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FE Evaluation of Pedestrian and Worker Fall Incidents — the Evolution of Analysis Techniques and Safety Requirements

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Abstract

Fall injury and fatality claims and legal cases involving ordinary pedestrians as well as employees/contractors at work sites have increased dramatically over the course of the author's 43-year engineering career. As a result, forensic engineers are frequently being contacted by insurers and attorneys to analyze these incidents. The need is to determine probable cause(s) and ascertain as to whether location features were designed, constructed, installed, manufactured, and/or maintained in accordance with the standard of care, including requirements specified in applicable codes and standards. The proper contemporary analysis techniques for these incidents are addressed in this paper as well as what constitutes proper basis for establishing a standard of care for involved installations and/or equipment. It will also expand on and update information provided in approximately two dozen past NAFE papers on various aspects of fall incident analysis, most of which are more than 10 to 30 years old.

Keywords

Forensic engineering, pedestrian, walkway, slip, trip, fall, stair, ramp, handrail, guard

Introduction

Pedestrian and worker access features that enable walking, ascending, or descending are a widespread part of the built environment in buildings, facilities, and public spaces, resulting in significant potential for hazardous incidents. The standard of care, including legally enforceable code and ordinance requirements for installation and maintenance of those features, has evolved significantly with a trend toward more stringent specifications, especially in the last 30 years. These standards and requirements are based on elimination of features that are generally considered to be trip, loss-of-balance, and/or fall hazards. Evaluation of claims or allegations of an injury being potentially related to a deviation of one or more access features from those standards of care requires knowledge on how those features are constructed and maintained, what specific standards are applicable, and how deviation of a feature from those standards could have been a factor in a specific incident. This paper addresses these issues and presents a few summarized case studies.

Access Features

Walkways or surfaces originally installed without elevation changes (not necessarily level) are the most common type of pedestrian or worker access feature. Of particular significance are doorways, including thresholds and landing areas on either side. For significant elevation changes, ramps and/or stairs are most commonly utilized. In many cases, handrails or guards (guardrails) are necessary on the sides of stairs and ramps to assist pedestrian stability, help identify the elevation change, and/or protect against falls from heights.

An often ignored or forgotten pedestrian access feature is proper illumination of other built features (both indoors and outdoors), especially at night. Another area of increasing concern for pedestrian access and safety are paved surfaces intended primarily for vehicle traffic, which could also be reasonably expected to be used by pedestrians, especially in parking areas. Of special concern are walkways and elevation change features provided primarily or solely for workers on commercial, industrial, and construction sites. At those restricted locations, falls from significant heights are a major concern.

The issue of walkway surface traction for proper pedestrian safety is of great importance. However, due to the scientific complexities of this issue, it is more properly the

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subject of separate papers devoted to that topic[1,2,3,4,5,6,56]. Therefore, this paper mentions means for documenting pedestrian access features in cases where a slip is claimed, but does not address surface slip resistance evaluation or standards of care.

Codes, Standards, and Laws

The most often-cited regulations are building and egress codes, government regulations, and/or national standards, which, in most localities, are adopted (possibly with amendments) by ordinance, frequently in accordance with state law. A listing and brief description of past and current nationally prominent codes is provided in **Figure 1**[7,8,9,10,11,12,13,14,15,16,17,18,19,20].

Since 2000, either the International Building Code (IBC) or the Life Safety Code (LSC) represents the law and the standard of care for construction (and, in many cases, maintenance) of pedestrian access features in most locations within the United States. One important note about both the LSC and the IBC and their predecessors is that most of the requirements governing pedestrian access features are located in single chapters covering means of egress (MOE) and accessibility for persons with physical challenges. However, these codes also include separate chapters for differing types of occupancies that may include additional special requirements for pedestrian access features at those locations.

The key factor with all of these codes is that they are only recommended for use by their publishing organizations, though they do serve as a widely recognized standard of care. They are only enforceable as a matter of law when required by the state or municipality where a property or structure resides. In addition, the enforcing authority (frequently referred to in the codes as the "authority having jurisdiction" or AHJ) may adopt any of these codes with its own amendments or even create its own code.

For free-standing residential structures housing one or two families only (or, in some locations, a slightly greater number, such as in a row of townhouses, based on AHJ enforcement), related residential codes have developed with generally less complex — and to a certain degree less

Code Type	Code Name/Publisher Acronym	Effective Yrs	Comments
Egress	Building Exits Code (BEC) - NFPA 101	1927 to 1963	Covered only facility means of egress (MOE) features
	Life Safety Code (LSC) - NFPA 101	1966 to present	Replaced BEC to cover MOE and other fire prevention/protection and emergency features
Building	National Building Code (NBC) - NBFU/AIA	1905 to 1976	First nationally recognized building code, created by property insurers
	Unified Building Code (UBC) - ICBO	1927 to 1997	One of three U.S. regional model building codes, primarily in Western states
	Southern Standard Building Code (SSBC) - SBCC	1945 to 1973	One of three U.S. regional model building codes, primarily in Southeastern states
	Standard Building Code (SBC) - SBCCI	1973 to 1999	Update/replacement for SSBC, primarily a marketing name change
	BOCA National Building Code (BOCA) - BOCA	1950 to 1999	One of three U.S. regional model building codes, primarily in Midwestern and Northeastern states
	International Building Code (IBC) - ICC	2000 to present	Created by cooperative merging of three U.S. regional model building codes
Residential	One- and Two-Family Dwelling Code - CABO	1971 to 2000	Cooperative effort of three U.S. regional building code organizations, for houses
	International Residential Code (IRC) - ICC	1998 to present	Successor to CABO code for one- and two-family dwellings
Disabled Access	ADA Standards for Accessible Design	1991 to present	Based on U.S. federal legislation and regulations, mandatory for many public facilities
	American National Standard A117.1 - ANSI	1961 to present	Represents a design professional standard of care but only limited adoption by law or codes
Maintenance	BEC and LSC	1927 to present	Has general maintenance requirement specific to MOE
	International Property Maintenance Code (IPMC) - ICC	2000 to present	Provides maintenance requirements for all properties
	International Fire Code (IFC) - ICC	2000 to present	Provides construction and maintenance requirements for MOE and other fire safety features

