Physical Hazards: Gravitational

Core Body of Knowledge for the Generalist OHS Professional

Safety Institute of Australia Ltd

Australian OHS Education Accreditation Board

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The OHS Body of Knowledge for Generalist
OHS Professionals has been developed under the
auspices of the **Health and Safety Professionals Alliance**

The Technical Panel established by the Health and Safety Professionals Alliance (HaSPA) was responsible for developing the conceptual framework of the OHS Body of Knowledge and for selecting contributing authors and peer-reviewers. The Technical Panel comprised representatives from:

The Safety Institute of Australia supported the development of the OHS Body of Knowledge and will be providing ongoing support for the dissemination of the OHS Body of Knowledge and for the maintenance and further development of the Body of Knowledge through the Australian OHS Education Accreditation Board which is auspiced by the Safety Institute of Australia.

Synopsis of the OHS Body of Knowledge

Background

A defined body of knowledge is required as a basis for professional certification and for accreditation of education programs giving entry to a profession. The lack of such a body of knowledge for OHS professionals was identified in reviews of OHS legislation and OHS education in Australia. After a 2009 scoping study, WorkSafe Victoria provided funding to support a national project to develop and implement a core body of knowledge for generalist OHS professionals in Australia.

Development

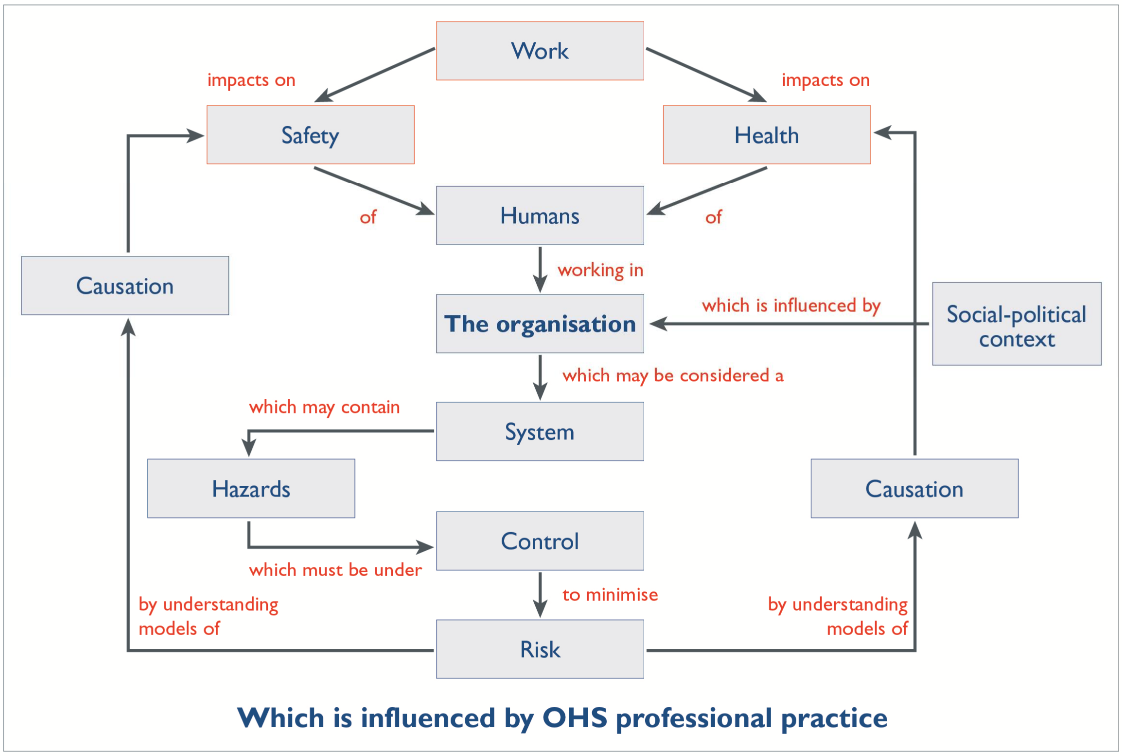
The process of developing and structuring the main content of this document was managed by a Technical Panel with representation from Victorian universities that teach OHS and from the Safety Institute of Australia, which is the main professional body for generalist OHS professionals in Australia. The Panel developed an initial conceptual framework which was then amended in accord with feedback received from OHS tertiary-level educators throughout Australia and the wider OHS profession. Specialist authors were invited to contribute chapters, which were then subjected to peer review and editing. It is anticipated that the resultant OHS Body of Knowledge will in future be regularly amended and updated as people use it and as the evidence base expands.

Conceptual structure

The OHS Body of Knowledge takes a ćconceptualô approach. As concepts are abstract, the OHS professional needs to organise the concepts into a framework in order to solve a problem. The overall framework used to structure the OHS Body of Knowledge is that:

> **Work** impacts on the **safety** and **health** of humans who work in **organisations**. Organisations are influenced by the **socio-political context**. Organisations may be considered a **system** which may contain **hazards** which must be under control to minimise **risk**. This can be achieved by understanding **models causation** for safety and for health which will result in improvement in the safety and health of people at work. The OHS professional applies **professional practice** to influence the organisation to being about this improvement.

This can be represented as:



Audience

The OHS Body of Knowledge provides a basis for accreditation of OHS professional education programs and certification of individual OHS professionals. It provides guidance for OHS educators in course development, and for OHS professionals and professional bodies in developing continuing professional development activities. Also, OHS regulators, employers and recruiters may find it useful for benchmarking OHS professional practice.

Application

Importantly, the OHS Body of Knowledge is neither a textbook nor a curriculum; rather it describes the key concepts, core theories and related evidence that should be shared by Australian generalist OHS professionals. This knowledge will be gained through a combination of education and experience.

Accessing and using the OHS Body of Knowledge for generalist OHS professionals

The OHS Body of Knowledge is published electronically. Each chapter can be downloaded separately. However users are advised to read the Introduction, which provides background to the information in individual chapters. They should also note the copyright requirements and the disclaimer before using or acting on the information.

Physical Hazards: Gravity

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Abstract

The term óslips, trips and fallsô is treated almost as a single word in the workplace context with, in some cases, differentiation between a ófall on the same levelô and óa fall from a height.ô Such occurrences rank among the most significant causal factors in workplace injury and death in Australia, and there have been only relatively minor reductions in the injury rate in the last 10 years. Hazard identification, risk assessment and development of control strategies require an understanding of the physics of gravitational energy and the mechanisms of causation. This chapter uses injury statistics to examine the extent of the problem and the agencies of injury of slips, trips and falls (on the same level and from heights), and due to being hit by falling objects. It facilitates understanding of gravitational hazards with an overview of the relevant physics of gravity and the normal gait of a person, and examines the different mechanisms of a slip, a trip and a misstep. The importance of building design in prevention of injuries related to gravitational hazards is highlighted through a discussion on causation and scenario examples for control. The chapter concludes by discussing the role of the generalist OHS professional in preventing injuries from gravitational hazards.

Keywords

gravity, slip, trip, fall, misstep, falling objects,

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1 Introduction

Physical hazards have been defined as ñsources of potentially damaging energyò (Viner, 1991, p. 42).[1] This chapter on gravitational hazards concerns the effects of unintended exposures to energy associated with gravitational forces in the workplace. Gravity ï defined in this context as the force of attraction by which bodies tend to fall towards the centre of the earth ï results in falls by people who have lost their balance for various reasons, as well as falls of unsecured objects.

The World Health Organisation defined a fall as ñan event which results in a person coming to rest inadvertently on the ground or floor or other lower levelò (WHO, 2010). Generally, falls occur after people lose their balance due to experiencing a slip, a trip or a misstep, or due to a failure or absence of an expected or required support mechanism. Injurious falls can occur on the same level ï referred to as óslips, trips or falls on the levelô (STFL) ï as well as from one level to another (i.e. falls from heights).

