DEFINITIONS

Slip, Trip, Imbalance and Fall

- Slip – Interaction between footwear and the walking surface
- Trip – Engagement with an object or irregular change in height along walking trajectory
- Imbalance – Stepping on unstable surface, like a lose tile, that cause instability
- Fall – An event that causes an individual to end up on the floor (ground)
STATISTICS

- Tens of thousands of pedestrians suffers slips, trips and imbalances each year and thousands occur each day.
- Cost of these injuries is in the billions of dollars per year.

CAUSES OF SLIPS AND FALLS

Source: National Flooring Safety Institute
FALLS

- Are commonplace affecting individuals from infant to old age
- Generally the outcome is no more serious than an embarrassment
- When injuries occur they can be debilitating and far-reaching
FALL PROBLEM

- Falls can occur on a level surface, on slopes, on steps, on stairs and from heights with different causes and results.
- Falls involves a loss of balance due to some reason, which results in the person falling to the ground or another level.

FALLS CATEGORIZED

- Circumstances (on the level, on a slope, on steps/stairs, from height)
- Age of the person (healthy adults, children, older persons)
- Place (hotel, terminal, parking area)
FALL FACTORS

Gait  Balance  Stature

Strength  Vision  Behavior

NORMAL WALKING

PHASES
- STANCE PHASE
- SWING PHASE

PERIODS
- INITIAL DOUBLE SUPPORT
- SINGLE LIMB STANCE
- SECOND DOUBLE SUPPORT
- INITIAL SWING
- MID SWING
- TERMINAL SWING

EVENTS
- FOOT STRIKE
- OPPOSITE FOOT OFF
- REVERSAL OF FOREAFT SHEAR
- OPPOSITE FOOT STRIKE
- FOOT OFF
- FOOT CLEARANCE TIBIA VERTICAL
- FOOT STRIKE

% OF CYCLE
- 0%
- 12%
- 50%
- 62%
- 100%
GAIT CYCLE

SLIP AND FALL DYNAMICS

Slip and Fall Dynamics

Center of gravity shift
50% limb on step
Injury to leg

R. Heel Strike
Loss of Balance
Fall Back and/or to Side
FALLS INFLUENCED BY

- Health
- Fatigue
- Medication
- Alcohol
- Environment
- Activity

FALL OUTCOMES

- Fall on the level – lower or upper limb fractures, sprains, back or head injuries.
- Falls from height – often serious, forces generated and severity depends on the distance of the fall and the contact surface.
SLIP FACTORS

- The most dominant factor effecting slip is the coefficient of friction between the footwear and the flooring material
- Walkway geometry
- Environmental conditions
FRICTION - DEFINITION

The interaction between two surfaces in contact while moving one relative to the other while maintaining contact.

HISTORICAL PERSPECTIVE

In 1495 Leonardo Da Vinci was the first to deduce the basic laws of friction and the causes of slips, trips and falls.
HISTORICAL PERSPECTIVE

In 1781 Charles – Augustin de Coulomb studied “Dry Friction” - The interaction between two contacting surfaces in the absence of lubricating fluid.

FRICTION - DEFINITION

At point A the block starts sliding on the surface.
Only at point A the following relationship holds:

\[ F_c = \mu_s W \]

where:
- \( F_c \) – Friction force
- \( \mu_s \) – Static Coefficient of friction
- \( N \) – Normal force

The coefficient of friction is given by

\[ \frac{F_c}{N} = \mu_s \]
FRICTION - EFFECT OF SLOPE

Equation still holds: \( F_c = \mu_s \times N \)

Where:
- \( F_c \) – Friction force
- \( \mu_s \) – Static Coefficient of friction
- \( N \) – Normal force

Coefficient of friction is given by:

\[
\frac{F}{N} = \mu_s \times \tan \alpha
\]

