Residential Deck Ledger Design from Tests

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Introduction

Outdoor decks are becoming increasingly popular with homeowners as they extend their living spaces to the outdoors. Unfortunately, building codes have minimal coverage on decks, and deck safety has become a serious problem. Over the past decade there have been numerous reports of deck, balcony and porch failures, often resulting in injury and loss of life. Primary causes for the collapses are: 1) deficient connections between the deck ledger and the house 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 house connection fails, the deck collapses catastrophically. The focus of this ***Wood Bits*** is the deck ledger-to-band joist connection. We describe laboratory testing and present the required on-center (oc) spacing requirements for a residential deck based on laboratory tests.

A sample of deck and balcony failures reported in the media since August 2004 is shown in Table 1. This list does not include the deck, balcony and porch failures where no reports were filed. Clearly there are problems that need to be solved regarding the design of these connections.

Table 1. Deck collapses reported in the media due to ledger connection failures since August 2004.

Location	Date	Resulting Injuries or Deaths
Loveland, OH	October 2005	13 injured
Virginia Beach, VA	October 2005	28 injured
Seneca, SC	September 2005	7 Injured
Elm Grove, WI	September 2005	9 Injured
Minneapolis, MN	September 2005	3 Injured
Portland, OR	August 2005	10 Injured
Sherwood, AK	August 2005	12 Injured
Troy, IL	July 2005	7 Injured
Fort Kent, ME	June 2005	5 Injured
San Francisco, CA	June 2005	3 Injured
Allentown, PA	June 2005	2 Injured
Napa, CA	April 2005	11 Injured
Durham, NC	March 2005	3 Injured
Columbus, OH	November 2004	1 Death
Pierce County, WA	October 2004	1 Death, 7 Injured
Wilmington, NC	October 2004	8 Injured
Milford, CT	September 2004	9 Injured
St. Louis, MO	August 2004	2 Injured
Polson, Montana	August 2004	80 Injured

Background

The 2003 International Residential Code 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 toenails or nails subject to withdrawal." According to this, nails alone can not to 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.

The technical reference for the engineering design of connections in wood construction is the *National Design Specification for Wood Construction* (NDS-2005); however, commonly accepted means of connecting deck ledgers to band joists fall outside the scope of NDS. Specifically, the NDS requirements for direct contact between members (ledger and band joist) is violated for bolts and lag screws, and the minimum penetration depth four diameters (4D) is not met when using ½-inch lag screws because a solid-sawn band joist is only 1-1/2 inches thick. (Note: Professional designers are reminded of the fact that tabulated values for lag screws in the NDS are based on the assumption of 8D penetration, or 4-inches for a ½-inch lag screw.)

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 allows for testing to derive design values. Therefore, we tested connections to simulate the deck ledger attachment to the house band joist.

Deck Ledger Connection Testing

Three connection details were tested as illustrated in Figure 1:

- ½-inch diameter lag screw with 15/32-inch wall sheathing between the ledger and band joist.
- ½-inch diameter bolt with 15/32-inch wall sheathing between the ledger and band joist.
- ½-inch diameter bolt with 15/32-inch wall sheathing and ½-inch stack of washers (for drainage) between the ledger and wall sheathing.