This chapter addresses falls on the same level and falls from heights, and incidents that involve people being struck by, or attempting to control, falling objects. Musculoskeletal injury can be caused by stresses generated within the body as a result of the often very rapid movements made during balance-recovery manoeuvres after an initial slip, trip or misstep. While a large proportion of such injuries are likely to be recorded in work injury statistics under body-stressing rather than in the fall-related categories, they should also be considered within the spectrum of hazards associated with gravity. As gravity acts on the mass of an object to give it weight, it is directly involved in hazards associated with manual-handling activities. However, such hazards (other than those associated with attempts to catch or restrain falling objects), are addressed in other chapters of the OHS Body of Knowledge.[2]

2 Historical perspective

While it has long been known that falls are one of the most common causes of accidental death and injury - occupationally, domestically and recreationally - the first International Conference on slipping, tripping, and falling accidents was held at the University of Surrey in 1982 as a joint venture by the UK Medical Commission on Accident Prevention and the University of Surry Robens Institute of Industrial and Environmental Health and Safety. Much of that conference was dedicated to research reports on slip resistance of floors and foot wear but also cautioned that ña too simplistic approach to slip prevention can be, of itself, a hazardò. (Davis, 1983).

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[1] See *OHS BoK* Hazard as a Concept

[2] See *OHS BoK* Biomechanical Hazards and *OHS BoK* Models of Causation: Health Determinants

In recognising that fall-prevention research is a critical aspect of implementing effective occupational safety improvements, the US National Institute for Occupational Safety and Health (NIOSH) has had fall prevention as a strategic research priority for at least the past 15 years, and has conducted a program of laboratory- and field-based research to identify fall risks and develop prevention strategies and technologies. Regular international conferences are held covering topics such as: epidemiology; design of buildings and of equipment; slip resistance of floors and shoes; use of ladders; gait and movement; personal factors and risk of falls; forensic analysis of injury events; and training including physical training. (CDC, 2010).

The importance of investigating ways to prevent falls has long been recognised by the International Ergonomics Association (IEA), which has a Technical Committee on Slips, Trips, and Falls and holds biennial conferences focussed on preventing these types of incidents (see CGSTF, 2011).

3 Extent of the problem

People are continually exposed to gravitational hazards, virtually from conception. While the risk is quite low that foetal damage might occur *in utero* if an expectant mother falls (especially in the first trimester), such incidents comprise one of the known causes of prenatal mortality. At the other end of the age spectrum, falls all too often precipitate rapid decline in the health and independence of elderly people, with hospitalisation, complications and untimely death being all too common outcomes. Despite this ówhole of lifeô exposure to fall hazards there appears to be widespread complacency concerning the magnitude of the hazard, as reflected in the disproportionately low levels of preventative action directed at falls when compared to preventative measures relating to other potential hazards with higher profiles. For example, in Australia from July 2002 to June 2005 there was an annual average of 343 deaths and 105,968 hospitalisations caused by falls in buildings; in contrast, 110 deaths and 3,300 injuries were due to fires in one year (Ozanne-Smith, Guy, Kelly & Clapperton, 2008). Factors that likely contribute to the generalised complacency about fall hazards include the very common experience of surviving, generally without apparent ill effect, the inevitable tumbles associated with infancy and childhood, the frequent and largely automatic recoveries made after disturbances to balance once the complex skills of ambulation have been mastered; and, the lack of physical damage resulting from a large proportion of falls.

That non-injurious falls are such a pervasive aspect of the human condition appears to have overshadowed the fact that falls are also a major cause of harm. Globally, only road traffic accidents cause more deaths and injuries than falls (Ozanne-Smith et al., 2008). Workplace injury statistics justify a greater focus on identifying hazards and controlling risks associated with gravitational risk than often occurs.

The data in Table 1 demonstrate that between 2000ï 01 and 2006ï 07, slips, trips and falls caused approximately 20% of serious occupational injuries (i.e. those that result in at least one week being lost from work) to Australian workers. Slips, trips and falls accounted for 5%ï 10% of the subset of those injuries that proved fatal. Falls were identified in a regional study as the most common cause of injuries leading to persons of most ages attending public hospitals for emergency treatment (SSWAHS, 2009). In 2006ï 07,[3] nearly 64% of fall-related occupational injuries involved STFLs, 30% involved falls from heights, and 7% involved stepping, kneeling or sitting on objects (Safe Work Australia, 2006ï 07). Sprains and strains were the largest single category of injuries caused by slips, trips or falls (50%), while 20% of injuries resulted in fractures of some type. In the same year, 21 people died as a result of experiencing a slip, trip or fall at work. A total of 45% of workers who experienced slips, trips or falls took 2ï 12 weeks off work due to their injuries (Safe Work Australia, 2006ï 07).

Table 1: Workplace injuries 2000–01 to 2006–07 (Safe Work Australia, 2006–07)

Mechanism	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	Total
	No. claims	No. claims	No. claims	No. claims	No. claims	No. claims	No. claims	No. claims
Falls, trips, slips of a person	28,490	27,815	28,785	26,285	28,485	27,975	27,125	195,950
Hitting object with part of body	11,480	10,340	10,305	10,200	10,350	10,315	9,840	72,920
Being hit by moving objects	19,975	19,915	20,320	19,970	19,750	20,175	19,300	139,305
Sound and pressure	4,590	4,405	3,835	4,090	4,320	4,135	3,540	28,015
Body stressing	63,485	61,630	60,800	62,200	61,560	57,500	56,750	422,926
Heat, radiation and electricity	2,165	2,045	2,130	1,955	1,985	2,085	2,040	14,405
Chemicals and other substances	1,945	1,915	1,860	1,765	1,850	1,595	1,485	12,415
Biological factors	615	610	520	565	560	595	485	3,950
Mental stress	6,845	7,715	8,455	8,815	8,665	7,135	6,580	54,210
Other and unspecified	10,795	10,730	9,955	9,715	8,930	8,105	7,950	65,180
Not stated	np	10	20	20	10	15	10	85
Total	150,380	147,025	147,080	147,580	146,465	139,630	134,105	1,012,260

Although national data on the direct costs of workplace slips, trips and falls are not available, estimates of the likely direct public hospital costs of fall-related hospitalisations (based on data presented in Ozanne-Smith et al., 2008) indicate that the annual average of 28,136 occupational falls that occurred over the seven years from 2000ï 01 to 2006ï 07 would have resulted in more than 299,000 public hospital bed days. At an average estimated cost per bed day of approximately $1000, those falls would have involved annual

[3] This was the most up-to-date complete data available at the time of writing.

direct public hospital costs in excess of $299 million. This figure increases to more than $1.1 billion if non-occupational falls are included. Workers' compensation cost estimates (based on data presented in WHSQ, 2007) suggest that the national cost of occupational falls approaches $130 million annually.

The experience is similar overseas, as demonstrated by international data. For example, the U.S. Bureau of Labor Statistics reported a total of 5,657 fatal work injuries for calendar year 2007. Of the fatality cases, 847 were associated with falls. In addition, of the 1,078,140 non-fatal occupational injuries and illnesses involving days away from work in 2008, there were 260,610 cases associated with slips and falls. The National Safety Council [2002] estimated that some 200,000 to 300,000 disabling injuries are caused by work-related falls each year, and that compensation and medical costs associated with employee slip and fall incidents were approximately $70 billion/year (Stout and Hsiao in CDC, 2010). The U.S. Bureau of Labor Statistics cites slipping, or loss of footing, as the primary event involved in those falls. In addition, fatalities caused by falls represent about 12% of the accidental death toll in the USA.

There are differences between the key agencies of injury for falls from a height and slips, trips and falls on the same level (Safe Work Australia, 2006ï 07) (Table 2). For example, almost three-quarters of STFL occurring in 2006ï 07 were attributed primarily to environmental conditions, whereas environmental conditions were nominated in less than half of all falls from heights.

Table 2: Major agency of injury arising from gravitational hazards 2006–07 (Safe Work Australia, 2006–07)

	% of claims for mechanism of injury		
Agency of injury	**Falls from height**	**Slip, trip or fall on the same level**	**Person being hit by falling objects**
Environmental conditions	45.1%	74.0%	3.6%
Ladders, mobile ramps, stairways	17.9%	1.6%	-
Road transport	12.0%	2.3%	-
Materials and substances, hand tools and appliances	-	-	76.6%

Table 3 provides an industry breakdown of claims for occupational incidents related to gravitational hazards (Safe Work Australia, 2006ï 07). Manufacturing and Construction industry workers incurred the largest proportion of incidents related to gravitational hazards (i.e. a total of 27% of damaging incidents caused by slips, trips and falls and 39% caused by impacts from falling objects). According to these data, slips, trips and falls in construction are equally split between falls from a height and falls on the same level whereas in manufacturing 70% of claims for slips, trips and falls are on the same level. Retail trade and property and business; which together account for 18% of claims for slips, trip and falls and 20% of persons being hit by falling objects; also have significantly more claims for slips, trips and falls on the same level than for falling from a height but in transport and storage 59% of claims are for slip, trip or fall on the same level compared with 41% for falls from a height.

