

# Design and Testing of Residential Deck Guard Rail Connections

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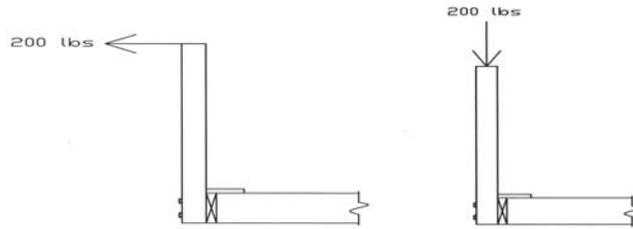
## Summary

Recent experiments to measure the strength and stiffness of wood guardrail post-to-deck connections show that commonly used connection designs do not meet the load requirements specified in the International Residential Code™ (IRC) [1, 2]. The experiments included connections with bolts, lag screws, and wood cleats to determine the connection load capacity. A concentrated design load of 890 N (200 lbs.) multiplied by a safety factor of 2.5 must be resisted by the guard rail system to meet building code requirements. The rail system should be capable of resisting the load, applied in any direction, at the top of the post and located 0.9 m, (36-inches) above the deck surface. A design solution is presented that can be used to construct a residential guardrail post-to-deck connection that can safely carry the required code load.

## 1. Introduction

Guardrails are intended to keep people from falling off a deck and onto the ground. Surprisingly, wooden guardrail systems have been used for decades and have not been previously tested to determine their safe load capacity. Each year in the USA, people are injured or killed from falls when guardrails fail. This paper presents the results of experiments to test the load capacity of various connection configurations for deck guardrails and to develop a safe connection design. Even if the deck is only one meter high, serious injuries can result from a fall. Today, many decks are 2+ meters above the ground and a fall from such a height can be deadly. This paper describes some results from a research program that we conducted to improve the safety of the guardrail system.

The International Residential building code [1, 2] states that deck guardrails must be designed to resist 890 N (200 lbs.) of load applied in any direction. The evident question for designers and builders is “how is this accomplished?” A guardrail is a system of components connected together and fastened to the deck. The system includes the posts, the rails, and pickets. 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 example loads that must be resisted by the post and therefore the post-to-deck connection. It shows a vertical load that might be caused by a person sitting on the top rail. The horizontal load is caused by people leaning against the rail or the post. In both cases, the force must be transferred from the rail- to the post- to the deck connection at the bottom of the post.



*Figure 1 Vertical and horizontal loads applied to the top of post (890 N=200 lbs)*

The vertical loads produce a shear force in the post-to-deck connection, and this force is relatively easy to resist because bolt or screw connections are very strong in shear. The horizontal loads however, are very difficult to resist because of the lever arm effect. The 890 N load applied at the top of the post produces thousands Newtons at the base of the post that must be resisted by the connection. The famous Greek scientist Archimedes once said “give me a long enough lever and a fulcrum point and I can move the world”. This same concept is the problem we face when trying to design a post-to-deck connection. For the tests described in this paper we applied a horizontal load to the top of the post and measured the maximum force each connection design could resist. We also measured the deflection of the post even though the building code does not specify any requirements for post deflection.

## **2. Test Methods and Materials**

### **2.1 Test arrangement**

We used the requirements set by the IRC (2000, 2003) to define the basic geometry for our test program. We assumed that the railing was 914 mm above the deck surface as specified by IRC and that the deck boards are 38.1 mm thick. This means that the horizontal load is applied to the post 952.5 mm above the top of the joist. We built a test frame for our Universal testing machine that is shown in Figures 2 and 3. The test set-up has a roller chain attached to the load cell of the machine and a pulley to redirect the force from the vertical motion of the machine to a horizontal force that is applied to the top of the post. The post is attached to a simulated deck system that includes two joists and a band joist with the post attached to the band joist, just as in a real deck. The deck system is firmly attached to the concrete floor of the laboratory so it cannot move during a test. We attached a transducer to the deck system to measure any motion just to verify that the deck was indeed rigidly attached to the floor. We also attached a transducer to the post to measure how much it deflected during a test.

Because the building code design load is 890 N, an acceptable post connection must be able to carry 2.22 kN in a test to incorporate a safety factor of 2.5.



*Figure 2 Test set-up for rail posts showing roller chain and pulley to redirect force from test machine to top of post*



*Figure 3 Test set-up showing close-up of loading*

## **2.2 Materials**

For this testing program, we used pressure treated (ACQ or CAB) Southern pine 50 by 200 mm (2 by 8 in.) joists and 100 by 100 mm (4 by 4 in.) posts. Some of the tests included a 50 by 152 mm (2 by 6 in.) deck board attached to the joists and band joist. All the wood specimens were kept wet before the test so that we would not have to apply an adjustment factor for wet-use since deck guardrails in-service may be expected to have high moisture content.

