground and a fall from such a height can be deadly.

This article describes the test results from a research program conducted to evaluate guardrail post-to-deck connections being used in many areas of the United States and to test a new connection system that would likely be judged as "code conforming" by building officials for residential applications. It should be noted that only the "authority having jurisdiction" can approve a construction detail, thus throughout this paper, reference to a test assembly as being "code-conforming" refers to the fact that this test procedure is based on provisions of the current model building codes. Testing was limited to *residential* guardrails assumed to be 36 inches in height, and do not directly apply to guardrails in general that are required by code to be at least 42 inches in height (*IBC* Section 1012.2.).

The most recent *IRC* codes (ICC 2000 and 2003a) specify in Tables R301.4 and R301.5, respectively, a minimum concentrated live load of 200 pounds for both guardrails and handrails. Footnote "d" to *IRC* Table R301.4 and Table 301.5 (ICC 2000 and 2003a) defines application of the 200-pound load: "A single concentrated load applied in any direction at any point along the top." The evident question for professional designers, plan reviewers, and deck contractors is "how can the code requirement be accomplished?" The *IRC* does not give prescriptive guidance on how to select a guardrail post and connect the post to the deck substructure such that a 200-pound load requirement will be met.

A simple solution for contractors is to use a stress-rated and notch-free 4 by 4, or larger as required by engineering design, that serves as both the deck support column and guardrail post. For example, it can be demonstrated that a pressure preservative-treated (PPT) 4 by 4 No. 2 southern pine post extending 36 inches above the deck floor will safely support a 200-pound concentrated outward load at the top of the railing when the 4 by 4 is bolted to the deck joist support beams without notching, and the 4 by 4 continues in one piece to the footing. The element thus serves as a support column in addition to the guardrail post. The large "bending moment" produced at the base of the guard rail post by the 200-pound load is resisted "internally" by the 4 by 4. However, in many cases, a design professional or deck designer is faced with a guardrail post spacing that does not match the spacing for the columns that support the overall deck structure.

Numerous plastic and wood/natural fiber-plastic composite (WPC) guardrail systems rely on wood 4 by 4s for structural support. The plastic manufacturers, and their building code reports (www.icc-es.org/Evaluation_Reports/index.shtml), typically limit the span of the top rail to about 6 feet. Thus, to utilize the "simple solution" to guardrail post design using one continuous piece of lumber (4 by 4) from the footer to the top rail, the deck support posts would need to match the on-center (o.c.) requirement of the plastic or WPC guardrail system. Some deck designers and owners may find the relatively close deck column spacing as being aesthetically unacceptable, thus the "simple solution" may not be desirable or accepted by the owner.

A guardrail is a system of components connected together and fastened to the deck. The system includes the posts, rails, pickets, and connections between the various parts and deck framing. This paper focuses on the connection between the post and the deck for the case when the guardrail is attached to the band joist on the ends of the joists. **Figure 1** shows two load cases that must be safely resisted by the post and the post connection to the deck structure. The horizontal load could be caused by people leaning against the top rail or by someone falling into the guardrail assembly. The vertical load could be caused by a person sitting on the top rail. In both cases, the force must be transferred from the top rail to the post, and from the post to the connection of the post to the deck substructure.

The vertical load depicted in **Figure 1** produces shear forces in the post-to-deck connection, and this force is relatively easy to resist by 1/2-inch lag screw or bolted connections. The horizontal load, however, is very difficult to accommodate in design because of the lever arm effect. The 200-pound load applied at the top of the post can easily produce several thousand pounds of load at the base of the post that must be carried by the connection.

For the tests described in this article, a horizontal load was applied to the top of the post in the outward and horizontal direction. The load was applied in the horizontal direction because it produces the maximum bending moment and resulting forces in the connection below. In other words, the "worst case scenario" was tested in anticipation that a person could accidentally fall into the guardrail producing a resultant force that is perpendicular to the post. Based on the code language, it is impossible to prove a detail by test when "a single concentrated load" is "applied in any direction" as any direction could mean any angle (0 to 360 degrees). The use of the word "any" includes the cases where the load is applied inward, toward the center of the deck floor, hereafter referred to as the "inward load case". An example of inward loading on a guardrail (or guardrail post) might be the unlikely case that a tree would fall against the guardrail, collapsing the railing, and continue to fall into the residential unit. The inward loading case was not evaluated in this testing program, and this limitation will be discussed in the conclusions to this article.

