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The science behind codes and standards for safe walkways: Changes in level, stairways, stair handrails and slip resistance

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ABSTRACT

Walkway codes and standards are often created through consensus by committees based on a number of factors, including historical precedence, common practice, cost, and empirical data. The authors maintain that in the formulation of codes and standards that impact pedestrian safety, the results of pertinent scientific research should be given significant weight. This article examines many elements of common walkway codes and standards related to changes in level, stairways, stair handrails, and slip resistance. It identifies which portions are based on or supported by empirical data; and which could benefit from additional scientific research. This article identifies areas in which additional research, codes, and standards may be beneficial to enhance pedestrian safety.

1. Introduction

Falls account for a leading cause of injury-related emergency department visits every year in the United States (U.S.), with over 10 million people injured from falls in 2010. Falls also are a leading cause of unintentional death in the U.S., resulting in more than 27,000 fatalities in 2010 (National Safety Council, 2014). Falls present a substantial problem in the workplace, comprising at least 20–40% of disabling occupational injuries in the U.S., the United Kingdom (U.K.) and Sweden (Courtney et al., 2001).

One way to avoid falls is to design, construct, and maintain walkways so that pedestrians can utilize them safely and for their intended purposes. The authors' forensics experience, as well as previous research, has indicated that the causes of falls have many factors, including the construction components of the walkway, footwear, housekeeping and maintenance practices, and safety policies and practices (Bentley, 2009; Chang and Matz, 2001; Gielo-Perczak et al., 2006; Kemmlert and Lundholm, 2001; Leamon, 1992; Quirion et al., 2008; Verma et al., 2011). Some standards address some of these latter factors, such as ASTM F695 (2009), ASTM F1240 (2009), and ASTM F2948 (2013). However, these standards will not be addressed in this article. Instead, this article will focus primarily on construction components of the walkway and related standards.

A walkway can be defined as "walking surfaces constructed for pedestrian usage including floors, ramps, walks, sidewalks, stair treads, parking lots and similar paved areas that may be reasonably foreseeable as pedestrian paths" (ASTM F1646-13). While surfaces such as footpaths and playing fields are excluded from this definition, a number of walkway standards such as ANSI/ASSE A1264.2-2012 and ASTM F1637-2013 note that walkways may be either interior or exterior surfaces intended for pedestrian use.

Walkway codes and standards, just as many other codes and standards, are often created through consensus by committees based on a number of factors, including historical precedence, common practice, cost, and empirical data. The authors maintain that codes and standards that can have an impact on human safety and welfare should give significant weight in their formulation to the results of pertinent scientific research. To that end, the purpose of this article is to examine many elements of common walkway codes and standards, indicate which portions are based on or supported by empirical data, and which could benefit from additional scientific research. Further, the purpose of this article is to identify areas in which additional research, codes, and standards may be beneficial. The article is divided into four sections: level walkways, stairways, stair handrails, and slip resistance of walkways.

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2. Level walkways

Many codes and standards such as the International Building Code (IBC), ICC/ANSI A117.1, Uniform Federal Accessibility Standards (UFAS, 2004), the Department of Justice (DOJ, 2010), and ASTM F1637 provide requirements for a level walkway, such as this requirement in ASTM F1637-13: “Adjoining walkway surfaces shall be made flush and fair, whenever possible and for new construction and existing facilities to the extent practicable”. The text continues by specifying how to manage walkways that deviate from “flush and fair”, which also reflects requirements in ICC/ANSI A117.1-2009, UFAS (2004) and the DOJ (2010):

i) “Changes in levels up to 1⁄4 in. (6 mm) may be vertical and without edge treatment.
ii) Changes in levels between 1⁄4 and 1⁄2 in. (6 and 12 mm) shall be beveled with a slope no greater than 1:2 (rise:run).
iii) Changes in levels greater than 1⁄2 in. (12 mm) shall be transitioned by means of a ramp or stairway…”

These requirements for how to manage walkway changes in level were first implemented in the 1980 version of ANSI A117.1. The foreword for ANSI A117.1-1980 indicated that the revisions were based on research funded by the U.S. Department of Housing and Urban Development (HUD) and started in 1974. Published research from this effort included Steinfeld et al. (1979a) and Steinfeld et al. (1979b).

2.1. Changes in level

Steinfeld et al. (1979a) did not include any research on walkway changes in level other than door thresholds. The description of their research on accessibility of doorways (Steinfeld et al., 1979a, Chap. 10), indicated they only used a 9.5 mm (3/8 in) square edge threshold in tests with wheelchair users. The chapter concluded with recommendations to refrain from using thresholds at interior doorways, to limit threshold height in exterior doorways to a maximum of 12 mm (1/2 in), and to bevel the edges. This recommendation for door thresholds was extended to recommendations for other walkway surfaces (Personal communication, Edward Steinfeld with Kenneth Nemire, August 2013).