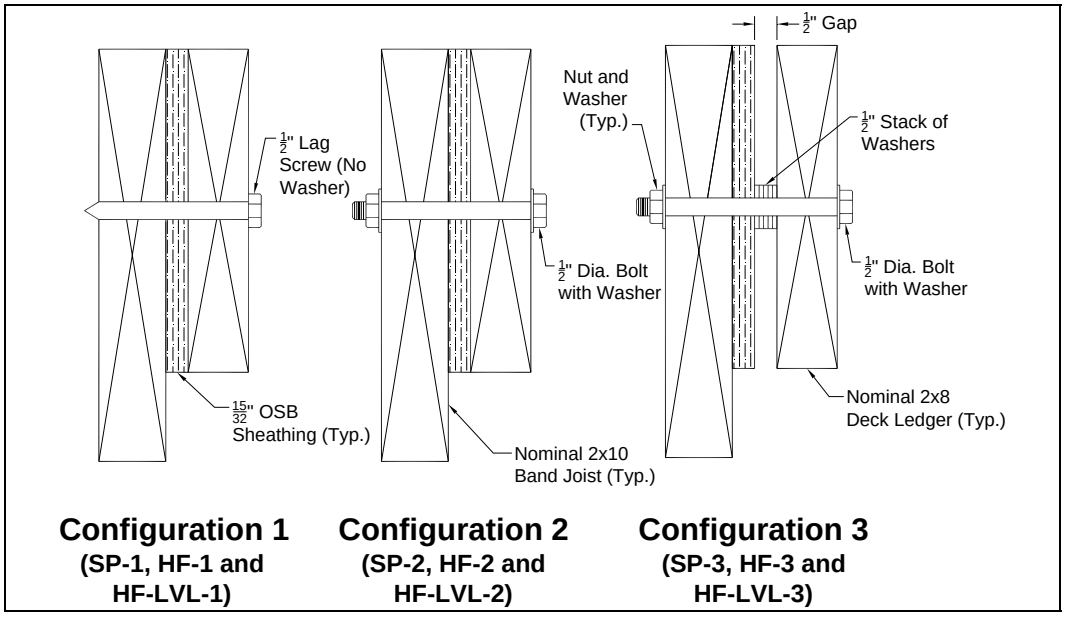

Figure 1. Ledger to band joist connection configurations tested at Washington State University (WSU).

Two types of band joist materials were used: 2x10 Spruce-Pine-Fir (SPF) lumber and 1-inch thick LVL (Douglas-fir) 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 rimboard is the minimum thickness that is currently sold in the marketplace. Thicker composite rimboard products with equivalent specific gravities of 0.50 or greater can be conservatively substituted for the LVL band joist material we tested.

Material for the deck ledger was preservative-pressure-treated (PPT) Southern Pine and incised, PPT Hem-fir. These represent the most common species groupings for PPT lumber, and the 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. Both the PPT Southern Pine and Hem-fir were treated to a retention level of 0.40 lbs/ft^3 of ACQ (Ground Contact), and the PPT Hem-fir was incised.

As specified in the NDS (AF&PA, 2005), 3/8 inch diameter lead holes were drilled in the band joists and ½-inch diameter clearance holes were drilled through the deck ledgers and OSB sheathing prior to assembling the lag screwed specimens. For the bolted specimens, 9/16-inch diameter clearance holes were drilled through the band joist, OSB and deck ledger.

Table 2 summarizes each of the 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 house band joists can be found in Loferski et al. (2004). Figure 2 shows a typical test specimen.

Table 2. Descriptions of ledger to house band joist connection Test Specimens at WSU.

Configuration	Description
HF-1	2x8 incised PPT Hem-Fir ledger attached to a 2x10 SPF band joist through 15/32" OSB using a ½"x 4" hot-dip galvanized lag screw
HF-2	2x8 incised PPT Hem-Fir ledger attached to a 2x10 SPF band joist through 15/32" OSB using a ½"x 4-1/2" hot-dip galvanized bolt
HF-3	2x8 incised PPT Hem-Fir ledger attached to a 2x10 SPF band joist through 15/32" OSB using a ½"x5" hot-dip galvanized bolt, and washers stacked ½" thick between the ledger and OSB.
HF-LVL-1	2x8 incised PPT Hem-Fir ledger attached to a 1-inch x 9-1/2 inch LVL band joist through 15/32" OSB using a ½"x 4" hot-dip galvanized lag screw
HF-LVL-2	2x8 incised PPT Hem-Fir ledger attached to a 1-inch x 9-1/2 inch LVL band joist through 15/32" OSB using a ½"x4-1/2" hot-dip galvanized bolt
HF-LVL-3	2x8 incised PPT Hem-Fir ledger attached to a 1-inch x 9-1/2 inch LVL band joist through 15/32" OSB using a ½"x5" hot-dip galvanized bolt, and washers stacked ½" thick between the ledger and OSB.

