Wood-framed Stair Stringer Design and Construction

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It's amazing that something as simple and as common as wood-framed stair stringers do not yet have specific prescriptive code construction provisions. Despite the commonality of wood-framed stair stringers, they still suffer from structural performance issues which result in scenarios that range from cracked drywall to severe injuries. While the International Code Council (ICC) recently moved to address lateral residential deck failures by bolstering the prescriptive requirements of Section R502.2.2 in the *2009 International Residential Code* (IRC), there still remains a void in an area where a few simple changes could make a dramatic difference.

According to the U.S. Consumer Product Safety Commission (CPSC) National Electronic Injury Surveillance System (NEISS), during 2008 through 2011, there were an estimated 10,000 instances nationally where an individual visited an emergency room with injuries related directly to a structural failure of wooden stairs. A cursory review of these instances reveals that the majority of those are related to wood tread failure and the minority related to wood-framed stringer failure. This article focuses on the design and construction of wood-framed stair stringers, through a review of current code requirements and rules-of-thumb; common structural performance issues; structural analysis considerations and examples; and, recommendations for mitigating this common construction deficiency.

Code Requirements

The ICC family of codes, the IRC and *International Building Code* (IBC), contain very few provisions regarding wood-framed stair stringer design and construction. Live loading is specified as 40 pounds per square foot for residential applications and 100 pounds per square foot for other applications (IBC Table 1607.1). The majority of the code provisions address dimensional restraints, such as width, rise/run, and vertical clearance. *Table 1* provides a summary of code requirements as well as some carpentry and building construction handbook recommendations for the dimensional restraints of stair rise and run.

Essentially that's it. The codes provide tables for prescriptively selecting the sufficient span of joists, rafters, girders, and headers for simple structural loading, but only provides limited dimensional restraints for stair construction. The only guidance provided to a builder for the structural capability (minimum throat depth) of wood-framed stair stringers comes from a carpentry handbook. Otherwise, it is left to the builder's common sense, experience, and available rules-of-thumb to prevent the stringers for a 10-foot flight of stairs to be constructed from two 2x8s.

Common Structural Performance Issues

Connections

Perhaps the most critical structural issue of wood-framed stair construction is the connection of the stair stringer to the supporting structure. More often than not, the lower end of a set of stringers is in direct bearing contact with its supporting structure and issues tend not to arise. Typical construction employs the use of a thrust/kicker block to prevent axial movement. More often, the most important connection is at the upper end of the stairs where the stringers are typically flush-framed to a header. Failure of this connection is often sudden and catastrophic, resulting in severe injuries. One recently documented instance resulted in serious injuries to several firefighters who were carrying an injured resident out of the home (Hench D., 2010).

Prescriptive fastening schedules in the IRC and IBC offer connection specifications for similar situations, such as a joist flush-framed to a header or girder (IRC Table R602.3(1) and IBC Table 2304.9.1). These connections entail

Table 1: Dimensional rise and run requirements/recommendations from various sources.

	Riser		Tread		Throat Depth	Flight Rise
	Min. (inches)	Max. (inches)	Min. (inches)	Max. (inches)	Min. (inches)	Max. (feet)
IRC 2009	-	7.75	10	-	-	12
IBC 2009	4	7	11	-	-	12
Handbooks[1]	6	8	9	12	3.5	12
Architectural Graphics Standard (1988)	5	9	8	16	-	12

[1] Dietz (1954); Feirer and Hutchins (1976).

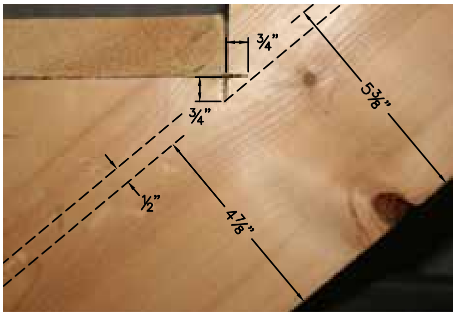

Figure 1: Effect of overcutting notches on effective throat depth.

face-nailing or toe-nailing; however, these connections cannot be directly applied to the upper connection of stair stringers because of their sloped grain condition. Another method of construction employs the use of a ledger to provide direct bearing for the stringers. This method can be suitable, but prescriptive provisions do not exist and need to be provided. With the widespread use of mechanical connectors in other aspects of modern wood-framed construction, it makes good sense that these could be used for this situation. Sloped sawn lumber face-mount hangers are common, simple to install, field adjustable, and capable of safely handling the connection forces from most wood-framed stringer applications.