Table 3: Claims for gravitational hazards by industry, 2006/07 (Safe Work Australia, 2006–07)

Industry	Slips, trips and falls of a person		Person being hit by falling objects	
	No. claims	% claims	No. claims	% claims
Agriculture, Forestry and Fishing	1035	3.8%	155	3.2%
Mining	565	2.1%	130	2.7%
Manufacturing	3775	13.9%	1205	24.9%
Electricity, Gas and Water Supply	125	0.5%	15	0.3%
Construction	3590	13.2%	700	14.4%
Wholesale Trade	1185	4.4%	315	6.5%
Retail Trade	2475	9.1%	590	12.2%
Accommodation, Cafes and Restaurants	1515	5.6%	205	4.2%
Transport and Storage	2370	8.7%	440	9.1%
Communication Services	235	0.9%	20	0.4%
Finance and Insurance	280	1.0%	10	0.2%
Property and Business Services	2340	8.6%	390	8.0%
Government Administration and Defence	1090	4.0%	70	1.4%
Education	1880	6.9%	130	2.7%
Health and Community Services	2805	10.3%	290	6.0%
Cultural and Recreational Services	730	2.7%	65	1.3%
Personal and Other Services	1075	4.0%	105	2.2%
Not Stated	60	0.2%	15	0.3%
Total	27125	100	4845	100

While more people sustain injuries as a result of falling than are injured or killed due to being struck by falling objects, the latter mechanism is still significant. According to national occupational injury statistics (Safe Work Australia, 2000/01 - 2007/08), some 125 deaths and 36,670 serious injuries that occurred over that period were due to falling objects impacting with workers. Annually for the same period, such incidents caused approximately 2ï 8% of occupational fatalities and approximately 3ï 4% of serious occupational injuries. More than 75% of injuries caused by falling objects were attributed to falling materials, substances, hand tools and appliances (Table 2).

In summary, data on the causes of deaths and injuries consistently identify falls as one of the most significant causal factors of workplace injury and death. Considering that the statistics also demonstrate associations between increasing age and risk levels, it is likely that the incidence will continue to increase due to an aging population. In evidence-based approaches to identifying hazards and controlling risks, the scientific investigation of gravitational hazards and the implementation of suitable prevention measures warrant higher priority than they are commonly afforded.

4 Understanding gravitational hazards

Controlling gravitational hazards requires an understanding of the mechanisms of causation of slips, trips and falls, and the physics of gravity that contribute to the mechanism of the loss of balance and the seriousness of the resultant injury. These issues are addressed in this section under the headings of physics, slips, trips, missteps and falls from heights.

4.1 Physics

In general, gravitational hazards arise when a potentially unstable or unsecured object is involved in a damaging impact due to the manner in which gravity causes the object to fall to a lower level if the instability is realised or the object is dropped (e.g. when a tool is dropped from a height, or a person trips and falls). The damaging forces that might ensue when a fall is interrupted arise when the energy associated with the momentum of the falling mass is transformed into another form of energy, primarily through processes such as:

- Absorption (e.g. the body is punctured, crushed, lacerated, shaken or knocked off balance)
- Deformation of the body posture against either natural stiffness or muscle effort (e.g. when a person attempts to arrest a falling object using muscle power).(Viner, 1991).

The magnitude of the forces associated with gravitational hazards is one of the key determinants of the risk of injury ï the higher the forces the greater the risk. The consideration of forces associated with (i.e. causing or resulting from) moving objects is referred to as kinetics. Stationary objects that can fall have *potential energy* (PE). The magnitude of that energy (in joules) may be calculated as follows:

$PE = mgh$ *where:* m = *object mass (kg)*
g = *acceleration due to gravity (e.g. 9.8 m/s²)*
h = *starting height (metres)*

Moving objects have *kinetic energy* (KE). The magnitude of that energy (also in joules) may be calculated as follows:

$KE = \frac{1}{2}mv^2$ where: m = *object mass (kg)*
v = *velocity (metres/s)*

Velocity (v) is the vector quantity of the rate of change in the position of a body, and has speed (in metres per second) and direction components. The vertically downwards velocity of a falling object[4] may be calculated as follows:

$v = \sqrt{2gd}$ where: g = *acceleration due to gravity (e.g. 9.8 m/s²)*
d = *displacement (fall distance in metres)*

Using the preceding formulae it may be calculated that a 5 kg object resting on an elevated walkway 4 m above the floor of a work area will have PE of 196 joules. If that object is knocked off the walkway and falls through 2.5 m before landing on the shoulder of a worker who is standing in the work area, the object's KE at the point of impact would be 122.5 joules. Similarly, a 75 kg worker who is standing on a floor with their centre of gravity located 1.2 m above that floor can be considered to have PE of approximately 882 joules. If that person slips with their feet out in front of their body and they fall onto their back (one of the more common types of injurious slips and falls), the vertical distance through which they can fall will approach 1.2 m and, on impact with the floor, up to 882 joules of PE could be converted to damaging forces through absorption. It is possible that a proportion of PE will be absorbed by the personôs legs in the partial collapse that often occurs during such an incident.

While PE and KE are useful, the potential for injury associated with gravitational hazards may be more readily appreciated by considering the velocity of the falling object or person at impact. Using the formula for velocity (see above) reveals that:

- The knee of a person who slips and drops onto that knee from an upright position on a level surface (as can occur when a foot slips backwards at toe-off) can be expected to impact with the surface at 2.99ï 3.41 m/s (or 10.8ï 12.3 km/h). This is because their centre of gravity can fall vertically through a distance of 0.455ï 0.595 m (knee height for 5% females and 95% males, respectively) (Pheasant, 1999)
- The buttocks of a person who falls backwards from an upright position on a level surface (as can occur when one or both feet slip forwards) can be expected to impact with the surface at 3.81ï 4.43 m/s (or 13.7ï 15.9 km/h). This is because their

[4] Assuming an initial velocity of zero.

centre of gravity can fall vertically through a distance of 0.74ï 1.0 m (hip height for 5% females and 95% males, respectively) (Pheasant, 1999).

Cadaver research (White & Bower, 1959) indicated that fractures due to a fall onto an unyielding surface can surface can occur to the lumbar spine at velocities of approximately 2.4 m/s, to the feet and ankles at approximately 3.5-4 m/s, and to the skull at approximately 4-7 m/s. A fall through a vertical distance of only 300 mm is sufficient to result in the falling object attaining a vertically downward velocity of more than 2.4 m/s.

Another useful way of conceptualising the risk of injury due to falling objects is provided by the concepts of momentum and impulse. The *momentum* of a moving object (expressed as M in units of kg m/s) is a measure of how difficult it is to arrest that movement, and is calculated using the formula:

$M = mv$ *where:* m = *object mass (kg)*
v = *velocity (metres/s)*

Impulse ï the combination of a given force and the time over which it is applied ï is expressed as I in units of newton seconds (Ns) and is calculated as follows:

$I = Ft$ *where:* F = *force acting (N)*
t = *time over which the force acts (s)*

Impulse provides a means of evaluating the magnitude of the forces that would have to be exerted by a body in order to resist the momentum of a falling object. Thus the 5 kg object referred to above that fell through 2.5 m before striking the worker's shoulder would have momentum of 35 kg m/s. Force (N) is required to halt the momentum (kg m/s): 1N is required to halt 1kg m/s momentum. Inserting that force into the impulse formula and using a realistic time frame of 0.1ï 0.5 s demonstrates that if the energy of that impact had to be resisted by the body's musculoskeletal system in order to arrest that momentum, the stresses imposed on the body would be similar in magnitude to those associated with the momentary support of a load of up to 350 kg (if the shorter time frame applied) and at least 70 kg (if the time involved approached 0.5 s). Obviously, attempts to lift such weights would involve very high risks of injury. These calculations also serve to highlight limitations of the use of hard hats to prevent injuries being caused by falling objects.

Basic engineering texts provide detailed information about the physics of gravity (e.g. see Introduction to Engineering Mechanics by B Schlenker and D McKern, 1990).

4.2 Slips

Slips occur when the frictional force acting between the relevant part of the shoe sole or foot and the pedestrian surface is insufficient to either effectively overcome the usually brief period of horizontal movement of the foot (or micro-slip) during the heel-strike phase of walking, or to counteract the horizontal force involved in accelerating the body forwards at toe-off. For slipping to be avoided, the available friction must exceed the maximum horizontal forces (or peak frictional demand) of the foot. A pedestrian surface is considered adequately slip resistive when ñthe available friction is sufficient to enable a person to traverse that surface without an unreasonable risk of slippingò (SA/SNZ 2004b p5).

