Design Guidelines for Safe Stairs

Getting the details right might save a life

by Gregory Harrison

What could be simpler than building a stair? Consider, for a moment, statistics from the National Safety Council and the Consumer Product Safety Commission: over 13,000 Americans die each year because of falls, with 3,800 killed on stairs each year. About 2.5 million stair falls are tallied each year, and 800,000 of them result in injuries that require professional medical care. However, because injuries can be treated in other than emergency rooms, it's probable that this figure is low—some published estimates put the true figure at more than 2 million serious injuries. Simply put, stairs are the most dangerous architectural feature in a house. It doesn't take much thought to realize that this problem is one that architects, engineers and builders create, and that it's also one they can readily solve.

In the course of my work as a safety engineer, expert witness and design consultant, I have studied thousands of stairs and hundreds of fall accidents. If you design, specify, sell or build stairs, I suspect that the subject of this article won't immediately arouse your interest. But I submit that a lawsuit for wrongful death or severe bodily injury caused by "your" stairway would.

The role of the codes—The philosophy of model building codes has been to relax stair safety requirements for one- and two-family dwellings, even though that's where the majority of fatalities occur. Why this is so is not clear, but the code agencies in general have a record that reflects a resistance to code changes affecting personal safety. Perhaps this is because professional safety engineers aren't typically consulted, or because the process of code development reduces the output to the lowest common denominator. The bottom line, though, is this: codes contain technical errors, and no code can anticipate every condition in the field, so don't rely on a building code or standard alone to guide the design or construction of stairs. Compliance with the codes is not a defense against negligence per se, contrary to what most architects and builders think. As one well-known trial attorney put it, "Codified negligence is still negligence."

Basic stair design—Based on my experience, I believe a safe stairway, whether in commercial or residential use, should have the following characteristics (top drawing, facing page).

1. Reachable, continuously graspable, and structurally stable handrails on both sides, with intermediate handrails as required;
2. Properly proportioned risers and treads with close tolerances;
3. Slip-resistant treads and nosings;
4. Adequate lighting, appropriately located and controlled;
5. Guardrails (and toeboards on steps if open on the side);
6. General compliance with the NFPA Life Safety Code; and
7. At least three steps.

There are other factors that, while not pertaining directly to the design of stairways, can figure into the safety equation. The stairs should be properly maintained, for example, with no loose treads or wobbly handrails. And there shouldn't be any environmentally triggered factors that could distract the stair user, such as mirrors or HVAC ducts that might suddenly blow air at a stair user.

Most of the requirements above seem to be the stuff of common sense, but several are so important that I'd like to explain them in detail: handrail design, tread/riser design, slip-resistance, short runs, and guardrails.

A safe handrail is crucial—A graspable handrail is *the* most important characteristic of a safe stair because, regardless of how a fall is caused, a good handrail offers the stair user a last chance to reduce the impact of a fall. A handrail also serves as a visual signal that a change of elevation exists, and it provides a continuing support for use by the elderly and by children. To be functional (remember form follows function?), a handrail must be *graspable*. One well-known architect and stair-safety researcher, Jake Pauls, has suggested what he calls, "The Acid Test of Graspability." Because the purpose of a handrail is to provide a secure grip for people who may be taking urgent and desperate action to prevent death or a disabling accident, Pauls suggests that designers be required to hang from two sections of their proposed handrails, one grasped with each hand, and maintain that grasp while suspended over a vat of acid. If his proposal were invoked, there would certainly be fewer handrails constructed of 2x4s, 2x6s, 2x8s and large-diameter pipes (which are particularly ungraspable by human beings).