Figure 1

Codes for pedestrian walkway features (means of egress). Note: Prior to 2000, the three Model Building Code organizations published some MOE maintenance requirements in their building codes and/or in separate codes.

stringent — requirements, including for pedestrian access features. Regulations and standards associated with pedestrian routes provided for access by persons with mobility impairments may also apply, depending on the type of facility and local authority requirements. Requirements for maintaining pedestrian features in a safe/usable condition also exist, depending on local authority adoption of available codes or their own specific requirements.

An important building code concept is "grandfathering" where the code that was mandated by the AHJ at the time of construction continues to apply to the structure or property up to the present day — even if newer code editions have more stringent requirements for pedestrian access and other features than exist at that property. Typically, if the structure or property undergoes a significant renovation, has a change in occupancy (usage or function), or if the AHJ deems that a particular feature not meeting the most current code requirements must be updated for public safety, then the newer requirements come into effect.

Unique to the Life Safety Code are differing requirements for new construction versus renovations where existing features (especially stairs and ramps) are left in place or are themselves repaired or improved. The LSC provides that these existing features may retain their original dimensional properties if they meet somewhat less stringent specific requirements. This is permitted because attempting to rebuild a feature (such as a staircase or ramp) with greatly differing dimensions may not be practical without major demolition and reconstruction in many buildings. Determining the actual construction (and/or major renovations) date(s) for a particular property can frequently be obtained online through the appropriate property tax assessor's office from design drawings prepared for the facility construction or renovation — or from the AHJ.

For the special case of protecting workers from falls at locations where they are employed that include out-of-the-ordinary potential access hazards, the primary force of law are the federal Occupational Safety and Health Administration regulations[21,22,23,24,25,26,27] as well as regulations from other agencies governing specific types of industries. Many states have also adopted additional provisions for worker safety. There are also two American National Standards[28,29] that provide standard of care provisions. Some of these ANSI provisions have been adopted by OSHA or other governing authorities for both permanent-type workplaces and construction sites, respectively.

An important explanatory reference for interpreting code provisions regarding pedestrian access features is the companion handbooks provided with the more recent editions of the LSC by the National Fire Protection Association (NFPA)[30]. Most editions of the LSC also include Annex A explanatory material, which provides non-mandatory advice or further details on the basis of certain code requirements. In addition, a useful standard of care reference for design professionals with regard to pedestrian access features (including some features not necessarily addressed by codes) has been published and updated for more than 80 years by the American Institute of Architects[31]. ASTM International first published its *Standard Practice for Safe Walking Surfaces*[32] nearly 30 years ago. However, it is not typically referenced in codes/ordinances (except for explanatory/informational reference in the LSC) or necessarily well known outside the engineering community. Therefore, it may not necessarily be accepted as a standard of care for some properties or jurisdictions.

Evaluation of Access Features

When assessing any access area alleged to have been involved in a pedestrian injury incident, it is important first to identify all of the access features that potentially could have been a factor in the described sequence of events. This is followed by determining how each of those features can be assessed objectively for comparison to applicable standards. As part of this initial assessment, the overall incident area and the individual features should be photographed. It may be helpful to photographically and/or video-graphically recreate the probable views of the reported pathway of the incident claimant/plaintiff based on the report of that person and any witnesses.

If possible, the incident area should be viewed and documented in lighting conditions similar to those reported. For outdoor inspections, the weather conditions at the time of the incident may need to be considered, including water flow or icing conditions. If there is significant delay between the dates of incident and inspection, then determine if there is any photographic evidence or online views of the area closer to the time of the incident for analysis of modifications or changes to the physical features.

Of particular importance is whether the property owner/manager has modified any of the pedestrian features of interest — either in response to the incident or for other reasons. Additionally, outdoors it can be important to document the location of the pedestrian access feature(s) claimed to have been involved in the incident relative to both adjacent building exits and also any marked ADA access features. Note: For measurements of details, such as stair treads, risers, and rail features, the author recommends that parameters be recorded with an accuracy of $\pm^1/_{16}$ inch. This is of sufficient precision to compare parameters to typical code requirements. Workmanship limitations for the construction of most pedestrian access features is such that greater precision is typically meaningless. In cases involving complex dimensional details, three-dimensional imaging/scanning may also be useful. Any walking surface instability, damage, or deterioration and its cause should also be documented in detail.

Flat Walkways

With "flat" walkways, the primary details to document are any elevation changes as well as clear width. Sloped surface grades and lengths between grade changes should be recorded. Additionally, document heights or profiles of any abrupt elevation changes, including doorway thresholds or trim strips between differing floor surfacing materials (for these types of investigations, a carpenter's or machinist's profile gauge may be useful), as shown in **Figures 2** and **14**.

A specific type of abrupt elevation change often found in parking decks — and the subject of a number of trip claims — are expansion joints with or without covers. Of particular interest, especially in outdoor decks and walkways, are abrupt elevation changes at joints or fractures in surfaces that appear to have occurred after construction.

