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Stairs:
Summary Bulletin

Prepared by:

The Home Modification Information Clearinghouse Project Team

Authored by
Yong-Moon Jung & Catherine Bridge

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Stair falls and injuries

It is true that people at all ages fall on stairs, however, 'falling is an epidemic that plagues the elderly more than any other segment of the population (Templer, 1992, p. 5).' Falls are the leading cause of admission to residential care facilities and to hospital (Hendrie, Hall, Arena, & Legge, 2004; Tinetti & Williams, 1997) and are the most common cause of injury related death, accounting for 30% of all injury related deaths (Henley, Kreisfeld, & Harrison, 2007). It was reported that, in Australia, approximately one in three older people aged 65 and over experienced falls at least once a year (Morris, et al., 2004). Fall incidence occurring on the stairs accounted for 12% of all fall injuries in the home (Bray, 2000). However despite the relatively smaller proportion, the risks of falls on stairs are greater than those on the floor as the consequences are likely to be more serious, particularly falling on descent (Templer, 1992).

Considering the prevalence of stairs in architecture, their ever-present existence, and their injurious characteristics, little attention or research has been devoted to improving their safety (Templer, 1992). There has long been the view that stair falls are caused by carelessness and lack of attention among users. Although initiatives for stair safety have given rise to installation of auxiliary devices such as handrails and warning signs, consideration of stair design itself has lacked. The literature has identified three major factors acting individually (or in combination) to stair falls;

1. user behavior, including the characteristics of the stair users,
2. maintenance, including the way stair are constructed, and
3. design, including the environment in which stairs are set (Gunatilaka, Clapperton, & Cassell, 2005; Roys, 2001).

Roys (2001) suggested that reduction in stair falls can be most effectively and fundamentally achieved thorough elimination of design-induced falls; the likelihood of stair accidents can be decreased by way of an improved design. An example of poor design includes large gaps in a balustrade, irregular sized rises and goings, too steep pitch, and goings being too narrow (see figure 1).

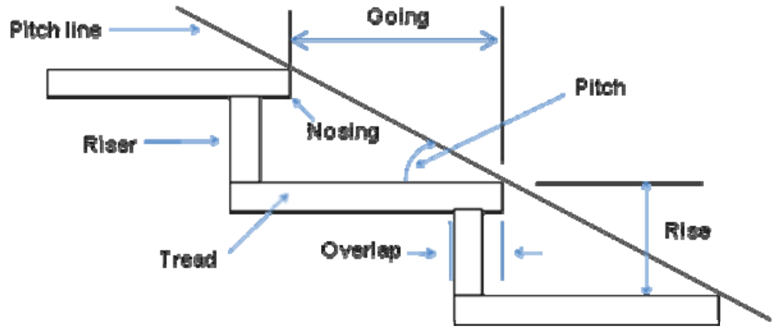


Figure 1. Stair definitions

Stair fall reduction could be best accomplished by the elimination of stair itself, using the alternative ways of vertical movement including elevators and ramps. The Australian Standards recommends that dwellings designed for older people and people with disabilities should be built on one level, with no entry step and unnecessary changes in levels in homes should be avoided where possible (Standards Australia, 2008). In reality stairs have been the default approach to managing multiple levels in buildings as installation of elevators is not always viable, particularly in private homes, and ramps require a greater amount of space (Sorensen, 1979). Therefore, building well-designed stairs and modifying stair environment are the most feasible options in minimising the structural falls on stairs.

Aims

This publication aims to review the general design principles and requirements for stair safety. It also investigates the diverse design features of stairs and subsequent implications for safe stair use, focusing on stair design and step geometry. The main aspects of stairs discussed in this publication include

- rise height and uniformity,
- step depth and width,
- slope, and
- tread configuration.

Other environmental factors such as stair covering, finish, handrails, and lighting will be also be discussed. In addition to the requirements of the Building Codes and Standards, other scientific evidence will also be reviewed. This publication is expected to provide information for a safe design and assist with stair selection in installing and modifying stairs.