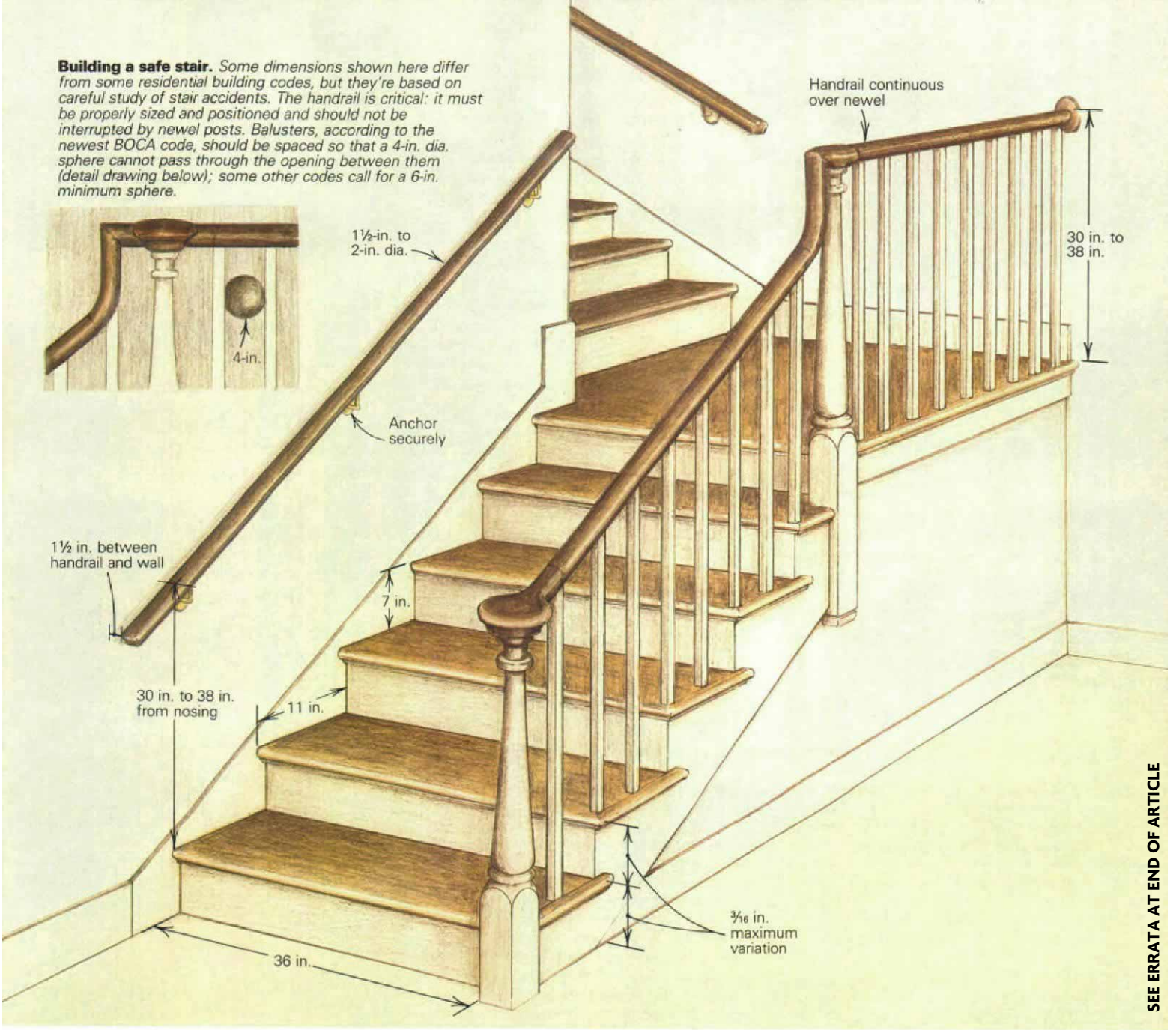
To be graspable means that you can curl your fingers and thumb around and underneath the handrail. After investigating hundreds of stair-fall accidents, I've come to the conclusion that the proper design of handrails has evidently been beyond the grasp of many designers and builders, especially in homes.

The National Fire Protection Association publishes Standard No. 101, called the *Life Safety Code* (LSC), and it contains, in Chapter 5, extensive architectural and engineering criteria relative to the safe design of stairs and ramps. I recommend that you get a copy (National Fire Protection Association, Batterymarch Park, Quincy, Mass. 02269; 800-344-3555). The 1988 LSC handily summarizes handrail graspability (see the sidebar on p. 68). The lack of. any handrail, or the existence of an oversized one, represents a very unsafe and dangerous condition. The dimensions of a proper handrail aren't difficult to understand (drawing, p. 68).