For each specimen tested, the maximum load each connection configuration could carry before it failed was measured. The deflection of the post at 36 inches above the simulated decking surface was also measured even though the building codes do not specify a deflection limit for this specific application. Based on observing numerous tests, the outward movement of the top of the post under load without breaking (ductility) is considered a positive attribute because it is likely to give warning to occupants that they may be overloading the assembly. Deflection limits are not believed to be necessary for traditional guardrail systems that are totally solid wood; however, it should be noted that the deflection of plastic and WPC guardrail systems is limited by provisions of AC174 (ICC Evaluation Service, Inc., 2005).

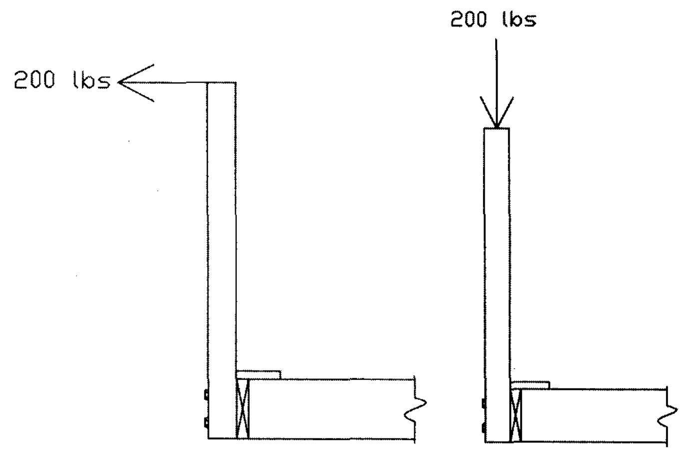

Figure 1.—The *IRC* (ICC 2000 and 2003) require "guardrails and handrails" to be designed to support a minimum single concentrated load of 200 pounds "...in any direction at any point along the top."

Guardrail Post-to-Deck Test Assembly

Requirements set by the *IRC* (ICC 2000 and 2003a) were used to define the basic geometry for the test program. The railing was set at 36 inches above the deck surface in conformance with the minimum height specified 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.

Target Test Load for Passing the Test

Because the building code minimum design load requirement is 200 pounds, a code-conforming post connection design, when tested in a laboratory, must be able to carry 200 pounds times an appropriate "safety factor". The safety factor of a design is intended to "protect" the stated design requirement when realizing that actual field installations are not perfect as constructed in a laboratory test, that the connection can degrade in-service due to repeated loads and weathering, and that some in-service loads may exceed the design load.[1]

The deck post, joists, and band joists test assembly was considered to be a "proposed construction" that is "not capable of being designed by approved engineering analysis" as described in Section 1712.1 of the *IBC* (ICC 2003b). Per *IBC* Section 1712.1, the "structural unit and connections" shall be tested as indicated in Section 1714. Section 1714 utilizes a safety factor of 2.5, a number that has been in the model codes for decades for testing structural assemblies. Therefore, in this testing program, a guardrail post-to-deck

[1] The safety factor in this application is not intended to account for (biological) decay of the wood components. If decay is detected in a post-to-deck connection assembly, the element should be immediately replaced with new PPT materials.