## **2.2 Connection configurations**

The testing program included commonly used post-to-deck connection configurations, such as bolts, lag screws, notched and un-notched posts, and wood cleats, attached in various configurations between the joists and band joist. None of these designs could resist the design load and the safety factor of 2.22 kN. The failure modes were interesting to observe. Lag screws connections failed in withdrawal of the threaded portion from the band joist at average load of 791 N. When the lag screw connections failed the post completely pulled away from the deck system often with no audible warning. Therefore we consider lag screws inadequate for attaching posts to decks.

For joints where the post is bolted to the band joist, the connections failed at an average load of 1 kN—barely surpassing the design load but with virtually no safety factor in the event of an overload. The bolted connections typically failed when the band joist “peeled” away from the deck joists as the screws that attached the band to the joists failed in withdrawal (Figure 5). We tested specimens with deck boards screwed to both the band joist and the deck joists in hope of increasing the failure loads. However, the screws failed early in the test and did not provide increased load resistance. Figures 4 and 5 show a typical failure of a specimen.



*Figure 4 Specimen with deck board and post*



*Figure 5 Failure of screws in withdrawal from joists*

We tested a variety of designs involving wood cleats that were lag screwed to the joists, and had bolts installed through the band, the post and the cleat as shown in Figures 6 and 7. The idea was to distribute the load over many fasteners and hopefully achieve the 2.22 kN load level. However, these designs did not withstand the required load because the wood failed in tension perpendicular to the grain in the cleat as shown in Figure 7.



*Figure 6 Wood cleats did not work*



*Figure 7 Splitting perpendicular to the grain in the wood cleats*

Some of the 100 by 100 mm post tests included notched posts attached with bolts. Notching reduces the strength of the post significantly and posts should not be notched. In-service, repeated moisture cycling causes cracks to develop from the notch. We tested a notched 50X100 mm post and it failed by splitting at the notch with only 550 N.

### **3. Connection Solution**

As the testing program progressed, we analyzed the failure modes and we developed a better understanding of the high level of forces involved in the connection at the base of the post. Because all the specimens failed by withdrawal of screws between the band and the joists, splitting of wood perpendicular to the grain, screw head pull-through, or bending of the screws, we realized that a successful design had to utilize bolts that are arranged to transfer the load from the post to the joist in shear (lateral loading) because bolted connections are very strong when

resisting lateral forces. Therefore, we sought to design a connection that stressed the bolts in the lateral loading.

We identified commercial steel connector plates that are designed for earthquake resistance in shear walls but could also be used to attach the post to the deck joists as shown in Figures 8 and 9. These connectors use three 12.7 mm (1/2 in.) diameter bolts: two bolts are installed in the joist and are loaded in shear, and the third 12.7 mm (1/2 in.) bolt passes through the post, the band, and the connector itself. This third bolt is loaded in tension. Figure 10 shows front and side views of the connection.



Figure 8 Connector holding post to joist with bolts



Figure 9 Another view of connection showing post located “outside” the band joist

The design uses a fourth bolt through the lower part of the post and the band to prevent rotation of the post. Only one connector is used per post and it is located 50.8 mm (2 in.) below the top edge of the joist to provide proper edge distance for the bolts. We purchased hot dipped galvanized Simpson Strong-Tie HD2A hold-down connectors and installed them as shown in Figures 8 to 10.