Standards and codes

Stair building is expected to comply with a number of Australian Standards (AS) and Part 3.9 of the Building Code of Australia, (Australian Building Codes Board, 2008). The Australian Standards were been developed to provide technical detail for the design and construction of buildings covered by the Building Code of Australia (BCA). AS 1428 (parts 1,2 and 3) deals with design for access and mobility - general requirements for access, enhanced and additional requirements for buildings and facilities, and requirements for children and adolescents with physical disabilities respectively. AS 1657 (Standards Australia, 1992b) and AS 4226 (Standards Australia, 2008) provide useful guidelines for safe stair construction including the size of the goings and the height of the steps.

The BCA refers to the previously cited Standards (and others) as referenced documents for the technical detail on how to achieve the required level of access for accessible stairways. The design and construction of accessible stairways in compliance with this These Standards, where referenced, hope to ensure compliance with the deemed-to-satisfy access provisions of the BCA. It should be noted that the preferred configurations for users with walking frames and severe ambulant disabilities may not comply with the normal requirements of the regulatory authorities (Standards Australia, 1992a). The relevant standard and code to be referenced for stair safety are as follows:

AS 1428.1 – 2001

Design for access and mobility, Part 1: General requirements for access – New building work

AS 1428.2 – 1992

Design for access and mobility, Part 2: Enhanced and additional requirements – Buildings and facilities

AS 1428.3 – 1992

Design for access and mobility - Requirements for children and adolescents with physical disabilities

AS 1657 – 1992

Fixed platforms, walkways, stairways and ladder – Design, construction and installation

AS 4226 – 2008

Guidelines for safe housing design

BCA (Vol 1) D2.3

Non-fire-isolated stairways and ramps

BCA (Vol 1) D2.8

Enclosure of space under stairs and ramps

BCA (Vol 1) D2.14

Landings

BCA (Vol 1) D2.16

Balustrades or other barriers

BCA (Vol 2) PART 3.9.1

Stair Construction

BCA (Vol 2) PART 3.9.2

Balustrades

General design requirements

Number of steps

The number of steps and risers is an important design factor that affects fall risk on stairs (Gunatilaka, et al., 2005). The BCA requires that for each flight, (that part of a stair that has a continuous series of risers), have not more than 18 nor less than 2 risers (Australian Building Codes Board, 2008). Research has shown that stair falls occur disproportionately to the number of risers (Jackson & Cohen, 1995; Templer, 1992). That is, probability of fall accident decreases with the length of flight. According to Jackson & Cohen's (1995) observation, 30 percent of accidents took place in one or two riser stairways. In order to reduce falls on one or two riser stairs, AS4226 (Standards Australia, 2008) requires that the number of risers should be no fewer than three. High fall incidence in a short flight is due to the lack of visual cues which indicate changes in elevation. Pedestrians are not able to adjust their gait to the unexpected change in surface conditions, and thus the use of ramp is recommended instead of one step risers wherever possible (Marletta, 1991). AS4226 (Standards Australia, 2008) also recommends changes in colour or light intensity, changes in wall or floor finishes, or the presence of handrail to obtain contrast for better visibility.

Size of risers and treads

Dimensional irregularity is a common cause of missteps and falls on stairs (Templer, 1992). The BCA calls for the dimensions of goings and risers of a stair to be constant throughout each stair flight. That is, all risers and goings in the same flight of stairs should have the same dimensions within a tolerance of ± 5 mm (Standards Australia, 1992b, 2008).

Comfort and safety on stairs are affected by the height of risers (Pauls, 1984). Irvine, Snook, & Sparshatt (1984) demonstrated that stair preference is more sensitive to changes in stair risers than to changes in goings. In general, high risers are regarded to pose increased risk as they demand more physical exertion, particularly of frail older people (Connell & Wolf, 1997). However, risers that are too low are also hazardous as they 'cause the foot coming off of it to land further back on the tread. A low riser will place the foot back so far that when the opposite foot attempts to clear the surface below, the heel will become caught on the tread surface (Rosen, 1983, p. 33).' Therefore, AS 4226 stipulates not only the upper but also the lower limits of the riser heights; riser heights should be uniform in the range between 150 mm and 180 mm (Standards Australia, 2008). However, for elderly people or people with ambulatory problems, a rise of 95-105 mm is recommended (CSIRO, 2001).