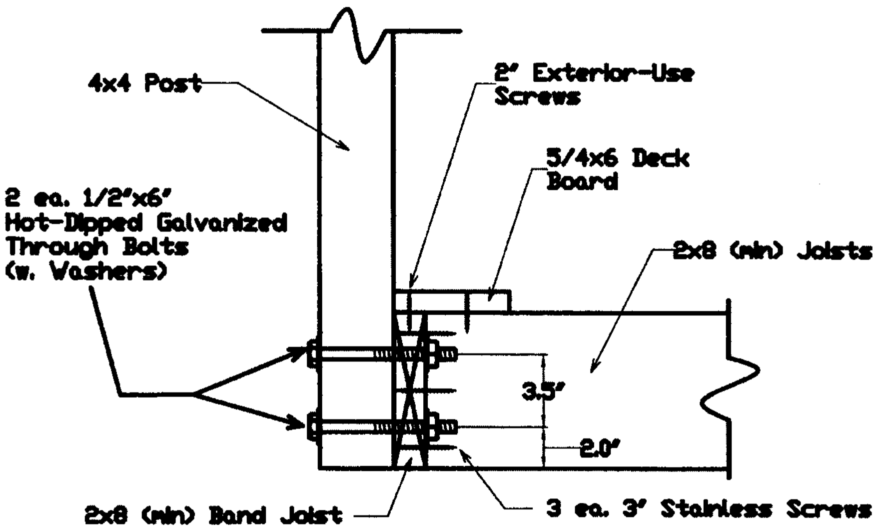

Figure 2.—This guardrail post detail "looks" very strong as it utilizes two 1/2- by 6-inch bolts, yet in a series of tests, the average failure load was only 47% of the test load requirement for a code-conforming design.

connection assembly was considered to be "code conforming" if the average test load for a design exceeded 500 pounds.

Materials

For this testing program, we used PPT (alkaline copper quaternary [ACQ] or copper azole type B [CA-B]) 2 by 8 southern pine simulated deck and band joists and 4 by 4 No. 2 southern pine posts. Some of the tests included a PPT 5/4 by 6 radius-edge-deck board attached to the joists and band joist. The lumber, both joists and posts, were purchased and kept "wet" before the assembly test so that a connection adjustment factor for "wet-use" would not have to be applied to the test data. Deck guardrail assemblies probably cycle at least once between wet (moisture content [MC] greater than 19%) and dry (MC less than 19%) conditions in-service. Therefore, these tests were conducted with wet PPT lumber.

The research program began with tests of commonly used post-to-deck connection configurations in Southwestern Virginia, including bolts, lag screws, notched and unnotched posts, and blocking attached in various configurations between the joists and band joist. None of these designs reached the target test load of 500 pounds needed to claim a code-conforming connection assembly.

Tests and Failure Modes

Five specimens of each configuration were tested. Two details were tested using 1/2-inch lag screws or 1/2-inch bolts as depicted in **Figure 3**. Both details relied on 2-inch decking screws and three 3-inch stainless steel screws to connect the band joist to the joists. Southern pine 5/4 deck boards were included in the tests to be representative of what contractors may be using in the field; however, it should be noted that relying on decking screws to stabilize a rail post connected to a band joist is an unreliable practice as the deck board may be replaced with deck boards and fasteners significantly weaker than what was tested.

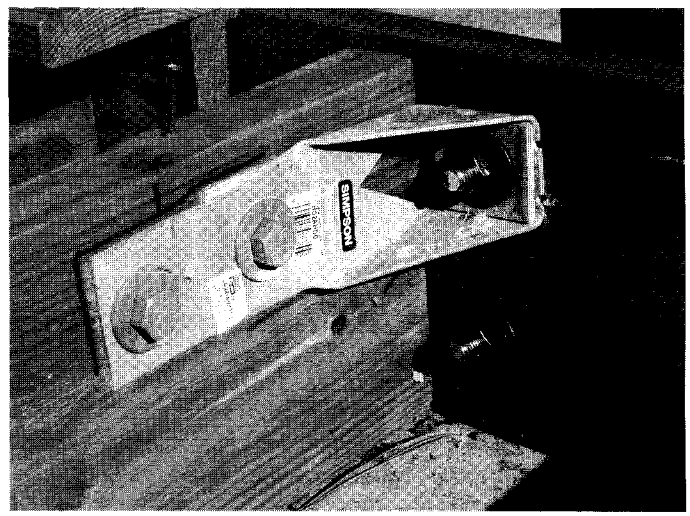

Figure 3.—Simpson Strong-Tie™ HD2A connector used to test an assembly with the post inside band joist (shown) and outside band joist.

1/2-inch Lag Screws or Bolts Did Not Pass the Test

The lag screw connection detail failed by withdrawal of the threaded portion from the band joist at an average ultimate load of 178 pounds. The first row of **Table 1** gives a summary of test results for the lag screw case. Deflection at the design load of 200 pounds was not recorded and reported because the assemblies, on average, failed before reaching 200 pounds. The average test load was only 35 percent of the requirement for a load tested assembly.

