Residential Deck Ledger Connection Testing and Design

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Introduction

Over the past decade, there have been numerous reports of deck, balcony, and porch failures, often resulting in injury and/or loss of life. During "deck season", about one collapse per week is reported in the news media. The primary causes for collapse are: 1) deficient connections between the deck ledger and the band joist and related decay and 2) deficient guardrail systems and related decay and corrosion of fasteners. The deck ledger connection problem is exacerbated by lack of structural redundancy, that is, when the ledger to band joist connection fails, the deck typically collapses catastrophically. In this article, ultimate load tests of hem-fir deck ledger connections are reported. The hem-fir ledger results are combined with southern pine deck ledger tests to yield one table containing on-center (o.c.) spacing of 1/2-inch fasteners for connecting ledgers to band joists.

Background

The *2003 International Residential Code (IRC)* specifies live loads of 40 psf and 60 psf for decks and balconies, respectively. The only *IRC* coverage on deck ledger connections is in Section R502.2.1 which states:

> "Where supported by attachment to an exterior wall, decks shall be positively anchored to the primary structure and designed for both vertical and lateral loads as applicable. Such attachment shall not be accomplished by the use of toe-nails or nails subject to withdrawal."

According to this, nails alone can not be used to connect a ledger to a band joist when no other lateral bracing system is in place to positively anchor the deck to the building against lateral loads. Thus, in the absence of a lateral bracing system installed on the deck, lag screws or bolts, or other "positive connection" devices, are required to design and construct a code-conforming deck.

Commonly accepted means of connecting deck ledgers to band joists are beyond the scope of the *2005 National Design Specification® for Wood Construction (NDS®)*. Specifically, *NDS* requirements for direct contact between members is violated (when ledger and band joist are separated by wall sheathing) for bolts and lag screws, and the minimum penetration depth of four diameters (4D) is not met when using 1/2-inch lag screws because a solid-sawn band joist is only 1-1/2 inches thick. Tabulated values for lag screws in the *NDS* are based on the assumption of 8D penetration, or 4 inches for a 1/2-inch lag screw.

Due to unique requirements of deck ledgers, a design alternative was needed. In cases where "a construction is not capable of being designed by approved engineering analysis" or "does not comply with applicable material design standards," the *International Building Code (IBC)* allows for testing to derive design values. Therefore, connections were tested to simulate the deck ledger attachment to a typical band joist used in residential construction.

Deck Ledger Connection Testing

Three connection details were tested as illustrated in **Figure 1**:

- 1/2-inch diameter lag screw with 15/32-inch wall sheathing between the ledger and band joist,
- 1/2-inch diameter bolt with 15/32-inch wall sheathing between the ledger and band joist, and
- 1/2-inch diameter bolt with 15/32-inch wall sheathing and 1/2-inch stack of washers (for drainage) between the ledger and wall sheathing.

Two types of band joist materials were used: 2 by 10 spruce-pine-fir (SPF) lumber and 1-inch-thick Douglas-fir (DF) laminated veneer lumber (LVL) rimboard. SPF has a relatively low specific gravity of G = 0.42, so other denser species groupings (e.g., hem-fir, Douglas-fir-larch, and southern pine) can be conservatively substituted in actual construction. Similarly, the 1-inch-thick rim board is the minimum thickness that is currently sold in the marketplace. Thicker composite rimboard products with equivalent specific gravities of 0.50 or greater (such as southern pine) can be conservatively substituted for the LVL band joist material tested.