The initial requirements for changes in level in the ANSI A117.1-1980 standard were created to make walkways more accessible for people who use wheelchairs, walkers and other ambulatory aids. Beginning about 1990, U.S. model codes began to mainstream selected requirements of ANSI A117.1 for the general safety of all users, a pattern also followed in the 1995 version of ASTM F1637. However, ASTM F1637-95 indicated that the standard was to make walkways safe for pedestrians, and may not be adequate for those with physical disabilities: “This practice is intended to provide reasonably safe walking surfaces for pedestrians wearing ordinary footwear. These guidelines may not be adequate for those with certain mobility impairments.”

The research regarding walkway changes in level that provided the foundation for standards in 1980, and afterwards, was based on research with people who used wheelchairs. There is other research involving pedestrians who do not use ambulatory aids that show that the 1980 standards for changes in level may be applicable to them as well. Studies of foot trajectory and minimum foot clearance of younger and older pedestrians while walking at self-selected paces indicate that changes in level as small as 6 mm (0.25 in) in a walking surface, such as a sidewalk, can present trip hazards to healthy ambulatory pedestrians (Begg et al., 2007; Murray et al., 1969; Murray et al., 1966; Winter, 1992; Winter et al., 1990).

Examination of data from these studies also shows that changes in level smaller than 6 mm (0.25 in) may disrupt gait and cause a trip and fall. For example, data from a sample of healthy elderly men showed that minimum foot clearance within two standard deviations of the mean (95% of the sample) included values of zero, indicating contact of the foot with the floor (Murray et al., 1969). Similarly, Begg et al. (2007) showed that minimum foot clearance at two standard deviations of the mean (95% of the sample) was 1.9 mm (0.076 in) for healthy younger adults (mean age 26.4 years), and −0.9 mm (−0.038 in; negative values are due to the skewed distribution of the data) for healthy older adults (mean age 72.1 years). These data indicate that minimum foot clearance in healthy adults can be lower than 6 mm (0.25 in).

This research on pedestrian gait would indicate that changes in walkway levels up to 6 mm (0.25 in), acceptable by standards such as ICC/ANSI A117.1-2009 and ASTM F1637-13, may pose trip hazards for some members of the healthy ambulatory population.

However, Begg et al. (2007) showed that the data for minimum foot clearance were not normally distributed, and had positive skew and positive kurtosis. Consequently, standard deviation would not accurately describe the variance in minimum foot clearance because it would provide an overestimate of the variance on the left side of the distribution. A more appropriate criterion for a change in level that may be vertical and without edge treatment, and that may pose an acceptable risk of tripping, may be at the 5th or 10th percentile minimum foot clearance. Begg et al. (2007) did not report data to determine either the 5th or 10th percentile values, so further analyses are needed. In addition, the results from Murray et al. (1969) and Begg et al. (2007) were based on a small sample of participants; a larger sample size would be useful.

Since the cited research evaluated gait parameters for healthy adults, and did not evaluate gait parameters for those pedestrians with infirmities or other common conditions that may affect walking, further evaluations are needed. With a significant and growing U.S. population of elderly citizens (Administration on Aging, 2013), it is important to design walkways for their expected use as well. Research is needed to evaluate minimum foot clearance in these populations so that standards for change in level may be reduced accordingly.

2.2. Beveled transitions

Section 4.5.2 of ANSI A117.1-1980 indicated that “Changes in level between 1⁄4 in and 1⁄2 in (6 and 13 mm) shall be beveled with a slope no greater than 1:2”. This requirement has been retained by many standards and requirements including ASTM F1637-2013 and ICC/ANSI A117.1-2009. IBC (2015) provides similar requirements in Section 1010.1.7: “… Raised thresholds and floor level changes greater than $^{1}/_{4}$ inch (6.4 mm) at doorways shall be beveled with a slope not greater than one unit vertical in two units horizontal (50-percent slope).”

While Steinfeld et al. (1979a) did not conduct any research on what bevel slope, or range of slopes, would facilitate access by wheelchair users, they noted that Department of Health accessibility standards at the time allowed a door threshold with a maximum 8% beveled slope (Steinfeld et al., 1979a, p. 48).

While it may be assumed that a beveled walkway transition with a slope no greater than 1:2 (rise:run) also may reduce trip and fall incidents by eliminating abrupt vertical surfaces that can abruptly stop a swinging foot, and cause a stumble and fall, there is no known research on what slope may be of greatest benefit for pedestrians in or out of wheelchairs.