For the bolted deck rail post assembly shown in **Figure 3**, the connections failed at an average load of 237 pounds – barely surpassing the code required design load with almost no safety factor for the service life of the assembly. Referring to the second row of **Table 1**, the top of the post deflected, on average, 4.4 inches at 200 pounds of applied load. The average test load was only 47 percent of the test load requirement for a code-conforming design. The bolted con-

Table 1.—Summary of guardrail post-to-deck-connection testing results for four residential rail-post-assemblies involving PPT 2 by 8 No. 2 southern pine joists and 4 by 4 No. 2 southern pine posts.

Guardrail post-to-deck connection assembly	Average test load	Average deflection at 200 lb	Average test load[a] as percent of 500 lb	Meet building code test criteria?
	(lb)	(in.)	(%)	
1/2-inch lag screws	178	na	35	No
1/2-inch bolts	237	4.4	47	No
HD2A anchor (4 by 4 post inside band)	645	2.0	129	Yes
HD2A anchor (4 by 4 post outside band)	686	1.9	137	Yes

[a] The average test load for an assembly as a percent of the 500-pound test load requirement must be greater than 100% to be considered a "test proven assembly" by the authority having jurisdiction for an actual construction.

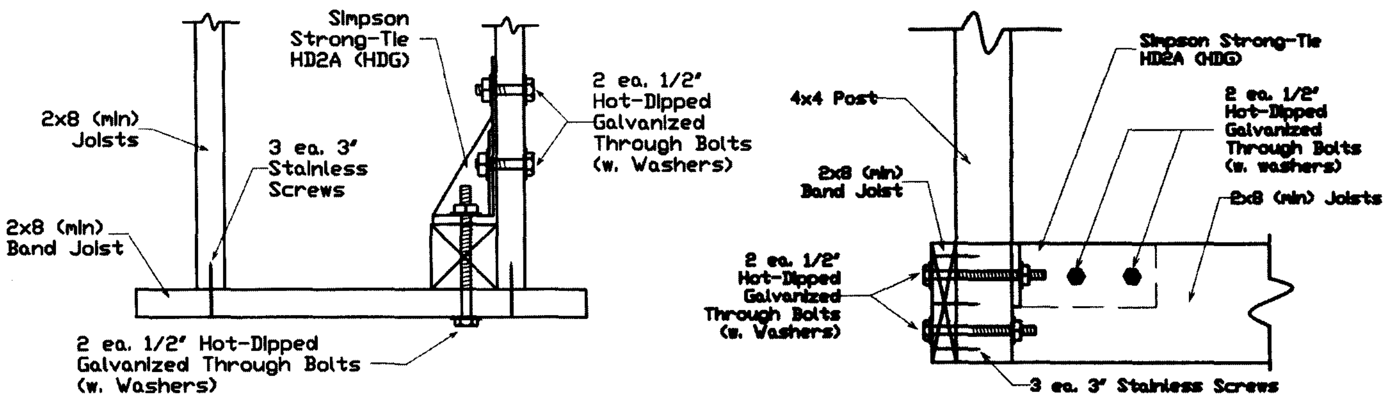

Figure 4.—Guardrail post test assembly details for 4 by 4 southern pine posts inside of band joist.

nections typically failed when the band joist "peeled" away from the deck joists as the screws that attached the band to the joists pulled out, or failed in withdrawal mode.

Other Designs Failed to Pass the Test

A variety of designs involving the use of 2 by 8 southern pine blocking that were "lag screwed" to the joists, and had bolts installed through the band, the post, and the blocking, were tested over a 3-month period. None of these designs met the required test load because the lumber components typically failed in tension perpendicular-to-grain due to extreme bearing stresses produce by the fasteners.

Some configurations included notched 4 by 4 posts attached with bolts to the band joist. Although none of the 4 by 4 laboratory test posts failed at the notch, notching reduces the strength of the post significantly and guardrail posts should not be notched. Repeated in-service moisture cycles typically cause cracks to develop and propagate from the corner of the notch along the slope-of-grain. Thus, notches in a guardrail post, coupled with "grade permitted" slope-of-grain and moisture cycles, can produce a very weak guardrail post during the service life of the deck.