When measuring elevation change heights, it can be important to document the vertical change at multiple points along the walkway width because variations are frequent. It's important to document surrounding conditions that appear to have possibly contributed to the elevation change initiation or progress (e.g., trees and roots adjacent to sidewalks). Specifically for sidewalks, if appropriate for the site, a small diameter probe rod may be useful for detection of voids or differing bearing strength soils beneath areas where differential settlement appears to have occurred (use appropriate safety practices if underground utility features may be present).

Figure 2
Use of profile gauge to measure elevation change details.

For elevation changes at or close to doorways, important details include size of landing areas on either side of the door or doorway, height of those landings relative to each other and the door threshold, width of the landings relative to the doorway width, and swing or slide details for the door(s). The type of floor or walkway surfacing materials should also be documented. A tool that may be particularly useful on sloping surfaces or for documenting any type of elevation change (especially over longer distances) is a laser-type leveling or scanning instrument for accurately establishing the difference in elevation between two or more locations.

Stairs

For stairways (including single steps or risers), it is most crucial to document the depth of each tread and height of each riser, typically at multiple points across the width of the stairway. The LSC and its associated Handbook, in Annex A for the stairway requirements, provides useful guidance on how to determine those parameters, including for stairs where overlaps, tread slopes, or soft surface materials are present. In most cases, the author has found that a steel carpenter's square combined with a short carpenter's level are the most efficient and accurate means for obtaining these measurements, though other references specify potentially effective alternative methods[33,34,35]. Curbs are a special case — basically a single riser step — and the documented parameters should include the height (including any variations over its length), any damage or deterioration, and any added coloring or other visual enhancement.

For stairways, the presence or absence of handrails and/or guards should be documented, keeping in mind that, depending on the stair age and configuration, they may not be required, required on one side only, required on both sides, or even required at intermediate locations for wide stairs. Handrail and guard height must be measured as accurately as possible above the leading edge of treads (nosing); the LSC Handbook illustrates this as the height above the imaginary sloped line that connects each tread nose. For this measurement, a combination of a ruler or tape and a 4-foot carpenter's level is best (a graduated level is ideal). The distance the rail extends beyond the topmost and bottommost risers on a staircase may also be of importance.

Other critical handrail dimensions involve determining if it has continuous "graspability" and include the cross-sectional profile/dimensions of the rail (another potential application for a profile gauge), the clearance between the rail and any adjoining wall or other surfaces, and how the rail supports and balusters are connected. The LSC Handbook has a good discussion and illustrations on graspability and these other rail details.

Whether they occur on stairs, ramps, or a level height, several details are critical for claims involving a person that fell over or through a guard system or lost balance and fell due to a loose or failed guard or handrail. This includes spacing between balusters as well as the details on how the rail system is or was anchored to the walkway or ground, walls, and posts. Failed handrail or guard system evaluations may be complicated by expedited post-incident repairs and possibly even disposal of removed hardware. This may necessitate reliance on photographs, statements, and repair documents — or even similar exemplar rail systems at the same property. Further details on evaluating guards/guardrail systems involved in incidents are also available[36,37,38,39].

Documenting the presence or absence of features that visually delineate the tread and riser boundaries/edges on stairs can be of importance in many cases. It is not uncommon for the original incident claim or later disclosure to allege that visibility of those features contributed to the occurrence. Photography focused on objectively documenting the visual contrast between those features (or lack thereof) can be most helpful.

Evaluations of pedestrian features should consider whether a particular feature that was alleged to have been a factor in an incident can be readily perceived by persons[40]. Another issue with some stairways is the stability of the treads or tread surfaces, especially as they age. Some stair treads may deteriorate, and, in some metal staircases with inserted wood or concrete treads, the supports or fasteners may loosen, resulting in treads that shift under a user's weight (**Figure 3**). Therefore, in cases where it was alleged that a user lost balance due to movement of the staircase or treads, careful examination of the entire structure (including the treads) for signs of damage, deterioration, or non-rigid conditions is critical. Carpet-covered stairs can pose additional visualization and footing challenges, particularly if the carpet fit is loose. Those details should also be documented.

Figure 3
Concrete stair tread attachment to steel frame.

Ramps

For ramps, the most critical dimensional property is the slope, including the consistency of that slope from top to bottom and side to side. Slope can be properly measured with either a mechanical-type instrument or an electronic "smart level"-type instrument. When using many electronic instruments, it is critical to set or calibrate the zero slope value using a reference known level surface, in accordance with the manufacturer's instructions, and to document that process.

Ramp clear width is also an important parameter. For ramps, as with stairways, the presence or absence of handrails and/or guards/guardrails (including combinations of both) as well as their dimensional details are important. The same dimensional parameters should be measured for rail systems on ramps as for those on stairs. Some ramps with open sides (whether or not rails are present) may also have curbing or other boundaries whose presence, height, and width should be documented.

An increasingly widespread type of exterior ramp is a curb ramp, which provides for elevation change access across a curb. They are of two types: ramps formed or cut into the curb and sidewalk (standard type) or extended (built-up) curb ramps that are built out from a curb onto the lower elevation paving (**Figure 4**). Curb ramps

Figure 4
Combination standard and extended curb ramp.
Lack of side flares on the extended portion presents
a trip hazard to pedestrians approaching laterally.

that are not delineated by rails or other barriers to prevent pedestrian cross traffic must have sloping side flares, so measurement of those side flare dimensions and slopes is of the utmost importance. When measuring ramp slopes, it is essential to document the direction and magnitude of the maximum slopes. As with stairs, the documentation of the visual contrast between ramp features (especially on curb ramps) is an important part of any inspection. Further guidance on design of curb ramps — and the sidewalks they are a part of — is provided in a federal government informational publication[41].

