

Australian Standard[®]

Amusement rides and devices

Part 1: Design and construction



This Australian Standard® was prepared by Committee ME-051, Amusement Rides and Devices. It was approved on behalf of the Council of Standards Australia on 9 July 2009. This Standard was published on 31 July 2009.

The following are represented on Committee ME-051:

- Australian Amusement Association
 - Australian Amusement Leisure and Recreation Association
 - Australian Chamber of Commerce and Industry
 - Consumers' Federation of Australia
 - Department of Commerce, Worksafe Division, WA
 - Department of Justice and Attorney General, Qld
 - Department of the Premier and Cabinet, SA
 - Engineers Australia
 - Insurance Council of Australia
 - Kidsafe
 - Safety Institute of Australia
 - Showmen's Guild of Australasia
 - Workcover New South Wales
 - Worksafe Victoria
-

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Standards Australia wishes to acknowledge the participation of the expert individuals that contributed to the development of this Standard through their representation on the Committee and through the public comment period.

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Australian Standard[®]

Amusement rides and devices

Part 1: Design and construction

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PREFACE

This Standard was prepared by Joint Standards Australia/Standards New Zealand Committee ME-051, Amusement Rides and Devices, to supersede AS 3533.1—1997 and AS 3533.1 Supp1—2003.

This Standard incorporates Amendment No. 1 (December 2011). The changes required by the Amendment are indicated in the text by a marginal bar and amendment number against the clause, note, table, figure or part thereof affected.

This Standard was prepared by the Australian members of the Joint Standards Australia/Standards New Zealand Committee, ME-051. After consultation with stakeholders in both countries, Standards Australia and Standards New Zealand decided to develop this Standard as an Australian Standard rather than an Australian/New Zealand Standard.

The objective of this Standard is to provide regulators, designers and manufacturers with requirements for the design and construction of amusement rides and devices to promote uniformity with regards to design principles, manufacture and registration of these devices.

Originally developed from technical literature, existing regulations and guidelines, this Standard has been developed through the combined experience of the Committee and the organizations represented on it, along with contributions from several individuals and organizations having expert knowledge in those areas covered by this Standard.

The Committee acknowledges the contributions made by those individuals and organizations and by the Royal Australian Air Force on the subject of the influence of acceleration on the human body (Appendix D), and wishes to record its appreciation of their permission to include this material.

Major changes to the previous edition are as follows:

- (a) Clarification of requirements for calculating the acceleration factor in Clause 2.1.4.
- (b) Clarification of when to assess a ride for intrinsic safety and inclusion of the text from AS 3533.1 Supp 1—2003 as Appendix E, providing guidance on determining if a ride's intrinsic safety is secured or not secured.
- (c) Revision of requirements relating to loads and the basis of design to address both permissible stress design and ultimate limit state design methodologies.
- (d) Expansion of requirements for passenger restraints to include a risk assessment process.
- (e) Revision of requirements for land-based toboggans with respect to automatic speed controls and safety zones around the channel.
- (f) Relocation of specific requirements for inflatable structures and roller coasters to separate Standards.
- (g) Removal of passenger ropeways and passenger conveyors from the scope of AS 3533.1.

The Committee also intends to refer to a new Standard for flying foxes that is under preparation by Committee SF-047, Artificial Climbing Structures, to replace the requirements in Clause 5.12. When the new Standard is published, this Standard will be amended accordingly.

Attention is drawn to AS 3533.2, which is written specifically for owners and operators involved in the day-to-day running of amusement rides and devices.

The term 'informative' has been used in this Standard to define the application of the appendix to which it applies. An 'informative' appendix is only for information and guidance.

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STANDARDS AUSTRALIA

Australian Standard Amusement rides and devices

Part 1: Design and construction

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE

This Standard specifies requirements for the design, manufacture and construction of fixed and portable amusement rides and devices, excluding—

- (a) miniature trains and railway systems owned and operated by model railway societies, clubs or associations;
- (b) rides or devices when operated under the control of public transport legislation;
- (c) plant specifically designed and used for sporting, professional stunt, theatrical or acrobatic activities; and
- (d) passenger ropeways and passenger conveyors (see AS 4722).