Material for the deck ledger was pressure preservative-treated (PPT) southern pine and incised, PPT hem-fir (HF). Both the PPT southern pine and hem-fir were treated to a retention level of 0.40 lb/ft^3 of alkaline copper quaternary (ACQ) (ground contact), and the PPT Hem-fir was incised. These represent the most common species groupings

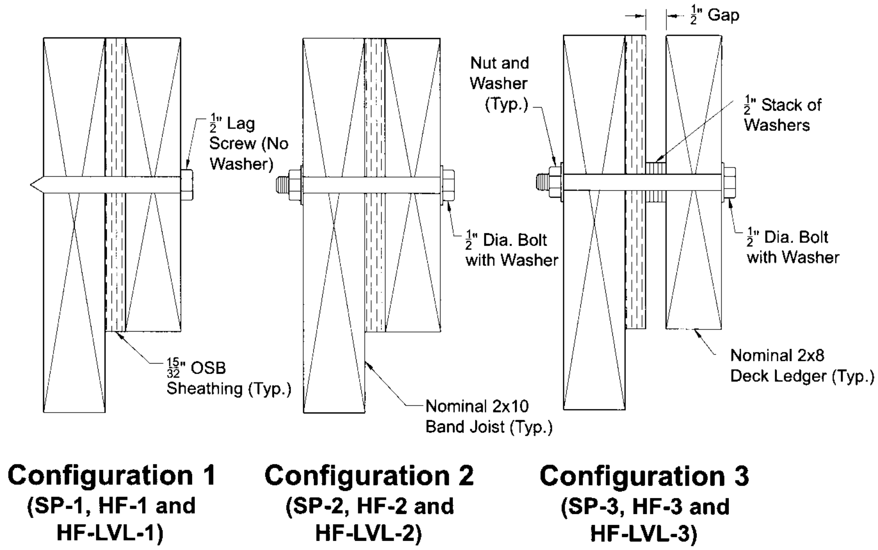

Figure 1.—Ledger to band joist connection configurations tested at Washington State University (WSU).

for PPT lumber, and other species with specific gravities greater than hem-fir (G = 0.43) can be conservatively substituted, provided that they are adequately treated to resist decay. The PPT southern pine and incised hem-fir ledgers were tested in the wet condition to represent a worst case condition in the field.

As specified in the *NDS* (AF&PA 2005), 3/8-inch diameter lead holes were drilled in the band joists and 1/2-inch diameter clearance holes were drilled through the deck ledgers and oriented strandboard (OSB) sheathing prior to assembling the lag screwed specimens. For the bolted specimens, 9/16-inch diameter clearance holes were drilled through the band joists, OSB, and deck ledgers.

Table 1.—Descriptions of 2 by 8 incised PPT HF ledger to band joist (either 2 by 10 SPF or 1- by 9-1/2-inch DF LVL) connection test specimens at WSU. All fasteners were hot-dipped galvanized (HDG).

Configuration	Description
HF-1	HF attached to SPF through 15/32-inch OSB using a 1/2- by 4-inch HDG lag screw
HF-2	HF attached to SPF through 15/32-inch OSB using a 1/2- by 4-1/2-inch HDG bolt
HF-3	HF attached to SPF through 15/32-inch OSB using a 1/2- by 5-inch HDG bolt, and washers stacked 1/2 inch thick between the ledger and the OSB
HF-LVL-1	HF attached to DF LVL band joist through 15/32-inch OSB using a 1/2- by 4-inch HDG lag screw
HF-LVL-2	HF attached to DF LVL band joist through 15/32-inch OSB using a 1/2- by 4-inch HDG bolt
HF-LVL-3	HF attached to a DF LVL band joist through 15/32-inch OSB using a 1/2- by 5-inch HDG bolt, and washers stacked 1/2 inch thick between the ledger and the OSB

Table 1 summarizes each of the HF test configurations. Fifteen specimens were tested for each configuration. Load was applied through a simulated deck portion that consisted of two joists that attached to the ledgers with joist hangers, and a backing member that held the joists in place at the ends opposite from the ledger. Details of testing PPT southern pine ledgers connected to SPF band joists can be found in Loferski et al. (2004). **Figure 2** shows a typical test specimen.