Heel strike is the most common part of the gait cycle for slips to occur. At this time, demand for frictional contact with the pedestrian surface is usually greatest, and encountering a different (and possibly less slip-resistant) pedestrian surface is most likely. However, slips can and do occur at toe-off. In either case, if the slip is both sufficiently long and rapid, a loss of balance and fall is a likely outcome. A loss of balance following a slip at heel strike generally results in the person falling backwards and landing on their buttocks or back (and sometimes on their shoulders or head), and also frequently involves impact with one or both hands thrust out behind (Figure 1). A slip at toe-off often results in the person initially dropping to their knee or falling with the trailing leg twisting beneath them (Figure 2).

For more information see Haslam and Stubbs (2006).

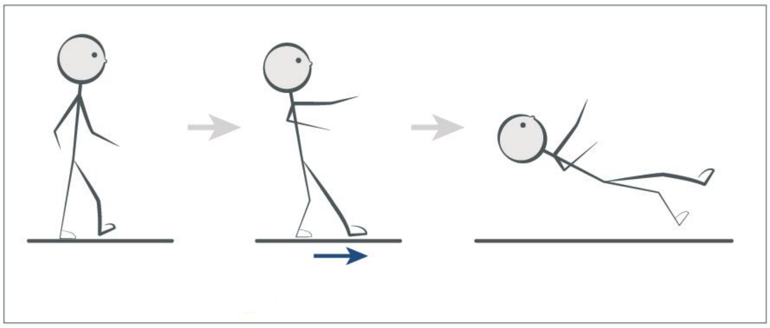

Figure 1: Heel-strike slip

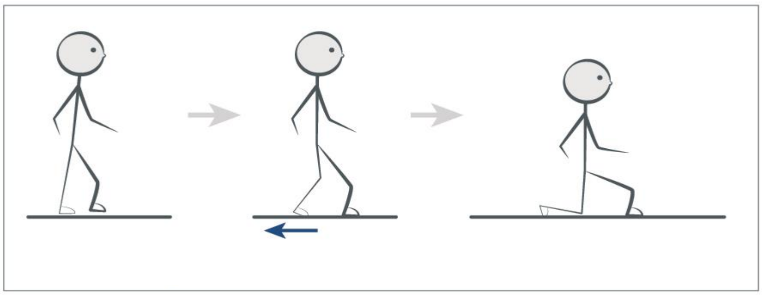

Figure 2: Toe-off slip

Providing for safe pedestrian movement involves considering the level of friction required, and comparing it to the level of friction provided by the pedestrian surface(s) in foreseeable conditions of use. *Friction* is defined in the current Australian Standards for slip resistance as ñAn intrinsic property of the two interfacing, interacting surfaces resulting from their micro- and macro-roughness, inter- and intra-molecular forces of attraction and repulsion, and their visco-elastic propertiesò (SA/SNZ, 2004a, p. 5). Expressed more simply, friction may be regarded as the force acting to prevent horizontal movement of an object across a surface despite the application of horizontal force to the object. The parameter commonly used to assess whether or not a slip might occur in a given situation is the *coefficient of friction* (COF), which is expressed as μ and calculated as follows:

$$\mu = F/N$$

where: F = *horizontal force required to slide the object across the surface*
N = *normal (i.e. vertical) force being exerted on the surface by the object*

Typically, the COF will be between about 0.1 and 0.8 for most common pedestrian surfaces and shoe sole materials. If the horizontal force is recorded at the point when movement of the object is initiated, the result is referred to as the *static coefficient of friction*. Conversely, if the horizontal force is recorded as the object is moving across the surface at a consistent speed, the result is referred to as the *dynamic coefficient of friction*. Usually the static coefficient of friction will be higher than the dynamic coefficient of friction. The distinction is important because some countries (e.g. USA) tend to rely primarily on static measurements, while others (including Australia) rely primarily on dynamic measurements.

Measurements reportedly made by Pye in the 1950s formed the basis of the often quoted conclusion that for adequate safety "the coefficient of friction between foot and floor should be not less than 0.40" (Pye, 1994,) ï a limit that incorporates a reasonable safety margin. Recent research supports this generally accepted proposition. For example, Zamora, Alcántara, Payá, Portolés and Algora (2008) concluded that a coefficient of friction of 0.40ï 0.55 is safe (i.e. adequately slip resistant) for <u>level</u> surfaces. Both the superseded (but still available) *AS/NZS 3661.1* (SA/SNZ, 1993) and the current *AS/NZS 4586* and *AS/NZS 4663* (SA/SNZ, 2004a,b) Australian Standards for slip resistance endorse that acceptance of a general minimum COF of 0.40 for pedestrian safety. Higher levels of slip resistance are required on sloping surfaces, with the magnitude of the increase proportional to the gradient. The following formula is provided in *HB 197* (SA, 1999) to determine the appropriate COF for a given gradient:

$$\mu = 0.0125S \quad \text{where: } \mu = \text{the COF required in a level situation}, \; S = \text{the slope (in percent) of the pedestrian surface}$$

The adjusted result also includes a reasonable margin for safety.

Ensuring that flooring is provided that produces coefficients of friction of at least 0.40 (when measured in accordance with Australian Standards)is a reasonable safety management approach when the main expected contaminant is water. Where more slippery contaminants can be anticipated flooring with higher levels of slip resistance is required; for example, in a commercial kitchen "a safe coefficient of friction might be 0.60 or above" (SA, 1999, p. 3).

The complexities in causation of slips are not yet fully understood. For example, while some individuals might successfully walk across an extremely slippery (e.g. icy) surface, others wearing the same footwear would slip; also, some individuals would have success only on some occasions. In this example, the environment is an important factor, but it is not the only one. Differences in gait between (and within) individuals may well be another factor. A large proportion of slips occur when there is some mismatch between pedestrian expectations about available friction and the level of friction that is actually available. Such mismatches can arise due to the following physical factors:

- A pedestrian surface that is inherently slippery (e.g. ice);
- A work area where lubricating contaminants are routinely present (e.g. water or another liquid, dust, larger objects such as ball bearings, beads);
- The casual presence of spills and contaminants (e.g. water tracked in on a wet day, a spilt drink);
- A sudden change in floor surfaces (e.g. from carpet to polished timber);
- A change in gradient of the pedestrian surface (e.g. a ramp);
- Fine growth (e.g. moss on a pavement);
- Excessive speed of movement for a given situation (e.g. running, or turning sharply);
- Footwear that is inadequately slip resistant in a given situation.

The likelihood of slips (and trips) occurring in the presence of physical risk factors can also be affected by:

- Perceptual issues including:
  - Lighting level(s)
  - Visual contrast ï between different surfaces as well as between the pedestrian surface and a slippery contaminant

    - The presence of glare
    - Presence/Appropriateness of warning signs.
- Cognitive issues including:
    - Expectation based on previous experience
    - Attention partly/wholly focussed on a task rather than just locomotion
    - Momentary distraction
    - Awareness of previous incidents
    - Awareness of warnings.
- Physical characteristics of the individual including:
    - Physical impairment;
    - Impairment of vision and/or or proprioception mechanisms;
    - Idiosyncratic gait;
    - Aging factors.

For more information see, for example, HSE (2011) and WorkSafe Victoria (2011).

With respect to aging, it is likely that healthy adults of all ages slip at approximately similar frequencies (Lockhart, Smith & Woldstad, 2005). However, as aging generally leads to deterioration in vision and proprioception as well as in strength and agility, middle-aged people will in general recover their balance after slipping (or tripping) less frequently than younger people, and older people will in general experience more falls than both young and middle-aged people (see, for example, DHA, 2005). In addition, factors such as a loss of bone density - also quite commonly associated with aging - tend to combine in a manner that results in an older person being more likely to sustain injury than a younger person who experiences the same type of fall.

4.3 Trips

Trips occur when the movement of the foot is impeded. Generally, this results from unintended contact (usually by the foot) with an obstruction in the path of travel (Figure 3); it also may be caused when the level of available friction is so high that micro-slipping (as occurs during heel strike and when pivoting) is not possible. While trips are most frequently experienced during forward movement, trips that occur during backward or sideways movement (e.g. in a poorly organised team lift in which at least one worker is unable to walk in a forwards direction) are more likely to result in a fall because people are less accustomed to walking in those directions and, therefore, less practiced at recovering from any trips they might experience when doing so.