NOTES:

- 1 The exclusion in Item (c) does not prevent such plant being used as an amusement device provided it complies with the relevant requirements in this Standard.
- 2 Specific requirements for particular types of amusement rides and devices are specified in Section 5 of this Standard, other Parts of AS 3533 and other Standards; the specific requirements take precedence over corresponding general requirements in this Standard where any difference exists. Clause 5.1 lists the other Parts of AS 3533 and the other Standards that will need to be consulted for certain types of amusement rides and devices.
- 3 The operation and maintenance of amusement rides and devices are covered by AS 3533.2. AS 3533.3 provides requirements for in-service inspections of amusement rides and devices.
- 4 Compliance with the requirements and conditions set down by associations such as The Australian Association of Live Steamers is generally required for the miniature trains and railway systems mentioned in Item (a) above.

1.2 REFERENCED DOCUMENTS

The following documents are referred to in this Standard:

AS

1056	Storage water heaters
1056.1	Part 1: General requirements
1056.2	Part 2: Specific requirements for water heaters with single shells
1056.3	Part 3: Specific requirements for water heaters with composite shells
1170	Structural design actions
1170.4	Part 4: Earthquake actions in Australia
1210	Pressure vessels
1210 Suppl	Unfired Pressure Vessels—Advanced design and construction (Supplement to AS 1210—1997)
1228	Pressure equipment—Boilers

AS	
1271	Safety valves, other valves, liquid level gauges, and other fittings for boilers and unfired pressure vessels
1319	Safety signs for the occupational environment
1394	Round steel wire for ropes
1403	Design of rotating steel shafts
1418	Cranes, hoists and winches
1418.1	Part 1: General requirements
1418.2	Part 2: Serial hoists and winches
1418.10	Part 10: Elevating work platforms
1530	Methods for fire tests on building materials, components and structures
1530.2	Part 2: Test for flammability of materials
1657	Fixed platforms, walkways, stairways, and ladders—Design, construction and installation
1668	The use of ventilation and airconditioning in buildings
1668.2	Part 2: Ventilation design for indoor air contaminant control
1725	Chain-link fabric security fencing and gates
1732	Fusible plugs for boilers
1735	Lifts, escalators and moving walks
1735.1	Part 1: General requirements
1768—1991	Lightning protection
1926	Swimming pool safety
1926.1	Part 1: Safety barriers for swimming pools
2159	Piling—Design and installation
2237	Plastics fuel and emission control tube
2293	Emergency escape lighting and exit signs for buildings
2293.1	Part 1: System design, installation and operation
2321	Short-link chain for lifting purposes
2444	Portable fire extinguishers and fire blankets—Selection and location
2593	Boilers—Safety management and supervision systems
2759	Steel wire rope—Use, operation and maintenance
2788	Pneumatic fluid power—General requirements for systems (ISO 4414:1998, MOD)
2790	Electricity generating sets—Transportable (Up to 25 kW)
2860	Textiles—Stitch types—Classification and terminology
3533	Amusement rides and devices
3533.2	Part 2: Operation and maintenance
3533.3	Part 3: In-service inspection
3533.4.1	Part 4.1: Specific requirements—Land-borne inflatable devices
3533.4.3	Part 4.3: Specific requirements—Roller coasters
3533.4.4	Part 4.4: Specific requirements—Concession go-karts
3569	Steel wire ropes
3791	Hydraulic hose