Results and Discussion

Failure modes included fastener head pulling through the ledger, the threaded portion of the lag screws withdrawing from the band joist, and splitting of the ledger in the region of the fastener. The test specimen assemblies displayed significant ductility with most displacing over 1-1/2 inches

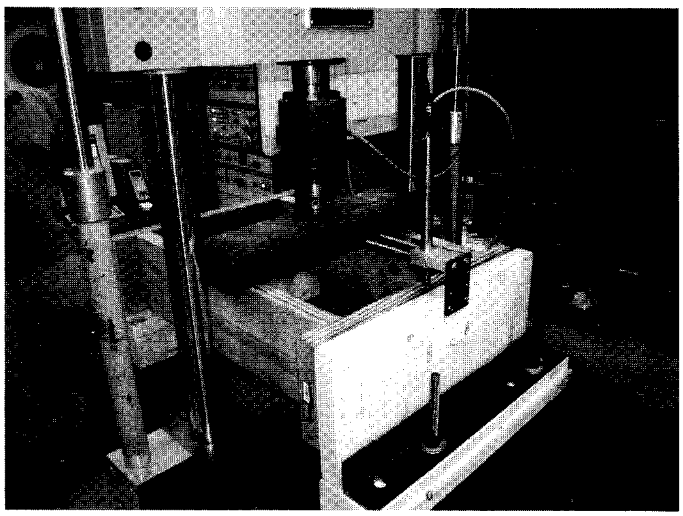

Figure 2.—Typical PPT southern pine ledger connection test specimen at Virginia Tech (Loferski et al. 2004). The pointed tip of the lag screw must extend beyond the inside face of the house band joist.

Table 2.—Summary of ledger-to-band joist connection test results from WSU.[a]

Tested configurations	Design load	Average displacement at design load
	(lb)	(in.)
HF ledger, 15/32-inch sheathing, SPF band, and 1/2-inch lag screw	451	0.19
HF ledger, 15/32-inch sheathing, SPF band, and 1/2-inch bolt	887	0.21
HF ledger, 1/2-inch washers, 15/32-inch sheathing, SPF band, and 1/2-inch bolt	673	0.23
HF ledger, 15/32-inch sheathing, LVL band, and 1/2-inch lag screw	468	0.05
HF ledger, 15/32-inch sheathing, LVL band, and 1/2-inch bolt	855	0.06
HF ledger, 1/2-inch washers, 15/32-inch sheathing, LVL band, and 1/2-inch bolt	614	0.09

[a] These data clearly demonstrate the superior strength of bolts over lag screws in the deck ledger application.

Table 3.—Calculated o.c. spacings (in.) for PPT HF or southern pine deck ledgers attached to SPF or a 1-inch-thick LVL band joist for residential deck joist spans with 40 psf live and 10 psf dead loads.

	Residential deck joist span (ft)						
Connection detail[a]	6	8	10	12	14	16	18
1/2-inch lag screws with 15/32-inch sheathing	30	23	18	15	13	11	10
1/2-inch bolts with 15/32-inch sheathing	36[b]	36[b]	34	29	24	21	19
1/2-inch bolts with 15/32-inch sheathing and 1/2-inch stacked washers	36[b]	36[b]	29	24	21	18	16

[a] Average deflections between the ledger and band joist at design load were less than 0.23 inch.

[b] These spacings were limited by a consideration of the bending strength of a 2 by 8 (minimum) ledger between the bolts or lag screws.