Apparent coefficient of friction is reduced

FRICTION - RAMP

Length of ramps between landings 10m for a 1:15 to 1:20 slope 5m for a 1:12 to 1:15 slope

Intermediate landing length between flights at least 1800mm

Max gradient 1:20

Min 1800mm x 1800mm

Unobstructed level space

For a standard ramp of 1:20 the apparent coefficient

\[
\frac{F}{N} = \mu_i - 0.05
\]

This difference might change the conditions from safe to unsafe
The transient from high to low coefficient of friction might cause slippage since human needs to take few steps to adjust their gate to the conditions.
The presence of contaminants, such soil, reduces the value of the coefficient of friction since the particles change the mechanism from sliding to, at least, partial rolling.

### FRICTION - EFFECT OF CONTAMINATE

The presence of contaminates, such soil, reduces the value of the coefficient of friction since the particles change the mechanism from sliding to, at least, partial rolling.

---

### FRICTION - EFFECT OF LOADS

<table>
<thead>
<tr>
<th>Load (g)</th>
<th>Speed (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>250</td>
<td>20</td>
</tr>
<tr>
<td>100</td>
<td>30</td>
</tr>
<tr>
<td>250</td>
<td>30</td>
</tr>
</tbody>
</table>

---

### Parameters Table

<table>
<thead>
<tr>
<th>Process</th>
<th>Sand particles</th>
<th>Initial pressure (x10^5 Pa)</th>
<th>Distance from nozzle (cm)</th>
<th>Load (g)</th>
<th>Speed (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>O0</td>
<td>2.76</td>
<td>5.1</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>2.76</td>
<td>5.1</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>BB</td>
<td>2.76</td>
<td>5.1</td>
<td>250</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>BB</td>
<td>2.07</td>
<td>5.1</td>
<td>250</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>BB</td>
<td>2.07</td>
<td>5.1</td>
<td>100</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>BB</td>
<td>2.07</td>
<td>5.1</td>
<td>250</td>
<td>30</td>
</tr>
</tbody>
</table>
**FRICTION**

| Effect of lubricant | The presence of lubricant, simple water, reduces the value of the coefficient of friction and therefore increases the chance for slippage. |

<table>
<thead>
<tr>
<th>Floor</th>
<th>DCOF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry ceramic</td>
<td>0.57</td>
</tr>
<tr>
<td>Dry steel</td>
<td>0.27</td>
</tr>
<tr>
<td>Oily plywood</td>
<td>0.43</td>
</tr>
<tr>
<td>Oily vinyl</td>
<td>0.11</td>
</tr>
</tbody>
</table>

**FRICTION – CHEMICAL INTERACTION**

Some surfaces are treated to be sticky. In this case the definition of coefficient of friction does not hold. Different methods have to be used to evaluate the slipping characteristic of the surface.
FRICION - MINIMUM REQUIREMENTS

The consensus is that coefficient of friction in excess of 0.5 is safe and represent slip-resistant surface.

ADA specifies minimum value of 0.6 on Surfaces accessible by handicap)

FRICION - STANDARDS

Occupational Safety & Health Administration (OSHA) 1918

Occupational Safety & Health Administration (OSHA) 1915

American with Disabilities Accessibility Guidelines (ADAAG) 15.2

ASTM

National Fire Protection Association (NFPA) 415/417

State and Local Building Codes
FRICTION - MEASUREMENTS

➢ ASTM C-1028 – Pull test

\[ \mu_s = \frac{F}{W} \]

System has to be calibrated using a STANDARD tile

FRICTION - MEASUREMENTS

➢ ASTM C-1028 – Calibration
FRICITION - MEASUREMENTS

ASTM has many standards related to friction measurements for variety of cases

B-460  D-1894
B-461  D-2047
B-526  D-2394
C-808  D-2714
many more

The expert has to pick up the relevant standard for the particular case.

