Are Balusters Strong Enough?

by Robert Randall, P.E., and Christopher Randall

Did you ever wonder whether those flimsy-looking balusters on Colonial staircases — sometimes called "candlestick" balusters — are strong enough to keep someone from falling through them? And more important, whether they're strong enough to comply with the building codes — some of which are quite stringent when it comes to stairs and guardrails?

The December '94 *Practical Engineering* column looked at BOCA code requirements for attaching railing posts. In this article, which is an extension of the same topic, we'll look at the strength of balusters, which by code must meet the criteria for a guardrail "infill." BOCA section 1615.8.2.1 requires that balusters "be designed and constructed for a horizontal concentrated load of 200 pounds applied on a 1-square-foot area at any point in the system…."

To narrow the scope of this article, we chose to evaluate three kinds of balusters: one commonly found on the exterior — the pressure-treated 2x2 — and two types of interior balusters of turned red oak (see Figure 1).

Interpreting the Code

At the start, we had to make some assumptions regarding the proper interpretation of BOCA's rule. We decided to interpret the "1-square-foot area" as a square, 1 foot by 1 foot. Since the code requires that the space between balusters be no more than 4 inches, this would mean, in the strictest interpretation, that the 1-square-foot load might involve only two balusters (Figure 2, page 79).

We further interpreted the BOCA code reference to a "concentrated" load as meaning a load applied equally and uniformly to all baluster elements within the square foot — and thus that any baluster must resist 100 pounds uniformly spread over any 12-inch section of a baluster.

Evaluation by Design

We first evaluated the various balusters from a *design* standpoint. We used the allowable stresses for visually graded dimension lumber taken from the 1991 NDS Supplement to the NFPA *National Design Specification for Wood Construction*.

Assuming No. 2 or better southern pine, the 2x2 exterior balusters proved to be strong enough for the code loads described above. However, all the interior balusters were found by design calculation to be overstressed by anywhere from 500% to 1,000%.

Evaluation by Testing

If the words of the code are to be taken literally — that the baluster infill system be *designed and constructed* for the specified loads — then the design calculations would disqualify the turned oak balusters. In order to see how realistic these calculations were, we next undertook a testing program.

We conducted a series of tests using a wire basket containing bricks to apply measured loads to the balusters, which we tested one at a time. Each baluster was supported in a horizontal position by its ends. A 12-inch-long foam-padded wooden "shoe" transferred the weight of the bricks to a 1-foot length of the baluster (Figure 3).

We carefully placed bricks into the basket one at a time until failure of the baluster occurred. While not up to recognized standards for certified testing laboratories, the test seemed a reasonable way to assess real-world performance of baluster assemblies. The results were in some cases surprising.

The exterior balusters all passed. High-quality 2x2s — those with clear, straight grain — would not break even when the basket was filled with 185 pounds of bricks. When we ripped them down to 3/4 inch square, the balusters could still support an impressive 126 pounds each, on average. In fact, even two 2x2s with serious knots at midspan, carefully selected at the lumberyard because of their defects, passed the test. (For the technically minded, calculated stresses ranged from 2.431 ksi for the knotty balusters to 13.779 ksi for the clear stock.)

Surprisingly, the interior balusters *almost all* passed the tests. Of 13 turned oak balusters tested, two failed at 95 pounds and 98 pounds, respectively. The average failure load across the entire 13 balusters was 141 pounds, ranging up to a maximum of 172 pounds. (Calculated bending stresses during testing ranged from 9.262 ksi to 18.956 ksi.)

Most of the tests were conducted with the baluster

Balusters Tested

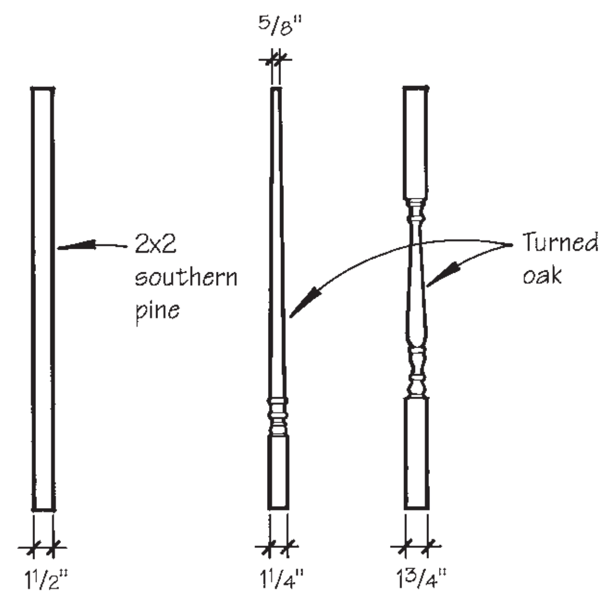

Figure 1. *The authors tested 2x2 southern pine balusters commonly found on exterior decks and two types of turned interior balusters.*