A1

AS

- 3892 Pressure equipment—Installation
- 3920 Assurance of product quality
- 3920.1 Part 1: Pressure equipment manufacture
- 3990 Mechanical equipment—Steelwork
- 3998 Non-destructive testing—Qualification and certification of personnel
- 4024 Safeguarding of machinery
- 4024.1 Part 1: General principles
- 4024.1801 Part 1801: Safety distances to prevent danger zones being reached by the upper limbs
- 4037 Pressure equipment—Examination and testing
- 4100 Steel structures
- 4722 Passenger ropeways and passenger conveyors
- 60204 Safety of machinery—Electrical equipment of machines
- 60204.1 Part 1: General requirements (IEC 60204-1, Ed.5 (FDIS) MOD)
- 60529 Degrees of protection provided by enclosures (IP Code)
- 61508 Functional safety of electrical/electronic/programmable electronic safety-related systems (series)
- 62061 Safety of machinery—Functional safety of safety-related electrical, electronic and programmable electronic control systems
- CB1 SAA Boiler Code (superseded)
- AS/NZS
- 1170 Structural design actions
- 1170.1 Part 1: Permanent, imposed and other actions
- 1170.2 Part 2: Wind actions
- 1170.3 Part 3: Snow and ice actions
- 1200 Pressure equipment
- 1530 Methods for fire tests on building materials, components and structures
- 1530.3 Part 3: Simultaneous determination of ignitability, flame propagation, heat release and smoke release
- 1554 Structural steel welding
- 1554.1 Part 1: Welding of steel structures
- 1554.2 Part 2: Stud welding (steel studs to steel)
- 1554.3 Part 3: Welding of reinforcing steel
- 1554.4 Part 4: Welding of high strength quenched and tempered steels
- 1554.5 Part 5: Welding of steel structures subject to high levels of fatigue loading
- 1554.6 Part 6: Welding stainless steels for structural purposes
- 1664 Aluminium structures
- 1664.1 Part 1: Limit state design
- 1664.2 Part 2: Allowable stress design
- 1668 The use of ventilation and airconditioning in buildings
- 1668.1 Part 1: Fire and smoke control in multi-compartment buildings
- 1768:2007 Lightning protection
- 1869 Hose and hose assemblies for liquefied petroleum gases (LP Gas), natural gas and town gas

AS/NZS

- 1891 Industrial fall-arrest systems and devices
- 1891.1 Part 1: Harnesses and ancillary equipment
- 3000 Electrical installations (known as the Australian/New Zealand Wiring Rules)
- 3002 Electrical installations—Shows and carnivals
- 3136 Approval and test specification—Electrical equipment for spa and swimming pools
- 3190 Approval and test specification—Residual current devices (current-operated earth-leakage devices)
- 3191 Electric flexible cords
- 3500 Plumbing and drainage
- 3500.4 Part 4: Heated water services
- 3788 Pressure equipment—In-service inspection
- 3832 Electrical installations—Cold-cathode illumination systems
- 4360 Risk management
- 5848 Code of practice for bungee jumping
- 61558 Safety of power transformers, power supply units and similar
- 61558.1 Part 1: General requirements and tests (IEC 61558-1 Ed.2, MOD)
- 61558.2.4 Part 2.4: Particular requirements for isolating transformers for general use (IEC 61558-2-4:1997, MOD)
- 61558.2.6 Part 2.6: Particular requirements for safety isolating transformers for general use (IEC 61558-2-6:1997, MOD)

AS/NZS ISO

- 9000 Quality management systems—Fundamentals and vocabulary
- 9001 Quality management systems—Requirements

BS

- 2573 Rules for the design of cranes (series)

DIN

- 15018 Cranes (series)
- 15020 Lifting appliances (series)

OTHER DOCUMENTS

Australian Uniform Building Regulations Co-ordinating Council
Building Code of Australia (BCA)

Australian Miniature Boiler Safety Committee
AMBSC Code Part 1 Issue 6—1994: Copper boilers
AMBSC Code Part 2 Issue 4—1995: Steel boilers

American Society for Testing Materials (ASTM)
F2291 Standard practice for design of amusement rides and devices

1.3 DEFINITIONS

For the purpose of this Standard, the definitions below apply.

1.3.1 Amusement device

An arrangement of equipment that produces the desired effect of amusement or entertainment when the patron moves through it or on it primarily by his or her own action, or any other system that is not covered by the term ‘amusement ride’.

NOTE: See Clause 1.3.2.