Illumination

In many fall injury claims, there may be an allegation that inadequate lighting prevented the injured party from visualizing the pedestrian pathway, especially at elevation changes. This can be a potential factor indoors (potentially at any time) or outside — usually for incidents occurring in twilight or nighttime conditions. The engineering investigator should recommend that the inspection include an illumination study, if there is any reason to believe that lighting conditions may become a factor in a fall incident claim or case.

The first step in evaluations where illumination was potentially a factor is to determine (as much as possible) the factors present at the date and time of the incident that would have affected the light intensity (both natural and artificial) on the pedestrian access features of interest. The goal with this initial research is to prepare for an inspection during conditions that replicate the incident lighting conditions as closely as possible.

The first factor to consider includes the number, type, and location of all artificial luminaires (including which were actually illuminated at the time of the incident) that could have affected the light intensity in the subject area. Of great interest is any shadowing of that light produced by permanent or movable physical features in the area or, in some cases, pedestrian or vehicle traffic. Outdoors, shading by trees and shrubs may need to be considered as a factor, including seasonal effects on foliage. Natural lighting, including lighting through windows, doorways, and skylights, must also be considered.

For natural lighting conditions during the day time, the sun angle and elevation (as well as any cloud cover) may need to be considered for the specific incident date and time. For night time or during twilight (the time before sunrise or after sunset when some solar illumination of the sky is still present), any sunlight effects as well as lighting from the moon need to be considered. There are a number of reputable online sources that will provide both sun and moon data (sky locations for each as well as lunar phases and percent illumination) at any given date and time at a specific GPS location or address[42]. Further available online is daily/hourly weather data for regions, based on the closest National Weather Service station[43]. Use of a professional-quality, properly calibrated illuminance meter (in accordance with the manufacturer's instructions), which can be placed on walkway surfaces, is critical for these types of evaluations.

Special Work Site Considerations

In addition to normal pedestrian features found at publicly accessible locations, industrial, commercial, and construction work sites limited to authorized workers typically have additional hazards for access. These can include elevated platforms with access stairs, ladders, or ramps (including stair/ladders that don't conform to the normal building code dimensional limitations) constructed of metal or fiberglass/plastic solid material or gratings. Although typical trip, slip, and fall hazards may be present at these locations, one of the most prevalent concerns is a fall from height.

At any location where a fall has occurred, evaluation of fixed fall protection features (if any), such as guardrails, gates, and ladder cages, should be performed. A federal government advisory document provides further guidance for evaluation of these types of features[44]. Where fixed fall protection is absent or appears inadequate, the evaluation should include provisions made for providing the workers with fall prevention and arrest equipment, including harnesses and lanyards. Provision of adequate strength lanyard anchor points can be a critical part of these types of evaluations, as are the employer's policies, procedures, and training provided to the workers regarding accident prevention and use of personal protective equipment[45,46].

In some cases, appropriate warning signage may be mandated or necessary. For some work sites — especially construction and demolition sites — the presence of permanent or temporary floor, wall, and/or roof openings may require special designs or protection provisions for fall prevention (**Figure 5**)[47]. A special case for work sites involves workers falling off of heavy vehicles or mobile machines, including construction site machinery, locomotives, airplane access equipment, etc.[48]. Additional considerations are necessary for worker protection during use of temporary scaffolding or other similar access hardware at construction sites[49].

Figure 5
Temporary floor opening at construction site requiring fall prevention features, such as covers or barricades per OSHA and ANSI requirements.

Another category of special cases, which may or may not technically involve a work site, affects situations and equipment for recreational activities. For example, activities such as natural surface or wall climbing, high diving, hunting and fishing, and amusement parks may have standards established through association groups or standards organizations, such as the American National Standards Institute, ASTM or Underwriters Laboratories (UL)[50,51].

Site Evidence Considerations

In many cases, the physical evidence may have been altered or destroyed following the incident. There are many instances where a property owner/manager, upon discovering that an incident has occurred, may have decided that improving, repairing, or even replacing pedestrian access features of interest is necessary. When a potential client first calls regarding possible retention for a case, it is advisable to query them regarding the site evidence conditions. Important actions may include a timely proper legal request regarding preservation of the evidence and prompt scheduling of an inspection (if needed) to avoid loss or spoliation of evidence. A further consideration for scheduling is to determine if weathering and pedestrian or vehicle traffic is likely to alter the pedestrian access features if an inspection is delayed.

When evaluating cases where some or all of the critical evidence has been altered or destroyed, photographs and witness statements (if available) can be evaluated to see if clear indications of feature compliance/deviation in regard to the relevant codes or standards can be determined. In some instances — where photographs are provided showing the intact evidence conditions — then a photogrammetric study may actually enable determination of key dimensions. Such a study may be enhanced by a site visit to measure intact features (shown in the provided photographs), which can be used as dimensional references. At some properties — where seemingly identical features are still in place or at locations other than where the incident occurred (e.g., apartment complex walkways, ramps and staircases) — these exemplars may be useful for acquiring dimensional and layout details when the actual subject features are no longer present.