FRICITION - MEASUREMENTS

ASTM E 303 – British pendulum tester
ASTM F 489 – James Machine
ASTM F 1677 – Brungraber Mark II

Good for lab environment
FRICTION - MEASUREMENTS

ASTM F 1679 – English XL
Standard was dismissed due to poor repeatability
FRICTION - MEASUREMENTS

Difficulties
✓ Sticktion in wet condition
✓ Local factors affect the measurement
✓ Surface was treated after the event
✓ No standard for statistical analysis
TRIP FACTORS

- Height of the obstacle which interfere with the swing
- Visibility
- Color of the obstacle

TRIP MECHANISM

- At the impact instant the body has linear momentum that is being interrupted by the impact.
- Body is supported by one foot and it is easy to lose balance
- The center of gravity of the body is ahead of the tripped leg and there is a moment that causes the fall.
TRIP LOCATIONS

Thermal Expansion Joints (Walkways)

Cracks or Wide Unfilled Joints

TRIP LOCATIONS

Sidewalk Breakage

Sidewalk Irregularity
TRIP LOCATIONS

Transition between two different surfaces

TRIP LOCATIONS

Roots penetrate the surface of the pavement
TRIP - MINIMUM REQUIREMENTS

The requirement is the height difference between two adjacent along the walkway will not exceed 0.25”.

TRIP - STANDARDS

- Occupational Safety & Health Administration (OSHA) 1918
- Occupational Safety & Health Administration (OSHA) 1915
- American with Disabilities Accessibility Guidelines (ADAAG) 15.2
- National Fire Protection Association (NFPA) 415/417
- ASTM
- State and Local Building Codes
IMBALANCE

IMBALANCE - DEFINITION
Stepping on unstable surface along a walking path e.g. a loose tile
Loose tile can be modeled as a tile attached to ground by a pivot or a ball joint depends on its motion.

As the tile tilts, the magnitude of the supporting friction force is reduced just the same as in a ramp. In this case the apparent COF changes with the tile’s angle. Also, the demand on the ankle might exceeds its capabilities.
ENGINEERING PRINCIPLES

- Understanding the hazard
- Minimizing the risk to the hazard
- Warning of the hazard
- Dealing with the hazard
- Eliminating the hazard through design

Reduction of Injuries and a Proactive Approach

BEST PRACTICE

- Comply with accessibility standards in the American Disabilities Act (ADA) of 1990.
- US Access Board has standards which act as guidance for pedestrian facilities.
BEST PRACTICES

- The most important (fundamental) level of preventing an accident is removing any hazard.
- Most accidents could have been easily preventable had management understood the dangers, identified the problem areas and quickly eliminated the hazard.

STANDARDS AND CODES

Based on reaching a consensus, which in effect is a minimum on which all participants can agree.

Not all situations are covered in the standard and code.

Other
- Professional Societies
- International Code Council
- Underwriters Laboratories
- Industry Associations
FALLING IN DIFFERENT ENVIRONMENTS

- Level walking surfaces
- Water, ice and snow
- Parking area
- Changes in level
- Entrances and exits
- Elevators and escalator
- Elevated surfaces
- Workplace falls
- Falls on public property
- Falls in residences
- Construction site
- Recreation and playground facilities
- Elderly and disabled

PATHWAYS

- Should have specified flooring materials
- Selected floor treatments
- Specific floor cleaning equipment and schedule
- Regular maintenance schedule
- Free of obstructions
- Non sudden change of grade greater than ¼ inch
- Static coefficient of friction equal or greater than 0.5
SLIP & TRIP ON STAIRS

Slip usually occurs during stepping down the stairs since the leading foot requires small horizontal support force.