1.3.2 Amusement ride

An arrangement of structural or mechanical elements (or both), that is designed to move patrons in a controlled manner and is not necessarily reliant on patrons moving themselves to obtain the desired effect of amusement or entertainment.

NOTES:

- 1 Within this Standard the word ‘device’ may refer to an amusement ride or an amusement device.
- 2 Some regulatory authorities may refer to amusement rides and devices as ‘amusement structures’.

1.3.3 Aquatic amusement device

A device that involves patrons being intentionally immersed in water, either partially or fully, for a short period of time at some stage during the ride.

1.3.4 Arm’s reach

A distance of 2.7 m above the relevant reference plane, e.g. walking surface, and 1.5 m sideways or downwards either from the top of any edge barrier that physically prevents arm access or from the edge of that surface if there is no effective edge barrier; alternatively, lower distances determined in accordance with AS 4024.1801 considering the circumstances and any protective structures present.

1.3.5 Attendant

A person working under the supervision of an operator.

1.3.6 Authority

The authority having statutory powers to enforce legislative requirements regarding the design, manufacture, installation, registration and operation of amusement rides and devices covered by this Standard.

NOTE: Appendix A contains information regarding legislative requirements for amusement rides and devices, and a list of some of the authorities responsible for overseeing the implementation of such requirements.

1.3.7 Cable waterskiing system

A device where patrons are towed along on a body of water by ropes attached to a powered, overhead, continuous cable system running around sheaves contained in support structures or towers.

1.3.8 Competent person

A person who has acquired through training, qualifications or experience, or a combination of these, the knowledge and skills enabling that person to perform a specified task.

NOTE: Appendix B provides suggestions for the training, qualifications or experience considered appropriate to possess for the various competent persons referred to in this Standard.

1.3.9 Designer

The person responsible for the design of an amusement device.

1.3.10 Fail-safe

A state or condition whereby, if any component of an amusement device fails, a system exists to prevent any increase of the assessed risk associated with the device.

NOTE: Information regarding fail-safe systems is given in Appendix C.

1.3.11 Flying fox

A device consisting of an elevated rope on which a pulley or trolley system (fox) is used to transport patrons between two support structures.

1.3.12 Flume

A shaped channel containing flowing water along which patrons are transported in various floating vehicles.

1.3.13 Operator

The person having overall control of an amusement device.

1.3.14 Passenger conveyor

A device where skiers and others are transported, while standing, for recreational purposes on a moving element, excluding devices used as loading conveyors.

1.3.15 Passenger ropeway

A powered ropeway used for transporting, in a horizontal or inclined plane, passengers moved by carriers that are—

- (a) attached to or supported by a moving rope; or
- (b) attached to a moving rope but supported by a standing rope, or other overhead structure.

The term includes the prime mover and any transmission machinery, supporting structure and equipment. It does not include equipment such as cog railways, cablecars running on rails, equipment such as flying foxes or elevating systems for vehicles or boat-style carriers associated with amusement rides such as log or boat flume rides.

1.3.16 Patron

A person participating in an amusement ride or device.

1.3.17 Proprietor

The person having, at any given time, the legal responsibility for the management of an amusement device.

1.3.18 Roller coaster

A device that transports patrons in wheeled vehicles that are continuously in contact with and travel along a fixed rail system permitting (in part or in whole) the motion to be the result of the acceleration due to gravity. Such devices may be categorized as 'inverting' roller coasters where, by virtue of a rotation of the rail, patrons attain an attitude of head below abdomen for at least some portion of the ride.

1.3.19 Toboggan ride (aquatic)

A device so designed that patrons seated on a toboggan travel down an inclined, trough-shaped track or shaped channel. The toboggan may be wheeled or on skids, and the device may or may not incorporate a braking system, a water stop or a combination of both.

1.3.20 Toboggan ride (land-based)

A device so designed that patrons seated on a toboggan travel down an inclined slope in a shaped channel set into the ground. The toboggan may be wheeled and incorporates a patron-operated braking system.

NOTE: The term 'bobsled' is also used for this device.