Determination of Access Features Acceptability or Deficiency

After performing a thorough study of access features at a reported incident location, it is important to identify what codes, standards, and/or laws define the requirements and/or standard of care for construction and maintenance of those features, based on when the structure was built or renovated. **Figure 6** provides a listing of most of the

Code	Flat Walkways	Stairs
BEC/LSC	No abrupt level change >¼" and < 4" since 2000 ed. 1:2 bevel on changes >¼" and <½"	Risers <7 to 8" Treads >9-11" Variations: <3/16" or 3/8"
IBC	No abrupt level change <4" since 2000 ed.	Risers <7" Treads >11" Variations: <3/8"
IRC	No specific parameters	Risers <7¾" Treads >10" Variations: <3/8"
RMCs*	Abrupt level changes typically not addressed	Risers <7¾ to 8" Treads >9" Variations: "uniform" or <3/16" or 3/8"
ADA	No abrupt level change >½", since 1980 1:2 bevel on changes >¼" and <½" since 1986	Stairs are not allowed in ADA accessible routes.

Figure 6
Key code parameters for certain pedestrian walkway features (means of egress).
*RMCs refer to the three regional model codes as well as the AIA NBC in effect in portions of the United States before 2000 (see **Figure 1**).

widely recognized and adopted codes and standards in the United States. A key concept when utilizing the building and egress codes is understanding what constitutes the means of egress, since these codes cover those indoor and outdoor features at buildings and facilities.

The 2024 edition of the LSC defines the "means of egress" as a continuous and unobstructed way of travel from any point in a building or structure to a public way. It further defines the "public way" as a street, alley, or other similar parcel of land essentially open to outside air deeded, dedicated, or otherwise permanently appropriated to the public for public use and having a clear width and height of not less than 10 feet. The LSC Annex A Explanatory Material additionally explains the means of egress includes courts and yards — and that reaching the public way means persons can move away from a building unimpeded, including in crowded conditions. It should be noted that older code editions had more limited means of egress scope definitions. If the evaluation potentially involves compliance of pedestrian access features within what appears to be a pathway designated for ADA accessibility, then the definitions and descriptions of an "accessible route" as provided in the ADA accessibility regulations and standards are of great importance.

Flat Walkways

For indoor same level walkways, the current codes typically require flat level conditions without abrupt level changes, unless a compliant ramp or stairs is used — **Figure 6** provides details for each code. The LSC Annex A additionally provides a commentary discussing how small changes in elevation should be avoided due to increased occurrence for missteps due to the difficulty in visualizing them — and advising on how to increase their visualization if their construction is unavoidable. Since many of these small abrupt elevation changes in outdoor walkways are attributable to pavement condition changes, a critical factor (in many cases) may revolve around whether property maintenance requirements adopted into law by the AHJ requires the property owner to maintain walkways in a safe condition. Where adopted, the International Property Maintenance Code (IPMC) holds the property owner responsible for maintaining walkways, stairs, ramps, driveways, and parking spaces in a proper state of repair and safe condition.

Stairs

Stair treads and risers have had dimensional limits dating back to the earliest codes; however, those restrictions have generally (though not always) become more stringent over time — **Figure 6** provides details for each code. Some of the earlier codes also contained an archaic provision believed to be dated back to the 17th century for stairs, requiring the dimensional sum of the height of two adjacent risers and the depth of the tread in-between to be between 24 and 25 inches. However, this formula has generally been found to have little use in consistently reducing hazardous stair configurations (as explained in the LSC Handbook), and the advent of the IBC resulted in its final removal from the nationally recognized codes.

One important provision for stair treads equipped with attached full or partial depth walking surfaces coverings or finishes (a good example is wooden or concrete stairs with a leading edge or nosing metal plate installed) is that these features maintain a true level tread surface without any added trip hazard. Another evolving set of requirements to be aware of are those for the allowable curvature of tread leading edges (nosings) and overhangs between adjacent treads. The codes also have requirements dealing with whether or not open risers are permitted on certain types of staircases. Additionally, the codes have special dimensional requirements for winding or spiral type stairs, though these are generally considered more hazardous than standard stairs per the LSC Handbook.

Another major evolving set of requirements in the codes has been those requiring the use of handrails on stairs and their dimensional parameters. Depending on which code and edition is referenced, handrails have always been required on at least one side of a staircase, except for some low height flights. In earlier codes, handrails were required to be between 30 to 34 inches above the tread leading edges (in line with the riser). Starting in the 1980s, anthropomorphic studies caused the LSC to lead the way in raising that range — ultimately to the current 34 to 38 inches with allowance for the top rails of 42-inch-high guards with acceptable graspability to also serve as handrails.

Another evolving requirement in the codes involves details for graspability of handrails. Required in some codes for at least 40 years are rail cross-sections, which permit a wide range of hand sizes to exert a power grip with the fingers wrapped around and under the rail. The LSC Handbook provides useful diagrams illustrating these concepts and showing varying handrail shapes/sizes and their acceptability for use — notably, "2 x 4" or larger size lumber is not considered acceptable.

Over time, the codes have added and then tightened a requirement for handrail clearances to adjacent walls and how handrail supports should be configured to prevent interference with grasping. The codes also have varying and increasing requirements for how far handrail coverage must extend beyond the top and bottom ends of a staircase — and when and where additional intermediate handrails are required for wide stairs. For example, the LSC currently requires that new handrails continue at least 12 inches beyond the top riser in a level position and sloping down at least one tread width beyond the bottom riser. It also requires that a sufficient number of handrails be installed such that there is at least one within 30 inches of any staircase pathway, especially in the means of egress pathway.