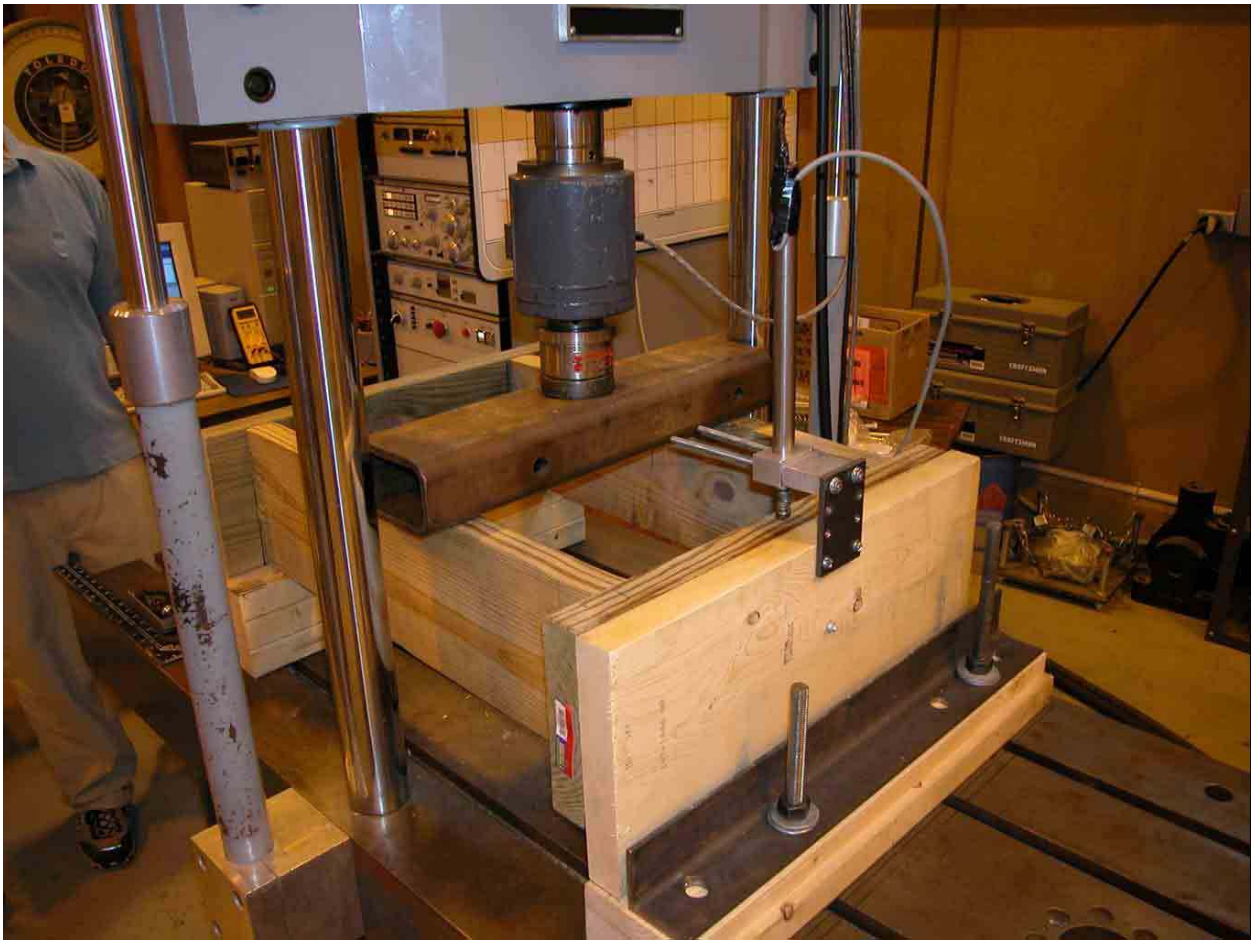

Figure 2. Typical PPT Southern Pine ledger connection test specimen at Virginia Tech. The pointed tip of the lag screw must extend beyond the inside face of the house band joist.

Results and Discussion

Failures 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. While the ends of the bolts with the nuts and washers did pull through the band joists, there was usually a significant amount of crushing and rotation beneath the 1" diameter washer, which often embedded itself in the band joist. The test specimen assemblies displayed significant ductility with most displacing over 1.5 inches before reaching their ultimate loads.

Table 3 summarizes the test HF and LVL results. The design loads per ½" 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 the lack of structural redundancy in most deck-to-house connections.

Table 3. Summary of ledger-to-house-band connection test results from WSU.