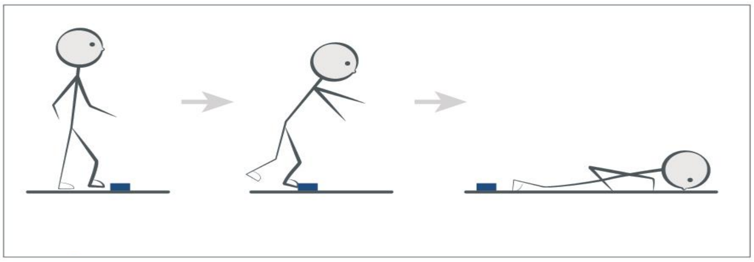

Figure 3: Trip

Many trips are caused by encounters with unobserved obstructions of relatively minor size. The *Guide to Traffic Engineering Practice Part 13 – Pedestrians* (Austroads, 1995) refers to a height difference of as little as 6 mm as sufficient to result in a potential trip hazard. The primary data for this and similar references is research published by Murray (1967), who reported that toe clearance for pedestrians walking across a level surface ranged from as little as 1 mm to about 38 mm, with a mean of 14 mm. Thus during a óstandardô stride, the toes of 50% of pedestrians could be expected to make contact with an undetected vertical face that was 14 mm high, while 50% of pedestrians would clear such a potential obstacle. Further, an undetected vertical face that was only 6 mm might still be contacted by up to 10% of pedestrians. Also, it is pertinent that Statewide Mutual (a self insurance mutual of NSW Local Government Authorities) suggested in its *Best Practice Manual – Footpaths, Nature Strips and Medians* that changes in level of less than 5 mm are to be regarded as imposing a low level of risk on pedestrians whereas changes in level of more than 10 mm in height create a high level of risk in good lighting conditions and a very high level of risk in areas of heavy shadow (Statewide Mutual, 2003).

4.4 Missteps

Thompson, Cohen, Horst, Johnson & Olsen (2005, p. 935) define a misstep as ñan unintentional departure from pedestrian gait appropriate for the walkway surfaceò and list the following among the important sub-types:

- Air steps ï which occur when a depression, a step down or change in gradient are unexpectedly encountered (Figure 4);
- Heel scuffs ï which usually occur on stairways with shallow treads when the heel becomes trapped under the overhanging riser as the pedestrian steps down to the next tread (Figure 5);
- Over-steps ï which occur on stairways when the descending foot lands too close to the nosing, or even beyond it, and is therefore unable to provide the pedestrian with the expected level of support (Figure 6);
- Under-steps ï which occur during stairway ascent and are usually relatively benign (Figure 7);

- Unstable footing ï which occur when the uneven or unstable nature of the pedestrian surface is not accommodated by the pedestrian, and typically results in inversion or eversion (or rolling) of the ankle.

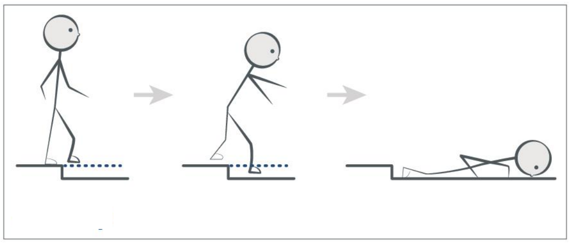

Figure 4: Air step

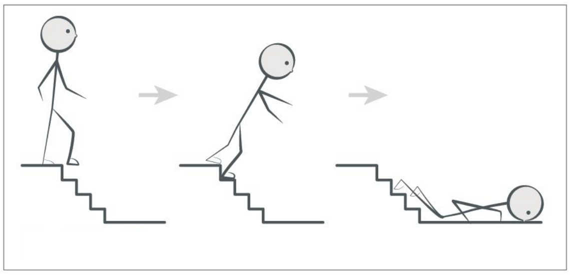

Figure 5: Heel scuff

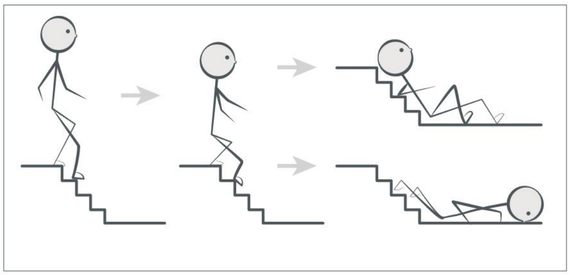

Figure 6: Over-step

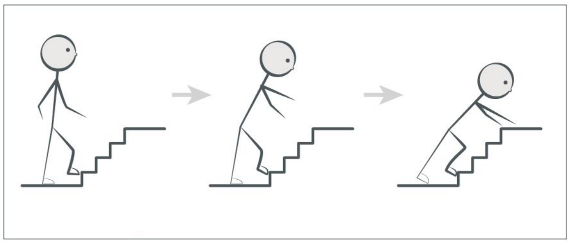

Figure 7: Under-step

Missteps are often associated with stairways. The Building Code of Australia (ABCB 2008) and *AS 1657 Fixed Platforms, Walkways, Stairways and Ladders – Design, Construction and Installation* (SA, 1992) contain detailed specifications in relation to stairway construction, including: maximum and minimum dimensions for treads and risers; adequate levels of slip resistance (at least on step nosings); and, the provision of handrails. Both of these documents also require goings and risers to be consistent within a flight of stairs. While the BCA does not set a specific limit in this regard, *AS 1657* specifies a maximum range for both risers and goings of ±5 mm.

Small dimensional faults on stairways can be hazardous, even when they are too small to be visually obvious. Tripping incidents can result when a part of the foot that is being moved fails to clear a nosing that is in a location inconsistent with other nosings in the flight, and missteps can occur when the foot to which weight is being transferred fails to land on the relevant nosing in a suitable location to provide stability. According to Sanders and McCormick (1992), ñdimensional non-uniformity of as little as 0.25 inches (6 mm) between adjacent riser heightsò is sufficient to cause tripping/misstepping incidents. Such faults are often too small to be seen by users, but can be readily detected by making simple but careful measurements. Inconsistent patterns of wear on treads and/or risers are often indications of such faults.

Air steps associated with steps and stairways usually occur when a step or stairway is not seen or when a person believes, incorrectly, that they have reached the bottom of a stairway they are descending or, less commonly, that they have not yet reached the top of a stairway they are ascending. Heel scuffs are most likely to occur on shallow treads, with that likelihood increasing if a nosing significantly overhangs the next step tread. Over-steps also generally occur on steps with shallow treads and/or if the stairway has dimensional inconsistencies, with a combination of the two being most hazardous. Under-steps, which result from failure to lift the foot to the necessary height when stepping up to the next step, generally occur when risers are too high and/or if the stairway has dimensional inconsistencies. The reduced risk of injury (compared to over-steps) is because the person who loses their balance after under-stepping usually falls forwards onto the ascending stairway in front of them, and therefore through a relatively small vertical distance.

4.5 Falls from heights

National occupational injury data (Safe Work Australia. (2001/02 - 2007/08) reveal that 119 (5.9%) of the 2,016 fatal incidents and 56,080 (5.8%) of the 974,810 serious injury events that occurred during the eight-year period involved falls from heights. By comparison, 28 (1.4%) of those fatalities and 122,075 (12.5%) of those serious injuries were attributed to falls on the same level. Consequently, the occupational injury data support the intuitive expectation that generally the risk of injury and death increases as the vertical distance increases due to corresponding increases in velocity and momentum at impact. However, deaths and serious injuries also occur as a result of falls from relatively low heights, and falls on the same level. For example, of 214 fatalities resulting from falls between 1989 and 1992 in Western Australia, 60% related to falls through less than 5 m (DOCEP, n.d.).

A guide to the injury potential of impact with the ground by a person who falls from a height is provided by calculating the possible vertically downwards velocity of a person who falls from a height. Using the formula for velocity (i.e. $v = \sqrt{2gd}$), it may be calculated that a person who falls from an upright position on an unguarded stationary platform that is only 0.6 m above the surface on which they ultimately land on their back can be expected to effectively fall vertically through a distance of 1.5ï 1.8 metres. The vertically downward velocity of their body when they impact with the lower surface will be 5.4ï 5.9 m/s (or 19.5ï 21.4 km/h). A person who falls in the same manner from an upright position on a platform that is situated 2 m above the ground can be expected to attain a vertically downwards velocity of 7.6ï 7.9 m/s (or 27.3ï 28.4 km/h).