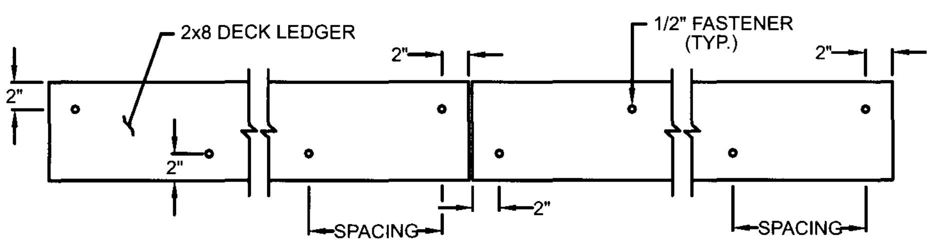

Figure 3.—Method for installing 1/2-inch diameter lag screws or bolts for use with **Table 3**. Fasteners should be staggered and an edge spacing of 2 inches should always be maintained.

before reaching their ultimate loads. **Table 2** summarizes the results for HF ledgers attached to either SPF or LVL. The design loads per 1/2-inch fastener in column 2 were computed by dividing the average ultimate loads (based on 15 replications per configuration) by a load duration factor of 1.6 and a safety factor of 3. The load duration factor converts the short-term strength to a "normal" duration that is used in design (AF&PA 2005). A safety factor of 2.5 has precedence in the *IBC*, but a more conservative factor of 3 was chosen due to lack of structural redundancy in most deck-to-band joist connections.

Assuming a residential deck live load of 40 psf and dead load of 10 psf, the required o.c. fastener spacing for the six cases tested were calculated for a range of deck spans (6 to 18 ft). Then, the closest fastener spacing among the Virginia Tech southern pine with SPF test data and the HF with SPF and LVL cases tested at WSU were tabulated in **Table 3**. The results from the two universities were combined for practical use, as the results were insensitive to the range of ledger/band joist materials tested.

In order to utilize the tables above for selecting the spacing for 1/2-inch diameter lag screws and bolts, it is important to install them according to *2005 NDS* requirements for "lead holes" and "clearance holes". To prevent in-service splitting, **Figure 3** shows the recommended placement of the 1/2-inch fasteners in a 2 by 8 (minimum) ledger. All fasteners should be hot-dipped galvanized, like those tested, or stainless steel as determined by the deck designer and approved by the building official.

Self-Supporting Design Option

A design option from relying on ledger connections for vertical load transfer is the use of a "self-supporting" deck detail as shown in **Figure 4**. The detail utilizes wood-to-wood bearing at the 6 by 6 (minimum) support posts. Compared to fasteners in shear, wood-to-wood bearing is an extremely efficient means to transfer load in a wood construction. An important part of the conceptual detail shown is the need, as well as *IRC* requirement, for lateral support of the overall deck structure. In this detail, 5/8-inch HDG threaded rods are shown to provide lateral support using a reinforced block wall or concrete foundation (reinforcement not shown). Another aspect of the detail is embedded 6 by 6 (minimum) PPT posts that provide redundancy against lateral movement or side sway. If the lateral restraint system specified by the deck designer failed to perform as intended, the embedded posts should prevent a total collapse of the deck structure. In sum-