It would seem obvious that the handrail should extend along the full length of a stair, but this isn't always done (bottom drawing, facing page). A stair design that allows steps to extend beyond the reach of the handrail is not a wise idea, particularly because those first steps are where most of the accidents happen.

I think builders and architects, out of professional duty and plain common sense, ought to provide handrails for *all* stairways, including those with only one or two steps (notwithstanding the lack of such a requirement in the current one- and two-family building codes). What could be cheaper than installing an attractive wood or brass handrail that stands ready to reduce or eliminate injuries for many years to come? Based on my professional accident investigations in residences, I'm convinced that much suffering and misery could easily be eliminated with the addition of proper handrails. Think of a proper handrail as analogous to a seatbelt or an airbag in a car.

Riser/tread design—During the design of any stair, risers and treads should be carefully detailed to result in the proper geometry and size. Human-factors research at the National Bureau of Standards (now known as the National Institute of Standards and Technology) has shown that foot travel clears a riser by as little as ⅜ in. Most codes require 3/16-in. maximum variation between adjacent risers and treads. That means that the steps should be carefully and solidly constructed: a stable step



Building a safe stair. *Some dimensions shown here differ from some residential building codes, but they're based on careful study of stair accidents. The handrail is critical: it must be properly sized and positioned and should not be interrupted by newel posts. Balusters, according to the newest BOCA code, should be spaced so that a 4-in. dia. sphere cannot pass through the opening between them (detail drawing below); some other codes call for a 6-in. minimum sphere.*

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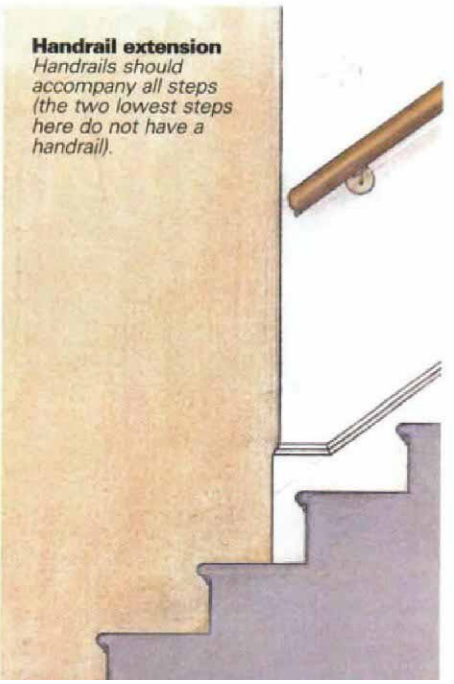
is less likely to warp or twist out of position and affect these tolerances. Finally, codes usually require that within the overall stairway, risers and treads not vary more than ⅜ in.

The ideal step dimensions, based on my review of the safety literature, is 7 in. for the riser and 11 in. for the tread, hence the "7-11 step." The minimum riser height by code is 4 in. and the maximum is about 8 in. Although I know of no code maximum for treads, unusually deep treads cause an abnormal gait that can cause missteps and a fall. The CABO One and Two Family Dwelling Code allows treads to be only 9 in. deep, which is ridiculous because almost all adult feet with shoes exceed this measurement.

One formula for expressing step geometry was put forth in 1672 by Francois Blondel of the Royal Academy of Architecture in Paris and takes the form of:

$2 \times R + T = 24$ in. to 25 in.



Handrail extension
Handrails should accompany all steps (the two lowest steps here do not have a handrail).

Other formulas found in older editions of various building codes include:

$R + T = 17$ to 17.5 in.

$R \times T = 70$ to 75 in.

These formulas have been eliminated from modern codes because they are far from perfect and exclude some safe designs; you should not rely on them.

Slip-resistant surfaces—The slip-resistance of stair treads is an important consideration in providing safe stairs, especially when it comes to the nosing area. Careful selection of materials is the best way to ensure safety, and certain materials are inherently dangerous as a stair surface: smooth concrete, polished marble, terrazzo, ceramic tile (especially glazed tile), painted wood, and most any other highly polished hard surface, including oak with a polyurethane finish.