4.6 Falling objects

With 20 fatalities and over 4000 claims in one year (Safe Work Australia, 2006ï 7) falling objects continue to impose significant risks on Australian workers. Data in Table 2 indicate that over 75% of the injuries from falling objects are primarily caused by falling materials, substances, hand tools and appliances, whereas environmental conditions were causally involved in only 3.6% on the incidents. Nearly 25% of these types of incidents occurred in the manufacturing sector, and a further 14.4%, 12.2% and 9.1% of them occurred in the construction, retail trades, and transport and storage industries respectively (Table 3).

5 Legislation and standards

Legislation and standards for gravitational hazards span the work health and safety (WHS)/occupational health and safety (OHS) legislation, the Australian Building Code and Australian Standards.

The national *Model Work Health and Safety Act* (*WHSA*) (Safe Work Australia, 2011a) sets out the general responsibilities for workplace safety, which include the requirements for those who manage, design, manufacture or install structures including buildings (*WHSA* ss 21ï 26) (Safe Work Australia, 2011a). The *Model Work Health and Safety Regulations* (*WHSR*) (Safe Work Australia, 2011b) provide more detail with respect to obligations relating to gravitational hazards, including the need to ensure, as far as is reasonably practicable, that:

> é the layout of the workplace allows, and the workplace is maintained so as to allow, for persons to enter and exit and to move about without risk to health and safety, both under normal working conditions and in an emergencyé [and that] floors and other surfaces are designed, installed and maintained to allow work to be carried out without risk to health and safety (*WHSR* s 31.1).

Similarly, the Regulations provide information (also in Part 3) concerning managing and minimising risks likely to be associated with falling objects, as well as information (in Part 4.4) pertaining to the risks of falls by people.

Two codes of practice developed under the *WHSR* are relevant to gravitational hazards. The draft *Code of Practice: How to Prevent Falls at Workplaces* (Safe Work Australia, 2010) provides quite extensive risk management information . It also notes that while risk assessment is not required if the method of control is known, where risk assessments are conducted there are a range of factors to consider (Safe Work Australia, 2010). The draft *Code of Practice: Managing the Work Environment and Facilities* (Safe Work Australia, 2011c) provides basic information concerning gravitational hazards.

As indicated in section 4, the design of buildings and other structures is a key factor in prevention of slips, trips and falls. The Building Code of Australia (BCA) is the principal document for regulating the building design profession (ASCC, 2006). It is ñproduced and maintained by the Australian Building Codes Board (ABCB) on behalf of the Federal Government and state and territory governments [and] has been given the status of building regulations by all states and territoriesò (COSH, 2008, p. ii). Although the BCA is comprehensive in regulating some aspects of design such as choice of material and construction methods, its scope is considerably less than that of the OHS statutes and regulations. It is relevant to note that the BCA does not address health and safety of workers during the construction process (Bluff, 2003).

5.1 Slips, trips and falls

While research focussing on the causes and prevention of falls has increased in the last three decades, the statutory requirements in Australia in terms of providing pedestrian surfaces that are reasonably free of potential slipping and tripping hazards are still quite limited. For example, the Building Code of Australia does not require floors associated with buildings to be slip resistant (a few specific exceptions notwithstanding), nor does it specifically address eliminating potential tripping and misstepping hazards from structures. The current Australian Standards for slip resistance (*AS/NZS 4586:2004* and *AS/NZS 4663:2004*) do not require the general provision of pedestrian surfaces that are slip resistant, instead only specify how measurements of slip resistance must be made. *HB 197* (SA, 199) provides useful recommendations for suitable surfaces in various situations. Conversely, *AS 1428.1–2009 Design for Access and Mobility Part 1: General Requirements for Access – New Building Work* (SA, 2009), which is referenced by the Building Code of Australia for those parts of buildings that are required to be áaccessible,ô requires pedestrian surfaces on continuous accessible paths of travel to and within buildings to be both slip resistant and free of other potential obstacles to safe movement, including changes of level of more than 5 mm. This apparently contradictory and unsatisfactory situation is under review, with the Australian Building Codes Board and Standards Australia currently considering revising both the Standards and the Building Code of Australia to encompass specifications in relation to required levels of slip resistance for pedestrian surfaces in various situations.

The draft *Code of Practice: Managing the Work Environment and Facilities* provides a range of recommendations aimed at preventing slip, strips and falls, including:

> Entries and exits should be slip resistant under wet and dry conditions.
>
> Aisles and walkways should be at least 600 mm wide and kept free of furniture or other obstructions at all times. Where it is necessary to clearly define entry and exit routes, the boundaries of the route should be marked by a permanent line of white, yellow or clearly contrasting colour at least 50 mm wide or by glowing markers. Entry and exit routes, stairs and walkways should be adequately lit.
>
> Open sides of staircases should be guarded with an upper rail at 900 mm or higher and a lower rail. A handrail should be provided on at least one side of every staircase. Additional handrails may be needed down the centre of wide staircasesé

> An untidy workplace can cause injuries, in particular injuries resulting from slips and trips, therefore good housekeeping practices are essential for all workplacesé
>
> é training all workers in good housekeeping procedures and their co-operation with these procedures is necessary to keep the workplace tidy.
>
> Floor surfaces should be suitable for the work area. The choice of floor surfaces or coverings will depend on the type of work carried out at the workplace, as well as the materials used during the work process, the likelihood of spills and other contaminants, including dust and the need for cleaning.
>
> Floors should be inspected regularly and maintained to eliminate slip and trip hazards. Common examples of hazards include trailing cables, uneven edges or broken surfaces, gratings or covers, loose mats or carpet tiles. Floor surfaces require sufficient grip to prevent slipping, especially in areas that may become wet or contaminated. (Safe Work Australia, 2011c, pp. 8ï 10)

Detailed information in relation to aspects of lighting for safe worker movement is also provided in that draft Code of Practice (Safe Work Australia, 2011c).

5.2 Falls from heights

Currently, varying legislative approaches exist across the Australian jurisdictions with respect to preventing exposure to fall hazards. Some do not specify any threshold heights, while for others the trigger heights for the implementation of specific controls vary from 1.8 m (ACT), through 2 m (VIC and NSW) to 3 m (QLD). The model regulations do not include height limits for managing risks from falls. Similarly, the draft *Code of Practice: How to Prevent Falls at Workplaces* states "Control measures are needed where there is a risk of injury irrespective of fall height" (Safe Work Australia, 2010, p. 8). This approach is reasonable because, as indicated earlier in this chapter, serious injury can be sustained as a result of same-level and low-height falls.

The draft Code of Practice contains extensive information about assessing and controlling risk of injury due to falls, promulgating the hierarchy of controls approach. A key recommendation is that work should be undertaken on the ground if possible. If this is not possible, undertaking work from engineered and properly constructed solid structures is preferable to suitable temporary structures such as scaffolds, which in turn are preferable to elevating work platforms. In all cases, work at heights should only be undertaken if the equipment and systems of work satisfy all appropriate Standards, Codes of Practice and legislative requirements; if safe means of access (including flooring free of slip and trip hazards, guardrails where required, and stairways and ladders that have appropriate and consistent dimensions and other characteristics) are provided and used; and if fall-arrest equipment such as safety lanyards, safety nets or catch platforms are available and properly used. The draft Code of Practice also contains extensive information on the safe use of ladders. Importantly, it advises that ladders are primarily tools for access or egress; they are not appropriate structures from which to work. Also, forklifts should never be used to lift or support workers unless a work box engineered to *AS 2359 Powered Industrial Trucks* (SA, 1995) is securely mounted and appropriate procedures are implemented.

5.3 Falling objects

The *Work Health and Safety Regulations* (Safe Work Australia, 2011b) address risk control strategies for falling objects with the required priority order being to eliminate the risks to health and safety of falling objects or, if it is not reasonably practicable to do so, to minimise any such risks, preferably by preventing objects from falling freely or at least by providing systems to arrest any such falls. Suggestions provided include the provision of secure physical barriers, the provision of safe means of raising and lowering objects, and the use of appropriate exclusion zones (*WHSR* s 4.4.8).

6 Control of gravitational hazards

The hierarchy of control[5] applies to managing gravitational hazards as it does to other hazards; that is, the preferred priority of control strategies is to:

- Eliminate the hazard
- Substitute the hazard with something safer
- Isolate the hazard from the people
- Reduce risk though engineering
- Reduce the level of harm using administrative actions
- Use personal protective equipment (PPE).