SLIP & TRIP ON STAIRS

Trip usually occurs where the stair riser is not uniform and the leading foot hitting the stair too low.
FALL ON STAIRS

✓ Poor illumination make it difficult to detect the stair’s nose
✓ Rich pattern on carpeted stairs make it difficult to see the edge of the stair (same with wood)

STAIRS - DEFINITION

- Nose
- Pitch line
- Tread depth
- Rise height
- Run
- Rise
### STAIRS - REQUIREMENTS

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riser</td>
<td>7” max. 4” min.</td>
</tr>
<tr>
<td>Tread</td>
<td>11” min.</td>
</tr>
<tr>
<td>Width</td>
<td>20” min.</td>
</tr>
<tr>
<td>Head room</td>
<td>80” min.</td>
</tr>
<tr>
<td>Riser deviation</td>
<td>0.375” max.</td>
</tr>
<tr>
<td>Tread deviation</td>
<td>0.375” max.</td>
</tr>
<tr>
<td>Leading edge</td>
<td>max. radius of 0.5”</td>
</tr>
<tr>
<td>Nose projection</td>
<td>1.25” max.</td>
</tr>
<tr>
<td>Tread slope</td>
<td>0.25” max.</td>
</tr>
</tbody>
</table>

Dimensions can vary and depend on use

### AGING AND FALLING

- Susceptibility to falling increases considerably with age
- One in three seniors will fall one or more times each year
- Injury is a potentially serious outcome of falling in older people
- Approximately half the falls occur within the persons home
- Impaired vision and hearing, peripheral sensation, muscle strength and reaction time all contribute to poor balance and falling
AGING AND FALLING

Type of injury, injuries among older people

66%

(265 yrs), VSS: WHE, LEB, PASH 1yr each, P&ACH 1yr

N = 5101

AGING AND FALLING

Location of injury, injuries among older people

Private home

Commercial area

(265 yrs), VSS: WHE, LEB, PASH 1yr each, P&ACH 1yr

N = 4132, where location recorded
AGING AND FALLING

Location of injury, injuries among older people

(265 yrs), FESS, WCH, LBM, BN,1 yr each, PANC 1yr
N = 4132, where location recorded

AGING AND FALLING

Location of falls in private homes, injuries among older people

(265 yrs), FESS, WCH, LBM, BN,1 yr each, PANC 1yr
N = 1618
AGING AND FALLING

Body parts injured,
injuries among older people

Head & Face 17%

Torso 13%

Arms 26%

Legs 30%

Other 4%

(≥65 yrs), VESS, WH, LRH, 
RMSH 2 yrs each, PANCH 1yr. 
Up to 3 injuries may be recorded per 
case. N of injuries=6298

AGING AND FALLING

Factors associated with falls in private homes. 

Table 1

Injuries among older people

<table>
<thead>
<tr>
<th>Factor</th>
<th>Cases N=1618*</th>
</tr>
</thead>
<tbody>
<tr>
<td>stairs or steps</td>
<td>143</td>
</tr>
<tr>
<td>chairs</td>
<td>92</td>
</tr>
<tr>
<td>floors or flooring materials</td>
<td>85</td>
</tr>
<tr>
<td>beds</td>
<td>72</td>
</tr>
<tr>
<td>ladders</td>
<td>64</td>
</tr>
<tr>
<td>concrete and other man-made outdoor surfaces</td>
<td>43</td>
</tr>
<tr>
<td>ground and other natural surfaces</td>
<td>42</td>
</tr>
<tr>
<td>water</td>
<td>36</td>
</tr>
<tr>
<td>baths or showers</td>
<td>34</td>
</tr>
<tr>
<td>crutches, canes or walkers</td>
<td>29</td>
</tr>
<tr>
<td>runners, throw-rugs, door-mats</td>
<td>24</td>
</tr>
<tr>
<td>rugs or carpets</td>
<td>21</td>
</tr>
</tbody>
</table>

(≥65 yrs), VESS, WH, LRH, RMSH 2 yrs each, PANCH 1yr
* Up to 4 factors may be recorded per case
ILLUMINATION AND FALLING