1.3.21 Train

A system of linked vehicles operating on rails, pavement or hard ground and powered by internal prime mover(s) or an independent, linked prime mover vehicle.

1.3.22 Vehicle

Any carrier (e.g. car, gondola, chair, capsule, compartment or similar) on or in which patrons are supported, contained or carried when participating in an amusement ride or using an amusement device.

1.3.23 Waterborne ride

A device that involves patrons travelling, either for part of or for the whole of the ride, in vehicles floating on and propelled by water in a flume. The flume may terminate at the foot of an elevating system that returns vehicles and patrons to a higher point. Patrons are not immersed at any time, and do not become wet unless due to incidental splashing.

1.3.24 Water slide

An aquatic amusement device with an inclined sliding surface terminating in a run-out trough or pool. Patrons descend the slide (with or without any sliding device between the body and the slide) usually under the influence of gravity with water as the friction-reducing medium.

SECTION 2 DESIGN

2.1 CLASSIFICATION

2.1.1 General

The classification of an amusement ride or device shall be determined by—

- (a) obtaining values for the speed, height and acceleration of the device in accordance with Clauses 2.1.2 to 2.1.4;
- (b) computing the dynamic product of those values in accordance with Clause 2.1.5; and
- (c) assessing the intrinsic safety of the device in accordance with Clause 2.1.6.

Following the determination in Items (a), (b) and (c) above, the classification of a device shall be obtained from Table 2.1.

2.1.2 Speed

The maximum speed relative to the ground attained by a point located at the patron's nominal centre of gravity, under normal conditions of use, is expressed in metres per second and designated as follows (default value when there is no movement of the patron to be taken as unity):

Speed = v m/s

NOTE: The speed of patrons may be that attained while crawling, walking or running under their own power, or may be due to the motion of the ride or device.

2.1.3 Height

The maximum height relative to the ground (or to a substantial platform) to which the patron is elevated by the motion of the ride or device, or which is attained by the patron by any other means, is expressed in metres and designated as follows:

Height = h m

2.1.4 Acceleration factor

The maximum acceleration factor (n) is calculated as the vector sum of all calculated ride-induced accelerations (including the acceleration due to gravity, taken as acting at the patron's nominal centre of gravity), expressed in multiples of the acceleration due to gravity and designated 'acceleration factor' as follows:

$$n = \frac{\text{absolute value of maximum acceleration (m/s}^2\text{)}}{g \text{ (m/s}^2\text{)}}$$

where

$$g = 9.81 \text{ m/s}^2$$

NOTES:

- 1 The maximum acceleration may have any direction in space and may occur at any location in a ride circuit.
- 2 The patron's ride-induced acceleration can be a maximum remote from the patron's centre of gravity, e.g. at the patron's head where the seat is spinning about a lateral axis.
- 3 The acceleration due to gravity is taken as acting at the patron's nominal centre of gravity.
- 4 Because the acceleration due to gravity has to be included in the vector sum, the value of n cannot be less than unity.
- 5 For basic facts on the effects of acceleration on the human body, refer to Appendix D. ASTM F2291 also provides advice and information on this subject.

2.1.5 Dynamic product

The dynamic product (P) is calculated by multiplying the values of v , h and n , obtained in accordance with Clauses 2.1.2 to 2.1.4, as follows:

$$P = v \times h \times n$$

The value of P shall be rounded to the first decimal place.

NOTE: The maximum values used to calculate P are not necessarily concurrent in the ride cycle.

2.1.6 Intrinsic safety

If the intrinsic safety of the ride or device is not assessed, the classification of the device shall be in accordance with that given in Table 2.1 for devices where the intrinsic safety is not secured.

If the intrinsic safety of the ride or device is to be categorized as either ‘secured’ or ‘not secured’, the relevance of each of the following aspects to the operation of the device shall be determined:

- (a) Patron support systems within vehicles.
- (b) Suspension systems and their connections to vehicles.
- (c) Patron restraint structures.
- (d) Patron restraint locking devices, including vehicle closures, doors and gates where containment loads are applied to the locks.
- (e) Overspeed control.
- (f) Emergency stopping control.
- (g) Reaction on loss of power.
- (h) Electrical protection in respect to electrocution.
- (i) Consequences of uncontrolled patron-determined movement.