6.1 Elimination and substitution

The discussion on mechanisms of slips, trip and falls in section 4 highlights the role of design of floor surfaces, stairways, walkways and ancillaries such as lighting in injury prevention. The careful design, construction and maintenance of workplaces can make a major contribution to eliminating, or at least minimising, the risk that people may sustain injury as a result of gravitational hazards. Providing means of access and work areas that are free of trip hazards, a choice of slip-resistant flooring that takes into consideration the characteristics of the contaminants likely to be present (e.g. water near entrances and other water sources, oil and grease in workshops, flour in bakeries, etc.), and of stairways and platforms with adequate edge protection are all important responsibilities of designers and builders. This is consistent with the concept of Safe Design, which is a key component in the lifecycle approach to controlling OHS hazards.[6] Safe Design is a process defined as:

> The integration of hazard identification and risk assessment methods early in the design process to eliminate or minimise the risks of injury throughout the life of the product being designed. It encompasses all design including facilities, hardware, systems, equipment, products, tooling, materials, energy controls, layout and configuration. (ASCC, 2006, p. 5)

[5] See *OHS BoK* Control
[6] See *OHS BoK* Control

Incorporation of the model for Safe Design into building design, modification and maintenance requires that these processes are an integral part of the broad management system, including financial and procurement processes as well as OHS.

6.2 Barriers and defences

While elimination is the optimal control strategy, it is often not practicable to eliminate the hazard and so the risk must be minimised through substitution and a combination of further controls. For example, the discussion in section 4.2 on the mechanism of slips highlighted the role of contaminants in the friction between a pedestrianôs foot and the floor. Similarly, the discussion in section 4.3 on trips referred to role of impediments to movement. While design is undoubtedly a key factor in prevention of slips and trips, work practices, particularly in relation to storage and housekeeping, are also important. Thus the notion of barriers and defences becomes important.[7]

The intent of barriers is to control, mitigate or protect from accidents or undesired events (Trbojevic, 2008); they may be social, organisational, hardware, cultural, behavioural or human. Thus isolation, engineering, administrative and PPE controls represent a range of barriers that can comprise a ódefence-in-depthô[8]. Isolation controls may include restricting access to work areas identified as higher risk for slips, trips and falls. Engineering controls may include floor treatments to increase slip resistance, lighting of work areas or drainage to prevent pooling of contaminants. Administrative controls may include maintenance/repair of leaking equipment or pipes, housekeeping practices, and marking of walkways, edges of steps and any changes in floor heights or surface types. Finally, PPE such as safety footwear, hard hats and restraints are often employed to protect workers against gravitational hazards.

Safety footwear

No Australian Standard sets performance criteria for the slip resistance of footwear. It is therefore perhaps not surprising that there is a significant range in the frictional performance of available footwear. Footwear performance can be affected by the material from which the shoe sole and heel are constructed, as well as by the type and condition of the tread pattern. It can also be affected by factors such as how well a shoe fits an individual, and the extent to which it is worn/damaged. Complicating matters further is the fact that rankings of shoe frictional performance are often inconsistent from one pedestrian surface/contaminant combination to another. Selection of the most appropriate footwear for a given workplace can involve simple subjective assessments being made through processes in which workers are asked to trial suitable options, and can also be based on

[7] See *OHS BoK* Control
[8] See *OHS BoK* Control

making objective measurements of coefficients of friction obtained by different footwear on the types of surfaces and contaminants known to be present.

Hard hats

The wearing of hard hats is common and frequently useful practice in areas where there is a risk of falling objects. However, as identified in the discussion of momentum and impulse in section 4.1, hard hats can offer limited protection from falling objects. AS/NZS 1801 Occupational Protective Helmets (SA/SNZ, 1997, s 4.6) requires:

> **SHOCK ABSORPTION TEST** When helmets are tested in accordance with Appendix C, the impact of 50 ±1 J shall not cause the deceleration of the striker to exceed 980 m/s^2, or the force transmitted to the headform shall not exceed 5.0 kN for any of the set of three conditioned helmets.

Fall arrest/restraint

Scaffolds, elevating work platforms or temporary guardrailing are the most effective fall-prevention measures. Where it is not practicable to use these higher-order controls, employers may need to consider the use of travel-restraint or fall-arrest systems. Travel-restraint systems are fall-prevention measures that limit the travel of workers to ensure they do not reach the live edge of a building or structure from which they may fall. Fall-arrest systems (also known as ‘fall injury prevention systems’) can be anchored to one point or a horizontal lifeline, and arrest the user in the event of a fall. The installation, selection and use of these devices require specialised knowledge and skills. All workers required to use these devices must be provided with appropriate training and be competent in their use.

6.3 Application of control strategies

The following examples of real situations and actual injury occurrences demonstrate how processes of identifying gravitational hazards and assessing and controlling associated risks using the hierarchy of control can be implemented to eliminate or at least control risks associate with gravitation hazards.

6.3.1 Slips and trips

Incident 1 *A worker in a poultry meat processing facility slipped when he stepped on chicken fat that was present on the floor, fell and ruptured his L5/S1 intervertebral disc.*

Issues:

- The floor of the work area was textured and slip resistant in the presence of water
- Even highly textured floors can be slippery in the presence of significant amounts of fatty contaminants;
- Such contaminants were routinely permitted to accumulate on the floor;

- Workers were unlikely to be capable of constantly maintaining awareness of the need to detect and avoid these contaminants.

Available preventative actions:

- Provide highly textured flooring and maintain it to ensure that the inherent level of slip resistance is maximised;
- Redesign work benches, waste receptacles and systems of work to minimise the amount of waste material that can reach the floor;
- Provide textured gratings on the floor through which waste material could fall;
- Implement systems of work involving more frequent cleaning of the floor, perhaps with dedicated cleaners or at least contaminant spotters.

Incident 2 *A cleaner at a medical facility slipped and fell down a stairway in wet conditions while carrying a heavy load. He sustained facial injuries as well as two ruptured intervertebral discs.*

Issues:

- The stairway comprised textured concrete, which would have been inherently slip resistant even when wet had it been regularly cleaned;
- The stairway was exposed to the weather in a shady area;
- At the time of the incident the stairway surfaces were contaminated with green material, presumably algae or moss;
- The load being carried compromised the ability of the worker to see the contaminated condition of the steps.

Available preventative actions:

- Maintain the inherent slip resistance of the stairway by thoroughly cleaning it on an appropriately regular basis;
- Provide cleaners with suitable trolleys with which to transport loads within the grounds to minimise the need for them to carry heavy loads.

Incident 3 *At a heavy-vehicle maintenance company an office worker who was hurrying to a meeting took a shortcut through the new workshop and slipped on the smooth concrete floor that was both wet (due to a roller door being left open during a shower of rain) and oily. He sustained permanently disabling back injuries.*

Issues:

- The floor was very smooth concrete, which is invariably very slippery when wet with water and even more so in the presence of water and oil;
- The floor was routinely contaminated with oil due to the systems of work in the workshop;

- There were no designated walkways through or within the workshop;
- Workers can be expected to take convenient shortcuts;
- Workers can be expected to become increasingly habituated to risks that they continually encounter.

Available preventative actions:

- Apply better design principles to the workshop, including provision of a more slip-resistant floor in the workshop and dedicated slip-resistant walkways;
- Install an awning above the external doorway;
- Provide slip-resistant flooring in areas near entrances that are likely to become wet during rain showers (e.g. apply paint-on treatment, etch or abrade the existing floor, replace the floor, deploy slip-resistant matting)
- Implement policies, procedures and systems of work, and provide adequate training and supervision, to prevent office workers from taking shortcuts through the potentially hazardous workshop.

Incident 4 *On a multi-level building site, a construction worker, who was assisting another worker to drag a very heavy load backwards, tripped when he inadvertently stepped into an unseen and unprotected floor penetration. He sustained injury to the knee that he twisted during his trip, stumble and fall.*

Issues:

- A number of penetrations had been cut into the floor sometime between the date of injury and the most recent previous occasion on which the worker had worked in the relevant area;
- Those penetrations were not covered or highlighted in any way, and the workers had not been warned of their presence;
- As is common on building sites, the workers were under pressure to finish tasks assigned to them as other workers who had to undertake separate activities in the relevant area were on standby.