Uncorrected deterioration or damage to stairways and handrails (for rails, see further discussion below under "Guards or Guardrails" section) that results in either dimensional changes that affect code compliance or user instability fall into the same category as discussed above regarding maintenance requirements for flat walkways. Where enforced, the IPMC requirements specifically mandate that property owners/and managers keep stairs and rails in a proper state of repair and safe condition.

Ramps

The maximum allowable value for the critical ramp parameter, slope, has become increasingly more stringent over time. In some of the earliest codes, the slope was allowed to be as steep as 1 in 6, whereas the most current codes require a slope no steeper than 1 in 12 (the current LSC allows existing ramps to be not steeper than 1 in 8, and the current IBC & International Residential Code allow ramps that are not part of the means of egress to be not steeper than 1 in 8).

The Building Exits Code (BEC) and older LSC editions allowed for differing ramps slopes based on the overall elevation change for the full ramp. Ramp slope can be of particular importance for exterior ramps that were wet at the time of an incident, since increasing slope will typically lower the effective slip resistance. As with stair tread and riser dimensions, older editions of the LSC and the BEC provided for differing slope limits, depending on the required width for an egress ramp.

Ramp handrail requirements are generally similar to those for stairs in any given code edition. It is important to understand that handrails can also help to delineate that the sometimes subtle elevation change of a ramp slope is present, potentially increasing user awareness. For curb ramps, rails are typically not required unless side flares are not provided (**Figure 4**), in which case rails or some other physical barrier or indication of the dropoff from the walkway onto the ramp may be mandated.

Where side flares are provided with a ramp, the typical code requirement is (and has been) that the slope not exceed 1 in 10. Deterioration of ramp surfaces is addressed similarly by the applicable maintenance code (including the IPMC where implemented) as a type of walkway surface. Extended (or built-up) curb ramps, in particular, are susceptible to edge damage where their material is at its thinnest, which can result in abrupt change in elevation trip hazards (**Figure 7**).

Guards or Guardrails

Within the building and egress codes, there has been a fairly consistent requirement that any level walking surface with an edge dropoff more than 30 inches (may differ in some locales) above the surrounding grade or level is required to have a guard system to inhibit pedestrian falls. The typical minimum required height for the top rail of these guard systems has been 42 inches. However, for stairs, differing code editions have permitted lower height guard and handrail combinations. And, in some codes, an open side guard requirement is based on the number of risers.

Evolving over time have been the provision and dimensional requirements for the intermediate rails, balusters, or other barriers that prevent persons (especially children) from falling through an intact guard system. Current requirements typically mandate that openings within guard systems be no greater than 4 inches with exceptions for certain types of installations. This is based on minimizing the risk of a child's head passing through or becoming entrapped in the barrier.

Figure 7
Extended curb ramp edge material loss potential trip hazard.

Important for guards and handrails — particularly where a fall incident is alleged to have occurred due to a rail system failing — are the strength requirements for these installations. These can also apply in cases where a handrail or guard/handrail combination on a stair or ramp is alleged to have flexed excessively while being used for balance. These strength requirements have generally evolved and become more stringent over time with quite a bit of variation between different codes, especially in earlier editions.

The earlier codes typically only had a basic top rail single point load resistance requirement whereas, when the IBC's requirements are enforced, the handrail or guard top rail must withstand a concentrated load of 200 pounds, a uniform load of 50 pounds per linear foot, and the intermediate portions of the systems must withstand a concentrated load of 50 pounds with a further reference to ASCE 7[52]. The International Code Council (ICC) also prescribes methodologies used by certified labs testing manufactured guard systems in AC 174[53]. Generally, complete analysis of a guard system or handrail support failure may involve structural engineering analysis and/or component (evidence or exemplar) testing for comparison to the applicable code loading requirements.

Many rail system failures are caused by weakness at the points where the system components are connected to the building structure. These weaknesses may be due to design, installation, and/or maintenance deficiencies. As with other pedestrian access features, the AHJ's property maintenance provisions would apply. If the IPMC is enforced, then it has a specific section requiring that the load-bearing capacity of rail systems be maintained by the property owner/manager.

Illumination

Dating back for at least 60 years, the various building and egress codes have required that walking surfaces be illuminated to a minimum level of 1.0 foot-candle (fcd). There are some exceptions (primarily related to performance venues) that are allowed to have specified reduced illumination levels while a performance is occurring. Recent editions of the LSC have increased the required value for stairs to 10 fcd. Maintenance of these illumination levels is generally required by the applicable codes. In some locales, older housing codes permitted illumination based on usage of a minimum wattage incandescent lamp.

Summary

The final determination to be made in any access features evaluation is whether or not any deficiencies identified may have been a probable or possible cause for a specific alleged injury incident. In some incidents — where the injured pedestrian can specifically identify a pedestrian access feature where they tripped or lost balance — examination of that feature (including dimensional, stability, presence/absence of critical components and illumination studies as appropriate) may be sufficient to establish whether or not design, installation, or maintenance deficiencies were probable causes or contributors to the incident. In more complex cases — and particularly if the injured person is unable or unavailable to provide sufficient detail on which portion of a pedestrian path was involved in a fall — a more sophisticated analysis of the incident dynamics may be necessary.

There also are cases in which the design or construction of pedestrian facilities may have resulted in injury due to interaction with a vehicle, where vehicle accident reconstruction expertise may be considered. For cases involving a structural failure, especially in staircases or rail systems, structural engineering expertise may be necessary. A further type of potentially complex case are those where features are provided within a commercial/industrial facility or on a construction site for worker access to equipment or machinery, and an injury occurs involving that interface.