- Lighting can disguise a defect or hazardous condition
- A change in the normal walking environment must be visible to the pedestrian and stand out from background stimuli
- Glare and too much or too little contrast in the walking environment can reduce the efficiency of the eye
- Walking surface should be evenly illuminated and should have a brightness level of at least 20 foot candles
- Contrast (ratio of dark to light) should be no less than 3:1 and no more than 20:1
- Measurement of luminosity and contrast requires a simple photographic light meter calibrated to read in foot candles

DISTRACTION AND WARNING

Visual
Noise
Signs
Announcements
FLOOR CONSIDERATIONS

- Slipperiness of the floor material
- Circumstances used
- Full range of contaminates that might be experienced
- Clean and maintenance protocols
- Slip resistance of installed floor might be different from factory product
- Effects of time on floor surface
- Finish and Treatments properties
- Impact of wear

WORKPLACE FALLS

- Weather conditions
- Walking surface
- Foot floor interface
- Footwear and equipment
- Working practices
- Job training
- Management & organization factors
PARKING LOTS

Typical illumination problem is that lights are obstructed by overgrown trees.

Stop blocks are not painted and cannot be detected because of poor lighting.

Rain and water on the surface cause glare.

Even shallow water hide potholes and other defects in the pavement.

TERMINAL FACILITIES

Passenger Flow

Walking Surface

Parking & External Areas

Changes in Level

Stairways

Handrails

Ramps

Entrances and Exits

Floor Coverings

Escalators

Elevators

Moving Walkways
TRUCK LOADING DOCK

- Dock levelers or plates
- Maintenance and cleaning
- Enclosed bays
- Wheel chocks

BATHROOMS

- Usually slippery conditions due to wet floor
- Coming out of a bath tub requires some balancing act which demands high coefficient of friction
- Older people have difficulty to get out of a bath tub
- Mats, which are supposed to provide high friction, might make the situation even worse
ICE AND SNOW

- Very low coefficient of friction
- Snow might cover obstacles
- Driastic change in coefficient of friction for the first step out the covered area

ELEVATORS, ESCALATORS, MOVING WALKWAYS

- Car and floor levels should be within 0.25 inch
- Large gap between the car and the floor can catch high heel shoe and cause a fall, same for escalator
- Avoid change in floor surface from one floor to another
- Suitcases and bags on moving walkways cause trip
- High acceleration or deceleration during step on/off from moving walkways can cause a fall
- Emergency stop of all these devices can cause a fall
FALL ON SIDEWALKS

- Smooth steel plate
- Irregular surface
- Uneven
- Cracks
- Potholes
- Defective expansion joints
- Lack of inspection
- Tree roots
- Leaking sprinkler
- Debris
- Sandy surface
- Water collecting
- Oil spills and grease
- Missing utility covers
- Corroded utility covers
- Broken parking signs
- Metal stubs
- Guywires anchored

RECREATION AND PLAY GROUNDS

- Foodstuff and liquid spills
- Debris and litter
- Insufficient lighting
- Unprotected high places
**FALL PREVENTION**

- Slip resistant floors
- Avoid presence of fall risks
- Cover outside walkways
- Design to exclude tripping
- Space for storage
- Avoid low steps
- Steps and stairs proper dimensions
- Step edge with contrast
- Avoid visual distractions
- Permanent access to high areas
- Avoid unpredictable moving surfaces
- Install grab rails
- Adequate lighting
- Facilitate cleaning and maintenance
- Design for durability
- Design for resistance to damage

**RISK REDUCTION**

- Education and awareness
- Perform risk assessment
- Implement controls
- Procedures for inspection
- Cleaning & maintenance protocols
- Warning signs
- Mark hazards
- Mark step edges
- Additional handrails & grab rails
- Barriers for edge protection
- Increase use of lighting
- Avoid awkward heavy loads
- Avoid rushing
- Protocols for inclement weather
- Devices to assist those in need
RISK REDUCTION