A Detail that Passed the Tests

As the testing program progressed, failure modes were analyzed to develop a better understanding of the high level of forces involved in the connection *at the base of the post.* Because all of the specimens failed by withdrawal of screws between the band and the joists, splitting of wood perpendicular-to-grain, screw head pull-through, or bending of the screws, it was realized that a successful design had to utilize bolts arranged in a way that they can transfer load from the post to the joist in shear (lateral loading) because bolted connections are very strong when resisting lateral or shearing type loads. Therefore, a connection design was sought that loaded bolts in lateral or shear mode. A commercial steel connector[2] (shown in **Fig. 3**) was identified that is typically used to resist wind and earthquake loads in shear walls, but could also be used to attach a guardrail post to a deck joist. In this deck application, these connectors utilize three 1/2-inch diameter bolts: two bolts are installed in the joist and are loaded in shear, and the third 1/2-inch bolt passes through the post, the band, and the connector itself. The third bolt is loaded in tension. These designs are depicted in **Figures 4 and 5**. In each case, another 1/2-inch bolt is installed in the lower part of the post and the band joist.

[2] Another commercially available connector, DeckLok, has been tested in the guardrail post application using a testing protocol similar to the testing research at Virginia Tech. The report is available at www.mtdecklok.com.

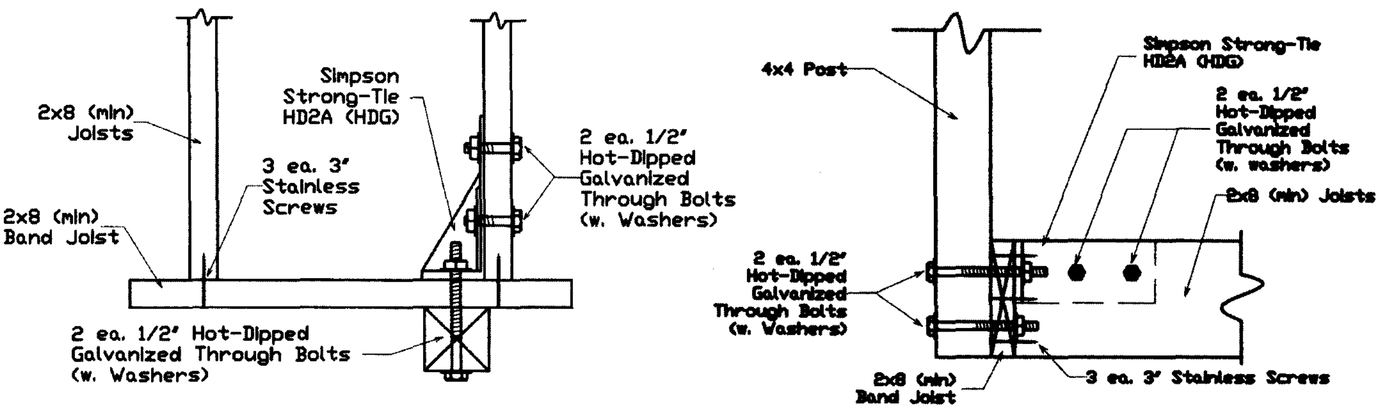

Figure 5.—Guardrail post test assembly details for 4 by 4 southern pine posts outside of band joist.

Only one Simpson StrongTie™ HD2A connector was used per post and the centerline of the connector was positioned 2 inches below the top edge of the 2 by 8 joist. Maintaining this dimension in the field is *extremely* important because it severely impacts the forces involved in the connection. In no case should the centerline of the HD2A be more than 2 inches from the top of the joist. A hot-dipped galvanized (HDG) HD2A connector was "special ordered" for these tests, and as a minimum, only the HDG version of the connector should be used in construction due to the corrosion potential with new lumber treatments.

Two Details Tested – Post Inside Band and Post Outside Band

Two joint configurations with five replications of each were tested: one with the post located inside the band as shown in **Figure 4**, and the other with the post located outside the band joist as shown in **Figure 5**. The flexibility in locating the post inside or outside of the band may be desirable or required for hollow plastic or WPC guardrail posts that slide over a solid-sawn 4 by 4 post and rely on the 4 by 4 for structural integrity. During testing, at least 650 pounds was applied to the top of the post and every specimen successfully survived this load. The test results are presented in the last two rows of **Table 1**. Note that the average test loads achieved were in excess of the 500-pound test load requirement necessary for a code-conforming tested assembly. In fact, specimens were not able to be tested to failure without potentially damaging test equipment.