Notching

The overcutting of notches at the tread/riser intersection during the construction of stair stringers is a common problem with unskilled or careless carpenters, as shown in *Figure 1*. In this instance the notches are overcut by three-quarters of an inch and unnecessarily reduce overall stringer strength. A less common, but largely more effective approach is to drill a one-quarter inch hole at the notch corner and cut to the hole with a handsaw or skillsaw. In both instances, the effective throat of the stringer is less than the theoretical throat. However, the drilled hole and careful cutting minimize the strength reduction and provides relief for the stress concentration created as a result of notching.

Deflection

Deflection of stair stringers is largely ignored in typical construction, but code required limits should be applied. While prescriptive provisions of the IRC provide no explicit restrictions on deflection, the IBC provides deflection limits (Table 1604.3) for various situations. From this table, the most applicable limits for stair stringers are L/360 for live loads and L/240 for total load. Total load can be used as the live load plus half of the dead load for wood with moisture

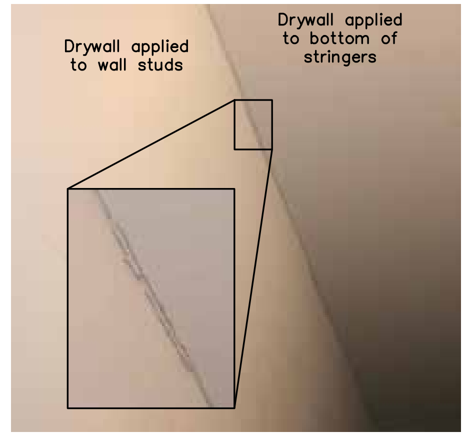

Figure 2: Cracked drywall caused by excessive deflection.

content below 16% at the time of installation (IBC Table 1604.3 note d). These limits are intended to reduce serviceability issues due to cracking of finishes and improve perception of structural performance among other things. As an example, *Figure 2* shows cracking of a taped drywall joint beneath a set of underperforming stair stringers. Drywall directly applied to the bottom of the stringers has moved excessively, causing a failure of the joint and an unsightly crack. *Figure 3 (page 46)* shows recent failure of a caulked joint between a tread and drywall of the same set of stairs. This finishing detail is common in lower-end construction. However, excessive deflection is less noticeable in typical higher-end construction where molding is attached to treads and specifically not attached to walls. Damage to finishes can be temporarily fixed, but will reappear without addressing the root of the problem, which is insufficient stringer stiffness.

Structural Analysis

Without a published or publically accepted method for analysis of wood-framed stair stringers, the method of analysis used for the purposes of this article will be to ignore any contribution of stringer material outside the effective depth. Without performing an extensive finite-element analysis of the notched profile, it is believed that very little integrity is added from the notched material.

Load distribution

In a theoretical three stringer configuration, one may be tempted to apply twice the tributary load to the center stringer as to the exterior stringers. Doing so would result in an unreasonably stout center stringer and does not lend itself easily to prescriptive provisions. However, when considering the contribution of the riser and in a lesser part the tread to load distribution, it is feasible to assume that the stringers may bear an equal share. By isolating the riser as shown in *Figure 4*, analysis demonstrates this equal share in a common situation. In theory this equal distribution does not occur, but with a sufficiently stiff riser the distribution can be assumed uniform and therefore more conducive to prescriptive provisions.

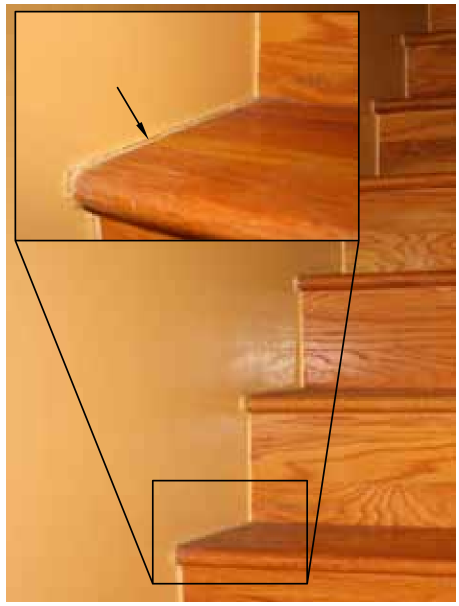

Figure 3: Cracked caulk caused by excessive deflection.