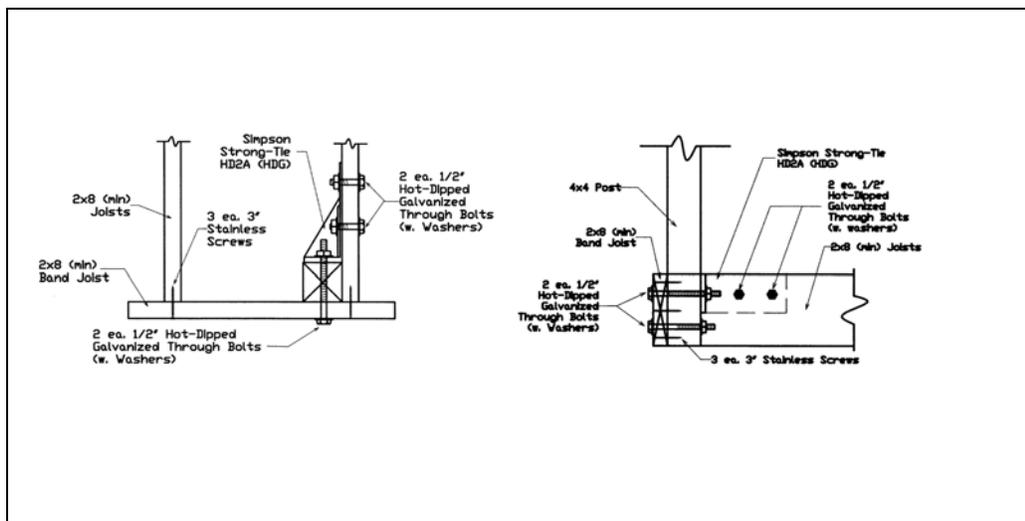


Figure 10 Schematic drawing showing top and side views of the post connection that passed the minimum load requirement

Figure 11 shows the post loaded at the design load and the relatively small amount of deflection of the post. Figure 12 shows the same post loaded at the 2.5 times the design load, and even with the large amount of deflection the connection is still capable of carrying additional load.



*Figure 11 The post loaded with the design load of 0.889 kN*



*Figure 12 The post loaded with 2.5 safety factor of 2.22 kN*

Using the connectors, we tested two joint configurations with five replications of each as follows: one with the post located inside the band as shown in Figure 10, and the other with the post located outside the band joist as shown in Figures 9, 11 and 12. These configurations provide flexibility in locating the post. We observed different failure modes for the two cases. When mounted inside the band, the washers under the bolt head embedded into the surface of the band joist and produced a stiff joint. When the post is located outside the band, the bolt head and washer pulled into the post and this produced more deflection at the top of the post.

Table 1 contains some data for the specimens we tested. The table includes the average test load at failure, the deflection of the top of the post at the design load, the average test load as a percent of the design load times the safety factor, and a decision if the connection meets the building code criteria for a tested assembly. Five replications of each connection configuration in Table 1 were tested.

*Table 1. Summary of guardrail post-to-deck-connection testing results for four residential rail-post-assemblies involving PPT 2x8 No. 2 Southern Pine joists and 4x4 No. 2 Southern Pine posts.*

Guardrail Post-to-Deck Connection Assembly	Average Test Load kN(lbs.)	Average Deflection at 0.89 kN (200 lbs.) mm(in.)	Average Test Load* as Percent of 2.22 kN (500 lbs.)	Meet Building Code Test Criteria?
12.7mm (½-inch) Lag screws	0.79(178)	NA	35%	No
12.7mm (½-inch) Bolts	1.05(237)	112(4.4)	47%	No
HD2A Anchor (4x4 post inside band)	2.87(645)	50.8(2.0)	129%	Yes
HD2A Anchor (4x4 post outside band)	3.05(686)	48.3(1.9)	137%	Yes

#### 4. Summary and Conclusions

The design of a code conforming guard rail post connection is difficult because of the high forces involved. The magnification of the horizontal force applied at the top of a post produces thousands of N’s of load at the base of the post that must be resisted by the connection. We tested many commonly used post connections and found that they cannot carry the required loads. We evaluated a commercially available connector (HD2A) and used it to construct a post-to-deck guardrail assembly that passed a load test based on building code provisions for a “tested assembly.” The test results apply only to 100 by 100 mm (4 by 4 in.) (or larger) PPT No. 2 Southern Pine posts located at the end of the 50 by 200 mm (2 by 8 in.) (or larger) PPT Southern Pine joists and attached to the band joist as shown in Figures 7, 8, and 9. It is extremely important for designers to:

- Specify the hot dipped galvanized (HDG) version (special order) of the HD2A connector, as a *minimum* level of protection against connector corrosion due to PPT lumber (wet-service), (caution, for decks subject to salt spray, stainless steel connectors and fasteners should be used)
- Specify 50 by 200 mm (2 by 8 in., minimum) PPT southern pine joists, and

- Detail the HD2A connection such that the centerline of the connector is no more than 50.8mm (2-inches) from the top of the joist.

## **5. References**

[1] International Code Council, Inc.(ICC). 2000. International Residential Code (IRC) for One- and Two-Family Dwellings. ICC, 4051 West Flossmoor Road, Country Club Hills, IL 60478-5795.

[2] International Code Council, Inc.(ICC). 2003a. International Residential Code (IRC) for One- and Two-Family Dwellings. ICC, 4051 West Flossmoor Road, Country Club Hills, IL 60478-5795.