For managed properties, an expert in the standard of care for property management practices may also be necessary. In some fall cases, expertise in human motion physics and/or human factors may be needed to scientifically address how the fall occurred and the location features factored into the fall initiation and occurrence. If these types of expertise (or other necessary specialty types of expertise) cannot be provided by the initially retained forensic engineer, then recommendations for adding additional expert(s) should be discussed with the client at the earliest possibility.

Typically, if an appropriate evidence inspection/review and evaluation of conditions found, in comparison to code requirements, does not identify any non-compliant conditions, then that determination should be provided to the client. This is particularly important in cases when retained by an attorney representing an injured pedestrian plaintiff — in many courts, an expert finding that there has been a violation of some legally established specification for pedestrian access features is necessary to prevent the case from being summarily dismissed.

It is advisable to verbally inform each client of any conditions found that may increase the hazard or risk for pedestrians — even if that is a potentially subjective finding — so that the client can make informed decisions and take action, as appropriate. This is particularly important if the determination is for a case or claim in which the client is in a potential defense position, so that they can determine if property remediation actions to reduce or eliminate those conditions should be accomplished.

Further details on slip, trip and/or loss of balance fall evaluations, claims, and cases are available in books authored by expert witnesses (including one referenced in the LSC), although some of the code details may differ from the most current standards and regulations[54,55].

Case A — Retail Center Entry Walkway

One of the main entries for a shopping mall building included concrete exterior approach walkways providing parking area access. This pavement had been poured in sections separated by visible joints. At many of these joints, differential settlement of the adjacent paving sections had occurred, resulting in sudden vertical elevation changes that (at some locations) exceeded ¼ inch or even ½ inch. Some of the joints that had elevation changes above these values had been striped with yellow paint, reportedly to indicate potential trip hazards to pedestrians. However, other joints with elevation changes above these values had not been striped with yellow paint, and, in some cases, the unpainted joints had greater magnitude sudden elevation changes than painted joints (**Figure 8**). A pedestrian tripped and fell while reportedly passing across an unpainted joint with an elevation change ranging from $^5/_8$ to $^3/_4$ inch (**Figure 9**).

The subject walkway area was part of an accessible route, including a curb ramp from marked ADA parking spaces. Based on the documented facility construction and renovation dates, appropriate editions of the LSC and ADA facilities requirements (including a state-mandated accessibility code) applied. These required that walkway elevation changes exceeding ½ inch be accomplished with a compliant ramp. The IPMC also was in effect for this facility and required that the walking surfaces be maintained in a safe condition. The inconsistent striping of joints with trip hazards potentially increased the risk of a pedestrian tripping on the unmarked joints with abrupt elevation changes.

Case B — Residence Interior Stairway

The injured pedestrian reported falling from near the top of this staircase, which included a right angle turn accomplished with two diagonal treads. The pedestrian further reported that handrails observed during the inspection, within this corner portion of the staircase, were added by the property owner after the incident (**Figures 10** and **11**). A dimensional study of the staircase revealed riser heights well over 8 inches, tread depths less than 9 inches, variations in these features exceeding 2 inches, handrail heights varying between 31 and 42 inches, and handrail wall clearances less than 1½ inches (including for the more recently added handrails).

Based on the townhouse's original construction date and location, the IRC requirements were applicable — this was an instance where the AHJ determined that the IRC was applicable to a residential structure containing more than two dwelling units due to provided firewall separations. The measured staircase dimensions were significantly non-compliant with the riser height, tread depth, riser/tread variation, handrail height, and handrail clearance requirements. The upper portion of the staircase, including the corner, effectively had no handrail coverage at the time of the incident in violation of that code. The riser and tread dimensions and the use of the corner as

Figure 8
Mall entry walkway and curb ramp – note yellow striped joints.

Figure 9
Measurement of incident location elevation change height.

Figure 10
Townhouse staircase lower portion and corner.

Figure 11
Townhouse staircase upper portion and corner, including handrails added after incident.

part of the staircase rather than as a landing indicated that the staircase overall had been built in an overly steep configuration to fit the limited space within this townhouse. These overall conditions would not only increase the risk of a fall but would also increase the potential that a fall might result in a pedestrian tumbling down the full stairway. **Figure 12** is an example of how to present staircase inspection findings in comparison to code requirements as part of an expert report.

Case C — Public Service Facility Doorway

The main entry doorway for a walk-in business included a manufactured metal threshold installed under the swinging type standard width door (**Figure 13**). Reportedly, a patron entering the business tripped on that threshold, which evidenced several elevation change features and a maximum height above the floors on either side (which themselves were at elevations differing by approximately $^{7}/_{8}$ inch) exceeding 1½ inches. Use of a profile gauge was valuable for documenting the actual threshold dimensions (**Figure 14**). The gauge study

Figure 13
Doorway threshold insert.

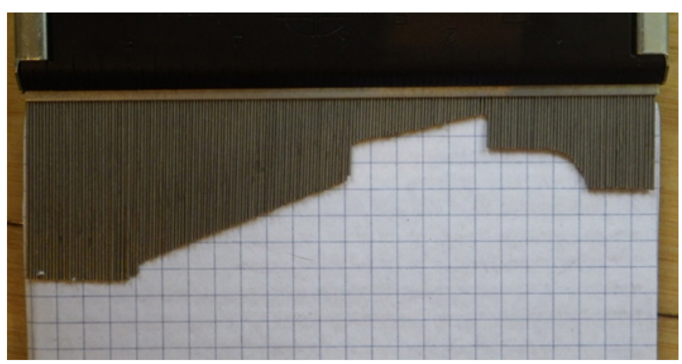

Figure 14
Threshold insert profile — each square equals ¼ inch.