Figure 6 depicts a typical maximum deflection during one test for the case of "post outside the band joist". From **Table 1**, the average deflection at the 200-pound design load at 37.5 inches above the simulated deck joists was 2.0 inches and 1.9 inches for the "inside" and "outside" details, respectively. Different failure mechanisms were observed for the two cases as the load increased up to the maximum of about 650 pounds. When the post was mounted inside the band, the washers under the bolt head embedded into the wide face of the 2 by 8 band joist indicating the role of the compression-perpendicular-to-grain strength of the band joist. When the post was located outside of the band, the bolt head and washer pulled well into the 4 by 4 post, crushing the wood fibers beneath the washer. Thus, for the post-outside-band case, the compression-perpendicular-to-grain strength of the 4 by 4 post was a factor in achieving the 500-pound test load requirement. Due to the role of compression-perpendicular-to-grain lumber strength in the tests, results for southern pine (G = 0.55) may not directly apply to other lower density species of guardrail posts used for deck construction in the United States.

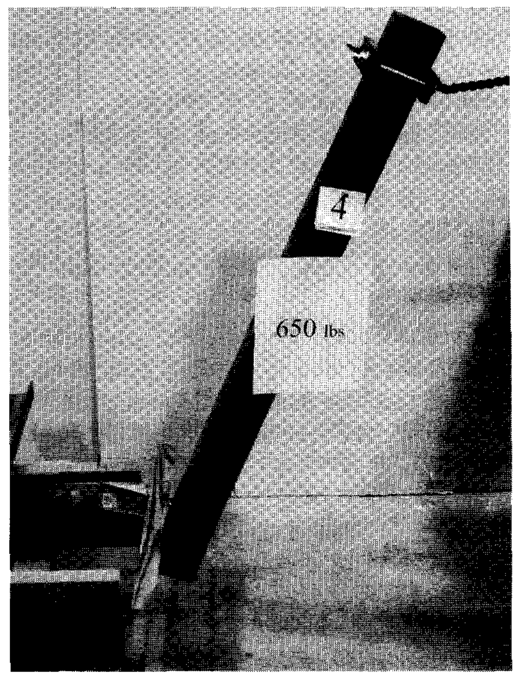

Figure 6.—Outside band joist specimen loaded with 650 pounds. The specimens exhibited extreme "ductility", and this test characteristic is considered a desirable safety feature.

Inward Load Case Not Tested

In this testing program, only one HD2A connector was used per post and the centerline of the connector was positioned 2 inches below the top edge of the 2 by 8 joist. It is possible that the guardrail post could be heavily loaded in the inward load direction, as by a falling tree. The HD2A connector post-to-deck assembly in the inward loading mode was not tested, and based on judgment, the assembly would not carry 500 pounds inward. However, it is believed that the assembly would carry 500 pounds in either direction by installing two HD2A connectors per post, one 2 inches from the bottom of the 2 by 8 band joist and one a 2 inches from the top of the 2 by 8 joist. The contractor, professional designer, and property owner should consider the option of using two HD2A connectors to achieve a 500-pound test load capacity in both directions – outward and inward.

Summary and Conclusions

A load tested post-to-deck-connection design is very difficult to achieve because of the high forces involved from the "lever action" of the post (with top rail) that extends 36 inches above the decking. Commonly used residential guardrail post connections were tested and found not capable of carrying test load levels that include a 2.5 safety factor, adopted from the *IBC* (ICC 2003b). As reported in **Table 1**, two guardrail post connection details utilizing 1/2-inch bolts or lag screws provided less than 50 percent of the test load that is expected for a load-tested code-conforming assembly.

A commercially available connector (HD2A) used to construct a post-to-deck guardrail assembly was evaluated, and it passed a load test based on building code provisions for a "tested assembly". The test results apply only to 4 by 4 (or larger) PPT No. 2 southern pine posts located at the end of 2 by 8 (or larger) PPT southern pine joists and attached to the band joist as shown in **Figures 4 and 5**. It is extremely important for designers to:

- specify as a minimum level of protection against connector corrosion due to PPT lumber (wet service), the hot-dipped galvanized (HDG) version (special order) of the HD2A connector,
- specify 2 by 8 (minimum) PPT southern pine joists, and
- detail the HD2A connection such that the centerline of the connector is no more than 2 inches from the top of the joist.

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