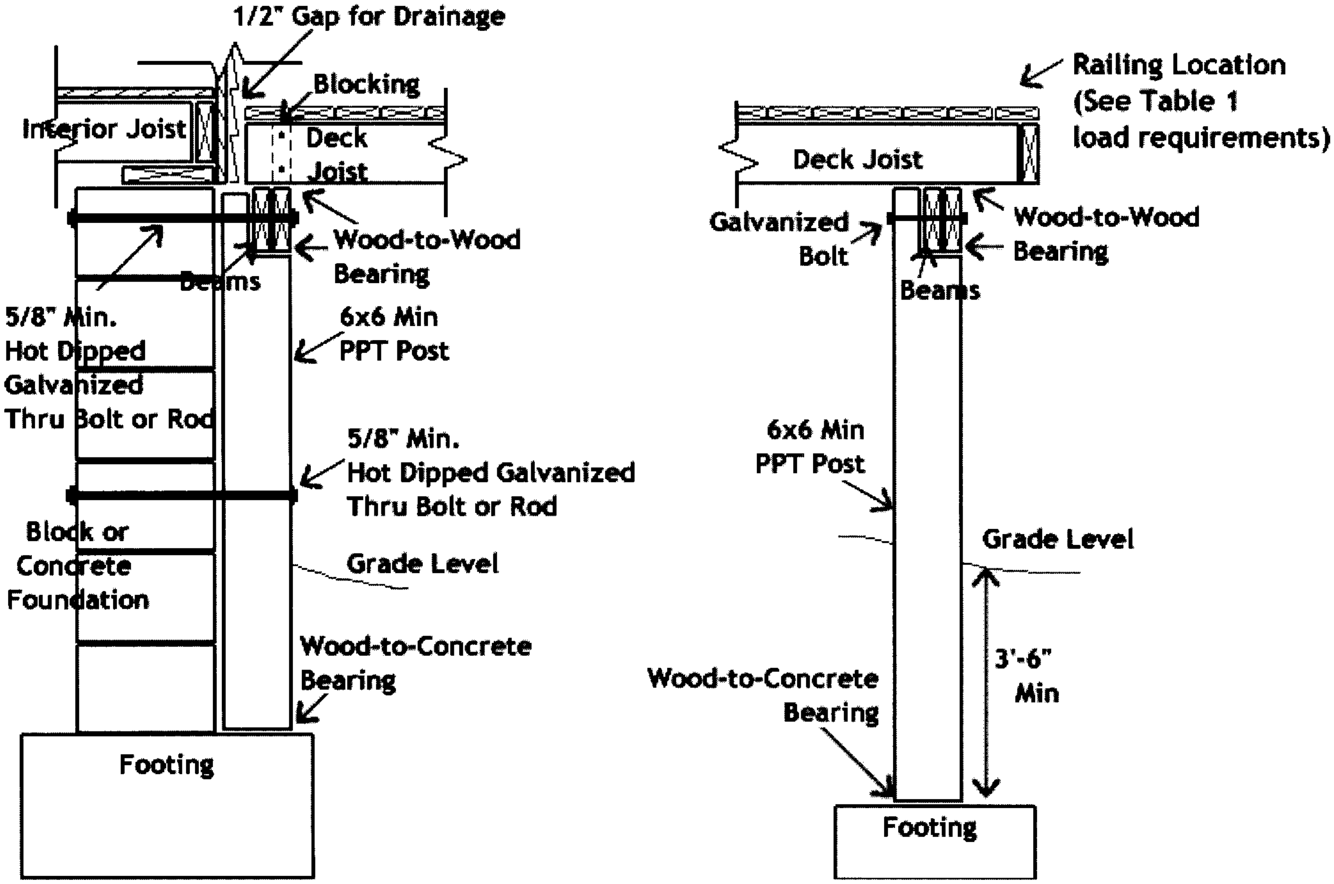

Figure 4.—A conceptual detail of a self-supporting deck from Anderson et al. 2003.

mary, the self-supporting deck option is a robust design alternative to consider and is being required by some jurisdictions when the house framing can not be verified or is not suitable for a deck ledger attachment.

Summary

Although a proposal for deck ledger design based on WSU and VT tests has been offered to the ICC IRC Committee for consideration, the *2006 IRC* has no prescriptive provisions for deck ledger connections at this time. Testing was conducted for three common deck ledger constructions using 1/2-inch diameter lag screws and bolts. The fastener spacing values in **Table 3** are limited to the following conditions:

- Deck live load of 40 psf and 10 psf dead (other loads may control residential deck ledger design such as snow, seismic, wind, and concentrated loads such as planters or hot tubs),
- Band joist lumber with G ≥ 0.42 (includes SPF, HF, Douglas-fir-Larch, and southern pine),
- Composite rimboard with thickness ≥ 1 inch and equivalent specific gravity ≥ 0.50,
- PPT deck ledger lumber with G ≥ 0.43 (includes HF, Douglas-fir-Larch, and southern pine),
- Deck ledger can be incised and wet,
- Proper installation (that includes a flashing detail),
- No decay present, and
- No fastener corrosion.

References

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