Dimension	IRC Section	IRC Requirement	LSC Section	LSC Requirement	Measured	Comments
Riser Height	R311.5.3.1	<7¾	7.2.2.2.1	<7, >4	All except topmost >7 2 risers >8³/₈	15 of 16 risers non-compliant with LSC, two risers major non-compliance with either code
Tread Depth	R311.5.3.2	>10	7.2.2.2.1	>11	All treads <8⁷/₈	Major non-compliance with either code all treads
Riser Height Variation	R311.5.3.1	<³/₈ all risers	7.2.2.3.6	<³/₈ all risers <³/₁₆ adjacent risers	Overall variation 2³/₈ greatest adjacent variation 2¹/₈	Non-compliant with either code Major non-compliance with LSC at two locations
Tread Depth Variation	R311.5.3.2	<³/₈ all treads	7.2.2.3.6	<³/₈ all treads <³/₁₆ adjacent treads	Overall variation ³/₈ greatest adjacent variation ³/₈	Compliant Non-compliant with LSC in three locations
Handrail Coverage	R311.5.6	Continuous full stair length	7.2.2.4.1	Continuous full stair length & at inside of turn	Reported/documented no handrails on or above turn	Non-compliant with either code at turn and stairs above it, non-compliant with LSC at turn inside corner
Handrail Height	R311.5.6.1	<38, >34 above nose slope	7.2.2.4.4.1	<38, >34 above nose slope	New rails on landing 31½ to 41¼	New rails non-compliant with either code
Handrail Clearance	R311.5.6.2	>1½	7.2.2.4.4.5	>2¼	Old and new rail <1⁷/₁₆	Non-compliant with either code

Figure 12
Case Study B — Comparison of stair dimensions to applicable code requirements (all dimensions in inches).
Notes: IRC = 2003 International Residential Code; LSC= 2003 Life Safety Code (NFPA 101);
staircase “landing” is part of staircase, since it includes two separate treads with a riser in-between.

revealed that passing across the uppermost portion of the threshold in either direction would expose a pedestrian to a greater than ¼-inch abrupt vertical localized elevation change, additionally elevated above the adjacent floors by more than ½ inch.

Based on the facility construction and renovation dates, the IBC and LSC were applicable to the subject doorway. The threshold profile was not in compliance with the doorway elevation change specifications in those codes. The subject threshold presented a much more vertically aggressive profile than the author has typically observed. It was hidden from the view of pedestrians until they opened the door — even then, they could only view it from almost directly above, presenting minimal opportunity to properly view this trip hazard.

Case D — Curb Ramp Outside of a Business

At a restaurant parking area sidewalk three-way intersection, a curb ramp had been installed. A patron walking from a car toward the restaurant on the sidewalk portion extending out into the parking lot reportedly lost balance when they unexpectedly stepped onto the ramp side slope/flare (**Figure 15**). Dimensional study of the ramp indicated that the main slope was steeper than 1:10 — and that the slope of both side flares was as steep as 1:4. The ramp was part of an accessible route from marked ADA parking spaces.

Based on the documented facility construction and renovation dates, appropriate editions of the SBC, LSC, and the ADA facilities requirements (including a state-mandated accessibility code) applied. These codes required that the ramp main slope not exceed 1:12 and the side flare slopes not exceed 1:10. In addition, no portion of the ramp had any visual indication of its presence in contrast to ADA requirements for visual and tactile warning features.

Case E – Exterior Walkway Single Step at Night

An outside sidewalk that was part of an apartment building means of egress had a single step down to a

Figure 15
Curb ramp flare with excessive slope.

Figure 16
Walkway at night looking toward single step down (indicated by arrow).

Figure 17
Primary illumination for walkway step down (arrow) at time of inspection

crossing sidewalk where it approached the parking area. A visitor did not visualize this feature at night and lost balance, crossing it from above (**Figure 16**). Illumination during nighttime inspection was documented to differ from the time of the incident — namely that new fixtures had been added, and non-functional fixtures had been restored to service (**Figure 17**). An illumination study at the walkway level indicated that in areas shadowed by adjacent shrubs and/or the walkway elevation change that lighting levels were less than 0.13 fcd with all lighting functioning. Temporary removal of that reportedly added illumination resulted in measured lighting levels below 0.06 fcd. At the inspection, the elevation change was striped yellow, although it was documented that this striping was not present on the incident date.

Based on the documented facility construction and renovation dates, appropriate editions of the SBC and LSC applied, which required illumination of at least 1.0 fcd. The actual lighting at the time of incident was demonstrated to be less than 10% of that required level.

Conclusions

As in all fields of forensic engineering, evaluation of alleged trip or loss of balance falls should be accomplished using both scientifically based inspection and analysis techniques along with proper research to determine what established rules and standards of care properly apply to the features at the incident location. The forensic engineering expert's findings should be based on an objective comparison of the evidence to the governing standards, minimizing subjective conclusions. The expert should typically limit his or her documented findings to the details of which, if any, pedestrian access feature conditions could be identified as definitely or probably not in compliance with the applicable standards and/or which features were compliant.

Generally, the specific identification of parties who may or may not have been responsible for a particular condition or incident causation, should be deferred to the legal and/or insurance claims professionals and systems. However, it may be appropriate for the forensic engineering expert to specifically identify where the documented deficient actions or omissions by an identified engineering design professional potentially or definitely contributed to improper pedestrian access feature conditions that were a factor in an incident occurrence.

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