Steps should be large enough to provide adequate footing (Pauls, 1982). Short tread steps can make people stumble or fall as people might place a foot far forward the tread in descending (Barss, Smith, Baker, & Mohan, 1998, p. 169). Stair treads should be level and able to accommodate the full length of an average adult's shoe (Standards Australia, 2008). However, too large a tread is not recommended as it is expensive and inefficient in terms of the space it occupies. According to AS1657, tread should be not less than 215 mm and at least 305 mm deep measured horizontally from nosing to nosing (Standards Australia, 1992b). Treads of 300 mm allow safe placement of a four-point walking stick, and treads of 575-600 mm are recommended for people using walking frames (CSIRO, 2001).

Slope

The combination of the dimensions of risers and goings results in the pitch of the stairs. The maximum pitch for the elderly people, young children, and people with mobility impairments is recommended at between 33 degrees and 35 degrees (Adler, 2002; Pauls, 1982). Pitch angles greater than 35 degrees are less suitable for elderly and disabled people. While stair slope used to be accepted at between 30 degree and 50 degree regardless of the riser and tread dimensions (Irvine, et al., 1990), slope is now recommended with the clear definitions with regard to riser and tread dimensions. The formula for relating the depth of treads and the height of risers was developed by Francois Blondel, a French architect, in 17th century (Templer, 1974). Based on observations of people' gaits, the formula suggested that twice the riser height plus the tread depth should be between 24 inch and 25 inch (610 mm and 635 mm). While there have been variations across the countries in applying this formula, it has been widely adopted in stair building.

The current Australian building standards also applies the formula, 2R + G, to quantify the relationship between riser (R), going (G), and slope. In principle, a lower stair pitch is recommended to minimise the likelihood of falls (Standards Australia, 2008). A steeper stair pitch might cause severe injury by failing to protect stair users from a longer fall (Barss, et al., 1998). The Standards (Standards Australia, 1992b) specifies the dimensions of riser and going along with the range of the slope as follows;

> the product of riser × going must not less than 45,000 nor more than 48,000, and a slope for a stairway should be between 45 degree and 26.5 degree.

The following diagram shows the recommended dimensions of riser and going applicable to a given slope. For example, for a 250 mm going a suitable rise would lie between 180 mm and 192 mm, and for a 170 mm rise a suitable going would be between 265 mm and 282 mm.