During a recent show of upscale new model

Drawings: Bob Goodfellow

homes, I noticed that most of the builders had installed highly polished marble or ceramic tile foyers and steps. Attendants were posted everywhere to give the visiting public verbal warnings about the very slippery conditions. With the steep price of each home in mind, I inquired as to whether or not the same attendants came with the house so that my guests would receive the same warning and, hence, reduce my liability. No deal. Not only would these steps require frequent cleaning cycles and constant scratch control, but numerous serious falls would surely occur over the years. Glazed tiles and polished stone belong on the walls, not on floors and especially not on steps. Given these conditions, however, there's all the more need for very graspable handrails on both sides, regardless of stair width.

Short and dangerous—Short flights of stairs are often employed to accommodate changes in elevation of less than 21 inches, both indoors and outdoors (such as for decks and patios). But short flights are inherently dangerous. In fact, flights of one or two risers are so undesirable that the Life Safely Code committees and model codes have, in the past, attempted to prohibit their use. They wanted to substitute ramps for stairs with fewer than three risers, or where changes of elevation were less than 21 inches.

The main reason short flights are dangerous is that many people do not see the steps until they have already begun to fall. Also, most stairway-fall accidents occur on the first or second step ascending or descending; if the flight only has two steps, a user will always be in the zone of relatively high hazard in either direction of travel. The LSC recommends the avoidance of short flights, but states that if steps are used in a short flight, the tread should be a minimum of 13 in. and that each step location should be readily visible. You would be well advised to read section A-5-1.6.2 of the 1988 NFPA LSC Standard No. 101 or the *Encyclopedia of Architecture* (Vol. 4, 1989) concerning this subject.

The most elegant way to prevent falls on short flights of stairs is to replace them with a ramp. If your client insists on having short flights, or if you've inherited the problem, there are ways to reduce the incidence of falls.

Because the primary problem is visual, you should include all possible visual cues to the presence of steps. Here are some possibilities:

—Slope handrails at the same pitch as the stairs.

—Use contrasting surfaces (a polished brass rail against a dark wall, for example).

—Install textured or patterned wall coverings so they follow the angle of the steps, thereby highlighting the change.

—Provide relatively intense lighting to highlight the steps.

—Remove geometric-print carpet from stairs (it can camouflage the presence of steps).

—Provide step nosings with illuminated strips embedded in their top surface; one manufacturer of such a product is Diamond Metal Ltd. (80 Colonnade Rd., Nepean, Ont. K2E 7L2; 613226-1123).

—If the room has a normal ceiling height, slope it downward over the steps, parallel to the stair angle. The change of ceiling plane will draw attention to the change in level.

—Provide tactile cues. The use of hardwood treads, for example, on all steps (including the top landing) can alert a pedestrian approaching from a carpeted area of an impending change underfoot. The sensation of stepping from padded carpet to a hard surface tends to cause one to look down to see what the change is about.

Guardrails—Balusters, railings, Plexiglas, tempered glass and other such guardrails serve a useful function: they keep you from falling *off* stairs and landings. Most codes require guardrails to be 42 in. to 44 in. high in commercial settings. The 36-in. height usually prescribed for residential applications is, I believe, inadequate. Based on a study performed by engineer Elliott Stephenson and backed by the American Academy of Pediatrics, the BOCA code responded efficiently (to their credit) and recently reduced the baluster spacing from 6 in. to 4 in. (see detail drawing, previous page). A 6-in. baluster spacing will allow 950 out of 1,000 children less than 10 years old to pass through, so it's not a very effective barrier. In stark contrast, few children, except those less than a year old, can pass completely through a 4-in. wide opening. The American Institute of Architects and the National Association of Home Builders have been less than enthusiastic about this and certain other safety-related changes, according to Mr. Stephenson. It has also been my professional experience, based on more than 20 years of meeting with architects, that they usually do not appreciate the possibility of falls. I'm sure many architects believe that I do not appreciate the aesthetic aspects of my suggestions, either.

Spirals, winders and landings—Other types of stairs such as spiral stairs and winders are not as safe as straight-run stairs because of the varying tread width. Thus, they require a *very* good handrail. Consult the NFPA LSC for details concerning risers and treads.