Tested Configurations	Design Load (lbs)	Average Displacement at design load (in)
HF ledger, 15/32" sheathing, SPF band, and ½" lag screw	451	0.19
HF ledger, 15/32" sheathing, SPF band, and ½" bolt	887	0.21
HF ledger, ½" washers, 15/32" sheathing, SPF band, and ½" bolt	673	0.23
HF ledger, 15/32" sheathing, LVL band, and ½" lag screw	468	0.05
HF ledger, 15/32" sheathing, LVL band, and ½" bolt	855	0.06
HF ledger, ½" washers, 15/32" sheathing, LVL band, and ½" bolt	614	0.09

Fastener spacings in Table 4 were developed by assuming deck live and dead loads of 40 psf and 10 psf, respectively. For example, a deck joist span of 16 ft would require a ledger capacity of (16 ft / 2) * (40 + 10 psf) = 400 lb/ft of ledger. This case would require 11-inch spacing for ½-in diameter lag screws with 15/32-in sheathing. The closest fastener spacings among the Virginia Tech Southern Pine test data and the HF and LVL cases tested at WSU are tabulated in Table 4. We were able to combine the test data for practical use, as the results were insensitive to the range of ledger/band joist materials tested.

Table 4. Calculated oc spacings (inches) for PPT Hem-fir 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.

Connection Detail*	Residential Deck Joist Span						
	6 ft	*8 ft*	*10 ft*	*12 ft*	*14 ft*	*16 ft*	*18 ft*
½-in lag screws with 15/32-in sheathing	***30***	***23***	***18***	***15***	***13***	***11***	***10***
½-in bolts with 15/32-in sheathing	***36*****	***36*****	***34***	***29***	***24***	***21***	***19***
½-in bolts with 15/32-in sheathing and ½-in stacked washers	***36*****	***36*****	***29***	***24***	***21***	***18***	***16***

* Average deflections between the ledger and band joist at design load were less than 0.23 in.

** These spacings were limited by a consideration of the bending strength of a 2x8 (minimum) ledger between the bolts or lag screws.

In order to utilize the tables above for selecting the spacing for 1/2" diameter lag screws and bolts, it is important to install them according to NDS 2005 requirements. Figure 4 shows the recommended method for installing these fasteners and how to use the spacings provided in the previous tables. Lead holes for the ½ in. diameter lag screws should be 3/8" diameter and the clearance holes should be ½" diameter. When installing bolts, the clearance hole should be 9/16", or at least 17/32" diameter. All fasteners should be hot-dip galvanized, like the ones tested for this article, or stainless steel as determined by the deck designer and approved by the building official.

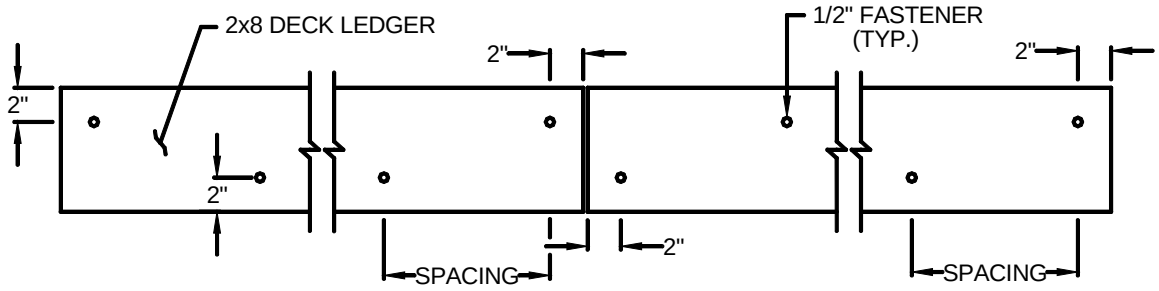

Figure 3. Method for installing ½"-diameter lag screws or bolts for use with Table 4. Fasteners should be staggered and an edge spacing of 2" should always be maintained.

Summary

Currently, the IRC has no prescriptive provisions for deck ledger connections. Testing was conducted for three common deck ledger constructions using ½-in diameter lag screws and bolts. The fastener spacings in Table 4 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.)
- Band joist lumber with specific gravity $\geq$ 0.42 (includes SPF, Hem-fir, DF-L and SP)
- Composite rimboard with thickness $\geq$ 1 inch and equivalent specific gravity $\geq$ 0.50
- PPT deck ledger lumber with SG $\geq$ 0.43 (includes Hem-fir, DF-L and SP)
- Deck ledger can be incised and wet
- Proper installation
- No decay present
- No fastener corrosion

References

Loferski, J. R., F. E. Woeste, R. Caudill, T. Platt and Q. Smith. 2004. Load – Tested Deck Ledger Connections. *Journal of Light Construction* March 2004 Edition: 71 – 78.

AF&PA. 2005. NDS – National Design Specification for Wood Construction ASD/LRFD. American Forest & Paper Association.

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