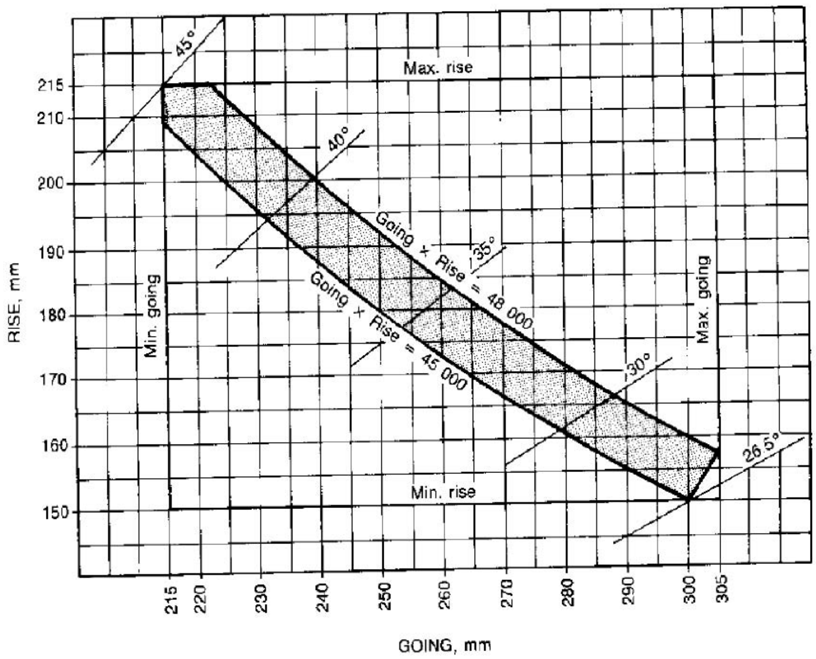


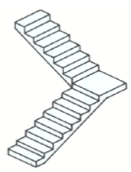
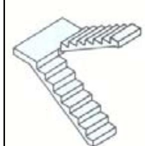
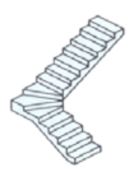
Figure 2. Suitable stair dimensions (source: Standards Australia, 1992a)

Design features of stairs

Stair shapes

There are a wide range of types of stairs. In general, stairs can be divided by their shape into straight and those other than straight. More detailed classification is possible; straight stairs, stairs with landings (including L stairs and U/return stairs), winder stairs, and curved stairs including circular and spiral stairs. It is assumed that each type has its own uses and purposes such as space utilisation, aesthetics, material, and preference of residents. It is generally acknowledged that wider and increased graduation in stairs are safer that narrower and steeper ones. However, they take up more space. The more complicated the stair design, the more costly they become. Therefore, there might be a compromise between safety, space and cost. The following table provides relevant factors in selecting stairs and design criteria applicable.

Table 1. Comparison of stair types

Stair types	Features	Diagrams	Advantages	Disadvantages	Requirements
Straight stairs	- Simplest design - No turns - Used most in home construction		- Easy to construct - Less expensive	- Long open space or high ceiling required - Difficult to accommodate in the floor plan	- Should comply with the general design requirements on risers, goings and slope
L-shaped stair (quarter-turn stair)	- One landing at some point along the flight of steps		- Useful when the space required for a straight stairs in not available - Possible to be located in the corner - Provision of resting place and the reduced distance of fall	- Probable to need more floor space than a straight stair - More difficult to construct than straight stairs	- The length and width of the landing should not be less than the width of the stairway. - Landings should have a minimum vertical clearance of not less than 2000mm. - Landings must be not less than 750mm (where this involves a change in direction, the length is measured 500mm from the inside edge of the landing). - Landings have a gradient not steeper than 1:50
U (double L-shaped) stairs (half-turn stair)	- Two flights of steps parallel to each other - 180˚ turn at one large landing		- Smaller space required - Useful when there need many risers but small floor space - Provision of a place to rest and the reduced distance of fall (same as the L-shaped stair)		
Winder stairs	- Pie-shaped steps which are substituted for a landing		- Less space required than L and double L stairs	- Less safe than L and double-L stairs due to the lack of step uniformity of winders	- The width of winders should be sufficient at midpoint. - The going of the winders should be constant.
Spiral / circular stairs	- Circular stairs: sweeps in a broad curve from one level to another - Spiral stairs: twists around a centre pole, from which steps radiate out		- Can be used where little space is available - Ideal for access to attic, basement rooms, and lighthouse - Better aesthetics	- Hard to climb - Not safe as they have winder steps - Not suitable for primary stair	- The radius to the centre-line of the stairway should not be less than 600mm. - The maximum width of the curved stairway should be 750mm.

Straight stairs are the easiest and most affordable type to build. However, stairs with landing such as L-shaped or U-shaped stairs are recommended as they are safer and easier to climb. Where stairs are extensively used by elderly persons, frequent landings with adequate standing space are recommended as resting places (Pauls, 1982). Winder stairs, circular, and spiral stair share the common design feature in that tread depths at the inside of the curve are narrow and deep at the outside. While they take less space than straight stairs, they pose serious danger for human locomotion due to lack of uniformity of steps (Rosen, 1983). AS1428.1 particularly suggests that spiral stairs should be avoided (Standards Australia, 2001). There is a rare justifiable need for spiral stairs, particularly when safety is concerned (Rosen, 1983).