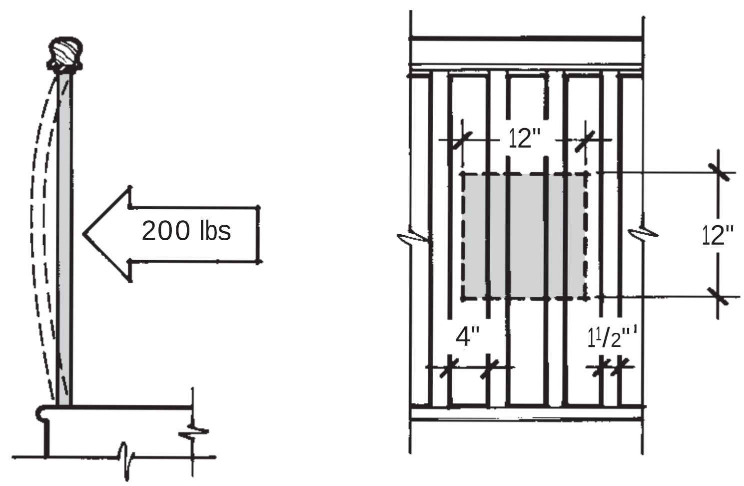

Figure 2. *In the strictest interpretation, a 200-pound load exerted against a 1-square-foot area of a typical baluster assembly might only encompass two balusters.*

ends supported by either a flat edge (for square-cut ends) or by insertion into a bored hole (for turned ends). Three tests, however, were conducted with the “upper” end secured by a single 6d galvanized finishing nail driven into a predrilled hole. We were quite surprised to find that there was nothing close to a failure of this toe-nailed connection. We even tried a separate test with the load applied as close as possible to the nailed connection and still the toe-nail held! In spite of the surprise success of the nailed connections, we still recommend using mortised connections if possible.

Design vs. Practice

Based upon our assessment, typical 2x2 pressure-treated southern pine balusters seem to be a safe choice for exterior guardrails. Our only cautions are to avoid pieces with prominent knots and to predrill to avoid splitting when driving screws.

The interior turned red oak balusters fall short of the code requirement that they be “designed” for the specified loads, since they do not pass what might be considered common design criteria. However, they came very close to passing a performance test; certainly, *on average*, our test samples exceeded the specified loading criteria. Concerned individuals might be wary, however, that samples from different lots of lumber, of different species, of different age, or of smaller dimension might fall short.

The discrepancies between calculations and testing were surprising only in how large the variance was. Particularly with wood, there is (hopefully) a safety factor built in to the calculations. In this case, though, the difference between calculations and testing were almost enough to change the conclusions.

Based on calculations alone, the BOCA code would seem to preclude the use of turned hardwood balusters in many common applications (although there is significant ambiguity on how to apply the requirements). Our testing program, on the other hand, suggests that these standard components are satisfactory. We have three suggestions:

1. Builders should place balusters 4 inches on-center. This would ensure that *three*, not two, balusters would be resisting the code load, increasing the safety factor by 50%. By this criterion, all the tested balusters would be acceptable.

2. Manufacturers might slightly increase the diameter of turned balusters, particularly at the narrowest points. The *section modulus*, a term used by engineers for a measure of the strength of a member, can be calculated for circular sections by the formula $S=.098175D^3$. The exponent, 3, is a powerful term and means that a 25% increase in diameter will almost double the strength.

3. Code agencies might consider reducing the load requirement as well as clarifying the ways to achieve compliance. At present, the builder is faced with a predicament in selecting decorative balusters for interior railings. ■

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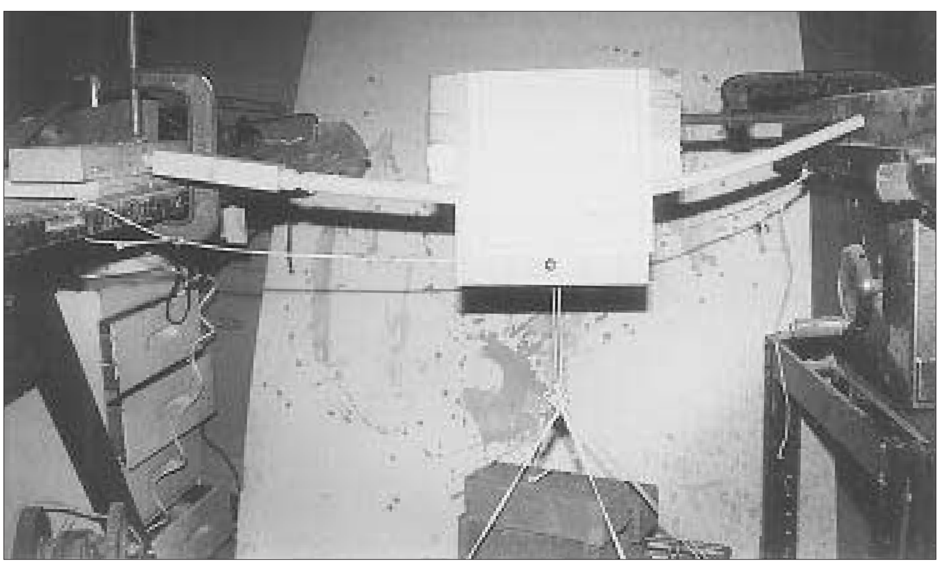

Figure 3. *A basket of bricks applied a measurable static load over a 1-foot length of the baluster in this test devised by the authors.*