Available preventative actions:

- Better coordination of the different trades to ensure that floor penetrations are not created any earlier in the process than necessary, and thereby to minimise the duration of any risk;
- Provide suitable (i.e. secure and sufficiently strong) covers over any penetrations, and erect suitable barriers around them;
- Provide appropriate warnings.

Incident 5 *To stop an approaching train, a railway flagman had to use an external steel stairway to gain access to the track. It was before sunrise in midwinter in a region* *where frosts are common. He slipped on the smooth and ice-coated nosing at the edge of the landing, fell down the stairway and sustained injuries to his back, neck and one of his knees.*

Issues:

- The landing above the stairway was expanded metal, and highly slip resistant even when wet or icy;
- The 50 mm-deep nosing strip comprised smooth metal and obviously would be slippery when wet or icy;
- There was no roof over the stairway, and no lighting was provided;
- The worker was not very familiar with the stairway, and had only previously used it in dry conditions;
- The worker had limited time in which to flag down an approaching train to ensure the health and safety of workers further along the track.

Available preventative actions:

- Ensure that all relevant surfaces (i.e. the landing and all nosings) are adequately slip resistant throughout);
- Apply a suitable anti-slip strip to the top-most nosing, and reapply as required;
- Provide adequate illumination to enable workers to use the stairway safely at night.

6.3.2 Falls from heights

Incident 1 *A labourer whose employer was vacating a warehouse sustained numerous injuries when he fell from the unfloored roof of an office area within the warehouse that had been used as temporary storage platform.*

Issues:

- The worker had been lifted onto the roof in the bucket of a bobcat;
- He worked while sitting on the top of the wall and reaching over the exposed plasterboard ceiling of the office below ï a ceiling that collapsed beneath him when he unintentionally leaned on it;
- No fall-arrest equipment was provided.

Available preventative actions:

- Ensure that the area above the offices (or any other area) is not used for storage unless and until it has secure flooring, suitable edge protection and safe means of access;
- Ensure that improvised means (i.e. the bobcat) are never used to lift workers into unsafe working situations;

- Provide properly engineered and safe temporary access, such as a set of mobile stairs with a work platform;
- Provide suitable fall-arrest systems and equipment.

Incident 2 *A construction-site labourer was transporting wheelbarrow-loads of bricks within a multi-level building when he stepped backwards while turning his barrow and fell down an open and unprotected elevator shaft in which the elevator had not yet been installed. He sustained multiple and permanently disabling physical and psychological injuries when he landed on scaffold supports and rubble at the foot of the shaft, and when the empty wheelbarrow landed on top of him.*

Issues:

- The work was being performed rapidly and in area with limited space for turning;
- There was no barrier across the opening, despite the fact that no work was being undertaken that necessitated the provision of access to the shaft;
- No catch platform or net was provided within the shaft.

Available preventative actions:

- Ensure that suitable barriers are deployed across the opening (and any other such openings);
- Install temporary flooring of adequate strength across the shaft at each floor level;
- Manage work scheduling to minimise the extent to which work has to be undertaken near the open lift shaft;
- Provide suitable fall-arrest systems and equipment.

6.3.3 Falling objects

Incident 1 *A labourer with limited experience in tree lopping obtained work with a tree lopping company. Two months later he was working on the ground in the front yard of a house when he heard another worker call out from the backyard for some rope. He carried a length of rope to the rear of the premises and was struck by a falling branch that had been partially cut from a tree and was not otherwise secured. He sustained several fractures as well as facial injuries.*

Issues:

- As the injured worker had been working in the front yard, he was not aware that lopping of overhanging branches had commenced;
- There was no exclusion zone established for the area in which branches were expected to fall;
- No warnings were provided before the worker entered the backyard;

- The worker could hear that the chainsaw was not in use, and did not expect any branches to fall.

Available preventative actions:

- Review the relevant code of practice (in this instance the *Amenity Tree Industry Code of Practice 1998*) and implement appropriate combinations of the strategies set out therein;
- Establish appropriate exclusion zones in areas where lopped material could be expected to fall;
- Use a crane and ropes or slings to control the lowering of lopped branches;
- Use ropes and pulleys appropriately to control the lowering of lopped branches, with such equipment being deployed before cutting commences;
- Issue warnings concerning any branches that are partially cut to all workers at the site and to any worker who is asked to bring equipment into a new area;
- Provide training and supervision with respect to precautions to take before entering drop zones.

Incident 2 *An inexperienced and untrained retail employee was attempting to use a manual pallet jack to move a pallet into a bay under warehouse-type racking. The pallet was stacked with cartons that were not secured. She sustained injuries to one of her legs when cartons containing reams of paper fell on her.*

Issues:

- There was a shallow gutter in the floor running across the front of the bay, impeding the smooth operation of the pallet jack;
- Plastic wrapping that had been securing the cartons was removed before the first attempt as the worker believed it would be easier to complete that aspect of the task when the load was still accessible from all sides;
- Before the incident occurred multiple attempts were made, by first one then two then three assistants, to push the load across the gutter and into the bay;
- No specific training had been provided in relation to how to perform the task.

Available preventative actions:

- Fill in the gutter (apparently an artefact of a previous use of the warehouse) to provide smooth flooring throughout areas where heavy loads had to be moved;
- Develop and effectively implement safe work procedures; ensure that any wrappings are retained on pallet-loads of potentially loose items until the load has been moved into the relevant retail display position;
- Ensure that any worker who is required to perform the task is adequately trained and supervised.

Incident 3 *A painter sustained permanent brain damage when he fell onto a concrete driveway after standing on top of an A-frame ladder to paint the balusters of balconies on multi-level units.*

Issues:

- The ladder was not secured in any way;
- The worker was not provided with any alternative means of gaining access to and from the balconies on which he had to perform painting tasks;
- The worker was a recent immigrant who had minimal language skills in English, was untrained, and was unaware of his rights as an Australian worker.

Available preventative actions:

- Review the relevant Australian Standards (e.g. *AS 1892.5.2000 Portable Ladders – Selection, Safe Use and Care*) and implement appropriate combinations of the information set out therein;
- Provide workers with safe means for gaining access to the locations where work has to be undertaken and for performing that work (e.g. suitable scaffolding or mobile equipment);
- Develop and effectively implement safe work procedures; ensure that workers do not climb too high on ladders generally and do not stand on the top of A-frame ladders in particular;
- Ensure that any worker who is required to perform the work is adequately trained and supervised.

7 Implications for OHS practice

Injury statistics for slips, trips and falls, and falling objects indicate that all generalist OHS professionals, irrespective of industry, will have to deal with these gravitational hazards and provide advice on their prevention and management. Ideally, prevention of slips, trips and falls will be considered and addressed at the design phase; however, there will always be the requirement for further strategies through management systems and work practices to maintain the design features and address any residual risk.

Providing effective advice on the prevention of gravitational hazards requires an understanding of the technical factors in the causation and likely severity of injury of slips, trips and falls. The generalist OHS professional should be able to provide this advice while considering the context of the management systems, work practices, and workplace and organisational culture.

The role of the generalist OHS professional should encompass hazard identification and risk assessment. The scenarios described in section 6.3 show that, in each situation, a risk assessment by a competent OHS professional would have revealed a significant risk of injury from gravitational hazards. The generalist OHS professional should be able to support such hazard-identification and risk-assessment activities and provide advice on design, but should also recognise when specialist advice is required.

8 Summary

A significant proportion of occupational injuries and fatalities are due to exposure of workers to gravitational hazards. These hazards are most usefully thought of in terms of gravitational energy; knowledge of how this energy behaves assists in understanding causation and should underpin risk assessments. The outcomes of loss of control of gravitational hazards may be a slip, trip or fall on the same level, a fall from a height or an object falling from a height. The mechanism of each of these outcomes is different. Slips are associated with the level of friction between the pedestrian's foot and the floor, and trips involve an encounter with an obstruction that inhibits movement. Missteps are mainly associated with steps or stairs, and falls occur when there is a loss of stability. Objects, such as building materials, tools and appliances, fall when they are not restrained.

Such hazards can be most effectively controlled, if not entirely eliminated, by the systematic application of knowledge of the causation of slips, trips and falls and the principles of the hierarchy of control to the design and management of workplaces and work. Where the hazard has not been designed out, or perhaps cannot be designed out, then a range of other controls are required which may include restrictions to access, maintenance practices, work practices and supervision. While PPE is the last line of defence and its limitations should be recognised, it still has a role in that footwear, hard hats and fall-arrest/restraint systems may be required in some situations.

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