Risers: open/closed

Generally there are two riser types; open and closed. Stairs made of independent treads without risers are called open-riser stairs, while those that have risers are called closed-riser stairs. Open-riser stairs can be built more economically with the use of less material. It can be of used as a kind of ladder when floor space limited and steep climbing is required. Open risers less restrict the view as they allow the pedestrians to see through the stairs.

However, open risers are less safe than closed risers because it is possible for a foot to slip through and toes might catch on the underside of the treads during ascent (CSIRO, 2001; Standards Australia, 2008). They can also pose visual problems to the persons on ascent as the background behind the open risers can be distracting. The dislike of the open-riser stairs was identified among older pedestrians. Being able to see through the floor below and the presence of space in front of them on the stairs reduced the confidence (Haslam, Sloane, Hill, Brooke-Wavell, & Howarth, 2001).

Open-riser stairs are not recommended by the AS (Standards Australia, 2008), however, when open risers are inevitable, the gap between the treads must not exceed 125 mm (Australian Building Codes Board, 2008). Treads on open-riser stairs must be strong enough to support the weight of the persons standing on it as they are not strengthened by risers (Thallon, 1998).

Nosings

A nosing is the front leading edge of the tread (see figure 1). Stair nosings are installed to facilitate recognition of the treads. Stair nosings often have a non-slip treatment to reduce the likelihood of slips and falls. Traditional stair design allowed the nosings to overhang the tread. However, Johnson (1979) argues that overhand nosings increase the risk of falling by decreasing the surface area for the foot to be placed on the tread and by catching toes or the tips of a crutch or cane.

Two shapes of stair nosing are available: rounded and sharp. Rounded nosings are seen to be safer than non-rounded ones, but they can cause slipping (Johnson, 1979). Too sharp a nosing can also be hazardous (CSIRO, 2001). Therefore, AS1657 recommends rounded nosings with a radius of 10-15 mm and splayed risers with a maximum projection of 25 mm (Standards Australia, 1992b). Stair nosings should be colour contrasted (Standards Australia, 1992b) and nosing strips should be flush with the surface of the treads (CSIRO, 2001), with the size being not less than 50 mm and not greater than 75 mm (Standards Australia, 2001).

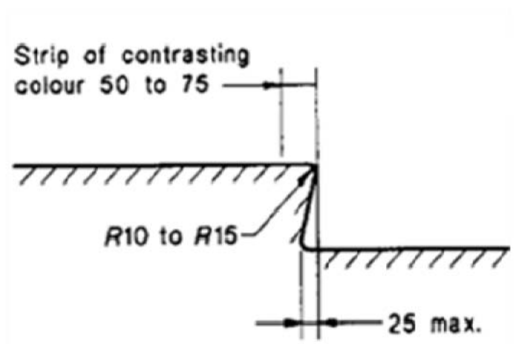


Figure 3. Recommended nosing design (source: Standards Australia, 1992a)

Checklist for stair design for homes

General

• Install stairs only where they are necessary

• Avoid single riser stairways

• Make steps visually prominent so that their presence is obvious

• Remove tripping surfaces and projecting obstacles on treads

Stair design

• Build steps so that each flight has not more than 18 nor less than 2

• Build step riser dimensions at least 150 mm but no higher than 180 mm (95 – 105 mm for elderly people or people with ambulatory problems)

• Build tread not less than 215 mm and at least 305 mm (575-600 mm for people using walking frames)

• Keep risers and treads consistent in size within a tolerance of ±5 mm

• Build a stairway so that the slope ranges at least 26.5 degrees but no higher than 45 degrees (less than 35 degrees for elderly and disabled people)

• Install landings as a resting place and device to reduce the distance of fall

• Avoid winding, curved and spiral stairs (when inevitable, ensure that the width of the steps at midpoint are constant and sufficient)

• Avoid open riser stair (when inevitable, ensure that the gap between the treads does not exceed 125mm)

• Provide slightly rounded nosings for visibility and injury reduction (with a radius of 10-15 mm)

Visibility

• Avoid tread materials and coverings with visually distracting patterns

• Mark nosings permanently if they are not distinctly visible

• Provide lighting that makes tread nosings distinctly visible

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