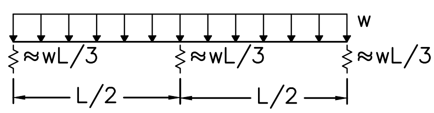

Figure 4: Stringer load distribution with a sufficiently stiff riser.

Inclined Beam Design

Because stair stringers are typically axially restrained at each end, it is prudent to review the comparison of the sloping beam method and the horizontal plane method. With the sloping beam method, the uniform load is resolved into components of load perpendicular to the longitudinal axis of the beam (bending) and parallel to the longitudinal axis of the beam (compression), and the span length is to be considered the inclined span. With the horizontal plane method, uniform load is applied directly to the horizontal span of the inclined beam. It has been shown that the two methods result in very similar bending moment and shear values (Breyer et. al., 2003), but also that the axial compression portion of the sloping beam method is insignificant when considering the interaction of compression and bending. For the purposes of this article, the horizontal plane method will be used due to its simplicity, popularity, and relative accuracy.

The following analysis demonstrates results of a typical wood-framed stair stringer configuration as well as several similar configurations. Consider 15 risers at 7¼-inch tall with 10½-inch wide treads and stringers cut from SPF No. 1/No. 2 2x12s. This configuration results in an effective throat depth of approximately 5 inches for a horizontal span of 12 feet and 3 inches. For a residential loading of 10 pounds per square foot dead and 40 pounds per square foot live and a one-foot tributary width (3-foot width with 3 stringers), the allowable bending strength ratio is 145% and the shear strength ratio is 50%. Live load deflections and total load deflections are 0.93 inches and 1.05 inches respectively, which are 127% and 72% more than the allowable limits of 0.41 inches and 0.61 inches. As discussed previously, excessive deflections are demonstrated and can be exacerbated by being exposed to the elements and experiencing a moisture content above 16% during construction. In which case, the total load deflection would increase to 1.16 inches which is 90% above the allowable limits.

For comparison, *Table 2* summarizes results from several additional analyses: stringers cut from 2x10s; 2x12 stringers with 2x6s sistered to the effective depth region; 2x12 stringers with a 2x4 strongback on the bottom; and stringers cut from a 1½-inch by 11⅞-inch engineered wood product (EWP).

The only configurations from this typical example that fully comply with the code requirements using this method of analysis are the 2x12 stringers with 2x6 sistering or with a 2x4 strongback.

Table 2: Analysis results for multiple configurations of the example problem.

	Bending Strength Ratio	Shear Strength Ratio	Live Load Deflection (inches)	Total Load Deflection (inches)
Code Limits	100%	100%	0.41	0.61
2x12	145%	50%	0.93 (227%)	1.05 (172%)
2x10	602%	82%	4.29 (1046%)	4.83 (792%)
2x12 with sister	71%	50% [2]	0.40 (98%)	0.45 (74%)
2x12 with strongback	70%	50% [2]	0.29 (71%)	0.33 (54%)
Engineered wood product [1]	40%	15%	0.54 (132%)	0.61 (100%)

[1] *EWP: F_b=2650psi, F_v=400psi, E=1,700,000psi*

[2] *Shear strength is not increased for reinforced stringer as the reinforcement does not need to extend full length, where maximum shear stresses occur.*

Recommendations

In an effort to mitigate one of the remaining all-too-common life safety issues in wood-framed construction, a concerted effort should be put forth to provide additional prescriptive provisions. The following action items are recommended:

1) Require that mechanical connectors be used for the upper end stringer connections, in a similar fashion that mechanical connectors have been implemented with deck lateral load connections. Both situations have a history of sudden and catastrophic failures which can be mitigated by the requirement of a well-controlled consistent connection method.
2) Supply prescriptive span tables "stair stringer spans for common lumber species" in the IRC and IBC based on effective throat depth. Separate tables for unreinforced, and reinforced spans should be provided. Nailing patterns for reinforced conditions should also be provided, appropriately in a fastening schedule.
3) Provide minimum riser and tread material and section limits to ensure that uniform load distribution occurs between stringers in a flight of stairs. Whether it is provided by conventional oak riser and treads, sheathing, or dimensional lumber, guidance should be provided.
4) Strongly recommend a ¼-inch drilled hole at the notch corner during construction of wood-framed stringers. Consequently, implement a code-required one-quarter inch reduction from the theoretical throat depth to the effective throat depth during the design process.▪

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