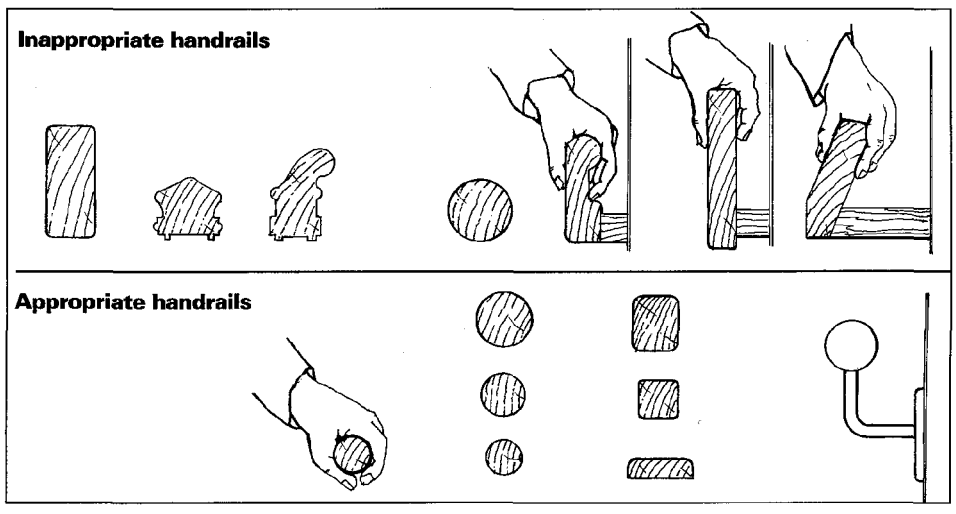
Straight-run stairs are not as safe as stairs that have landings—if you fall, you'll travel a bumpy road to the bottom of the stair. Landings shorten a fall, and they should be at least as long as the stair is wide. If a stair rises more than 12 feet (a vaulted interior space, for example) the code requires a landing. □

Gregory Harrison, P. E., has more than 20 years' experience as a safety, fire protection and civil engineer.

Handrail graspability

"Handrails should be designed so that they can be grasped firmly with a comfortable grip and so that the hand can slide along the rail without encountering obstructions. The profile of the rail should comfortably match the hand grips. For example, a round profile such as is provided by the simplest round tubing or pipe having an outside diameter of 1½ in. to 2 in. (3.8 cm to 5 cm) provides good graspability for adults. Factors such as the use of a handrail by small children and the wall fixing details should be taken into account in assessing handrail graspability. The most functional as well as the most preferred handrail shape and size is circular with a 1.5 in. (3.8 cm) outside diameter (according to research with adults). Handrails used predominately by children should be designed at the lower end of the permitted dimensional range. It should be noted that handrails are one of the most important components of a stair; therefore, design excesses such as oversized wood handrail sections should be avoided unless there is a readily perceived and easily grasped handhold provided. At all times in handrail design it is useful to remember the effectiveness of a simple round profile that permits some locking action by fingers as curl around the handrail."

—From the Life Safety Code, National Fire Protection Association, 800 Batterymarch Park, Quincy, Mass. 02269.



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Stair safety

Gregory Harrison's article on safe stairs *(FHB* #65, pp. 66-68) points out the necessity of safety as a criterion of stair design. However, his information about handrails seems out of place when he omits any mention of handrail returns. The 1985 UBC says, "Ends shall be retumed or shall terminate in newel posts or safety terminals." This seems an odd omission in an article that suggests safety features that are even beyond code requirements.

-Mike Mahan, Valley Center, Calif.

Author Gregory Harrison replies: You are correct. The handrail should return to the wall or terminate in a newel or the like. The reason for this is to provide a cue to the stair user that the end of the stair is, quite literally, "at hand." Another advantage is that it eliminates the possibility of a piece of clothing being snagged by the end of the railing, which could throw the stair user off balance.

I'd also like to clarify a label on the drawing on page 67. The balcony railing is noted as being between 30 in. and 38 in. high. While some codes permit this, I prefer a height of 42 in.