- Promote and monitor health
- Encourage exercise
- Promote good diet
- Adopt drug protocols
- Promote sleep management
- Discourage use of alcohol
- Encourage use of footwear
- Encourage use of proper clothing
- Promote eye exam and glasses

PREMISE LIABILITY

- Duty owed
- Trespasser
- Statues
- Notice
- Proximate cause
- Damages
INFORMATION NEEDS FOR SAFETY

- Provide information that can be rapidly assimilated using more than one sense.
- Provide detectable warnings.
- Provide warning of any potential dangers.
- Information from the environment to travel along pathways safely and efficiently.
- Obtained visually by observing cues at critical junctures as entrances and exits.
- Visually impaired depend on cues to estimate distances and directions to determine location.
- Information needs to be redundant and in the multiple format.

ACCIDENT INVESTIGATION

- Claimant and witness information
- Event information
- Occurrence analysis
- Incident reports
- Location information
- Lighting levels
- Conditions and design
CONDUCTING AN INVESTIGATION

- **Floor**
  - friction, roughness, maintenance, cleanliness, stability, contamination, condition, repair

- **Footwear**
  - type, sole, heel, wear, employer control, suitability

- **Personal**
  - sex, age, weight, eyesight, drugs, health condition, individual anthropometrics, level of concentration

- **Work System**
  - housekeeping, contamination, work arrangements, shift, time pressure, cleaning regime, handling of loads, walkways, safety culture, management

- **Environ**
  - day of week, month, lighting, temperature, humidity, ventilation, vibration, housekeeping, ice, snow, leaves

---

**CONDUCTING AN INVESTIGATION**

**TESTING and EXPERIMENTS**

Performed ASAP in order to preserve the surface condition as it was at the time of the accident

**GMC v. Carl PORRITT**

“Where testing is offered as evidence, the conditions in an experiment must be substantially similar to those at the time of the occurrence for evidence of the experiment to be admitted”

“For purpose of determining admissibility of scientific testing, determination of the similarity of the circumstances & conditions of a scientific test to those existing at the time of the occurrence is left to the discretion of the trial court.”
STATUTORY CONTROLS

- Workplace
- Environment
- Footwear
- Work System

THEORY OF LIABILITY

Failure to comply with code → Failure to correct → Failure to warn → Failure to inspect and maintain
DEFENDING

- Determine facts
- Analyze plaintiff information
- Evaluate prior accidents
- Review maintenance and inspection procedures
- Assemble facts
- Evaluate physical evidence
- Select expert
- Motion for summary judgment
- Limited immunity

VISION AND FALLING

- Vision and conspicuity
- Visual ability
WALKING AREA MAINTENANCE

- Floor cleaning
- Carpet and floor maintenance
- Floor Treatments
- Pavement maintenance

USEFUL EVIDENCE TO BUILD OR DEFEND CASE

- Review Accident Facts
- Evaluate Prior Accidents
- Review Maintenance and Inspection Procedures
- Assemble Facts (Complaint, Discovery)
- Evaluate Physical Evidence
SELECTING AN EXPERT

- Communications is the key to success in personal injury matters
- Factual interpretation and accurate analysis of information can be obtained only through a qualified expert
- Must be articulate and able to speak before a judge and jury
- Must be able to interpret information for the jury in simple terms

SELECTING AN EXPERT

**What to look for:**

- Education and Background
- Employment History
- Litigation Experience
- Appearance and Mannerisms
- Availability
USING THE EXPERT

Retaining an expert early can assist in case preparation and evaluation

✓ To identify issues and possible flaws in the case
✓ To provide assistance in preparing a comprehensive list of discovery information
✓ To assist the attorney and jury in understanding the technical aspects of the case and evaluating the facts as measured by the national standards of care

DUTY OF CARE

- Warn passengers of hazards
- Properly train personnel
- Have safety inspections
- Update design standards
- Provide effective communications