The intrinsic safety of the ride or device shall only be classified as ‘secured’ if, for each aspect determined to be relevant, the ride or device incorporates arrangements that address that aspect and those arrangements are fail-safe (see Clause 2.4.3.3).

If the relevant aspects listed in Items (a) to (i) above are not fail-safe, the amusement ride or device shall not be categorized as having intrinsic safety ‘secured’, thus precluding classification as Class 1.

Where any of the aspects listed in Items (a) to (i) above, as they may stem from the design of the device, are incapable of being fail-safe, the intrinsic safety of the amusement ride or device shall be categorized as ‘not secured’.

NOTE: Appendix E provides guidance for assessing the intrinsic safety of a ride or device. Appendix C contains additional information on failure to safety, with examples of fail-safe systems.

TABLE 2.1
CLASSIFICATION OF DEVICES

Intrinsic safety secured		Intrinsic safety not secured	
Class of device	Dynamic product (<i>P</i>)	Class of device	Dynamic product (<i>P</i>)
1	$0.1 < P \leq 25$	—	—
2	$25 < P \leq 100$	2	$0.1 < P \leq 25$
3	$100 < P \leq 200$	3	$25 < P \leq 100$
4	$200 < P$	4	$100 < P \leq 200$
—	—	5	$200 < P$

2.2 HAZARD IDENTIFICATION, RISK ASSESSMENT AND CONTROL OF RISK

In designing an amusement device, a designer is required to—

- (a) identify hazards associated with the use of the device;
- (b) ensure that an assessment is made to determine the risks associated with such identified hazards and any risks associated with patron characteristics; and
- (c) control such risks by implementing measures to either eliminate or minimize risks.

Designers shall take into account health and safety legislation (including noise levels), environmental impact and the relevant requirements of AS/NZS 4360 and AS 4024.1 when identifying hazards, assessing related risks and implementing control of such risks, and shall make known to the purchaser all risk assessment information, highlighting any residual risks associated with the ride or device, including any patron restrictions.

NOTE: AS 3533.2 provides guidance on the hazard identification, risk assessment and risk control process that may be applied to the operation of amusement rides and devices.

2.3 LOADS

2.3.1 General

The loads to be employed in design computations shall be selected or estimated in accordance with Clauses 2.3.2 to 2.3.8.

These Clauses do not apply to a building enclosing, or associated with, a ride or device that has no critical function in respect to the operational, mechanical or structural performance of the ride, i.e. the building only provides shelter (e.g. from rain or snow) for such aspects as black-out, operational support, boarding platforms or shelter for queue lines.

The requirements of the BCA and the AS/NZS 1170 series shall be applied to buildings associated with rides and devices.

Where amusement rides and devices are to be supported by buildings, the designer of the ride or device shall, on request, provide the dead, live and working loadings for the ride or device so the building design can proceed. Loadings quoted for the ride or device shall be carefully defined in respect of the inclusion or otherwise of AS/NZS 1170 load factors.

Where the designer of a ride or device is unavailable or the loadings appropriate to the design of a supporting building are not available, the building designer shall ensure that a competent person provides estimates for the ride actions relevant to the building design or, in the absence of such data, shall not permit the building to be used to support the ride or device.

2.3.2 Dead loads

Dead loads shall include all permanently applied mass loads arising from the following:

- (a) The mass of the structural components of the ride or device.
- (b) The mass of all fixed or moving components associated with the ride or device, including but not limited to the following:
 - (i) Drives and mechanical elements.
 - (ii) Decorations.
 - (iii) Electrical fitments, switchboards, and similar.
 - (iv) Floors, floor plates, handrails, and similar.
 - (v) Permanently fixed balance weights.
 - (vi) Hydraulic equipment, reservoirs, air compressors, auxiliary generators and similar attached items.

2.3.3 Live loads

Live loads shall include all those forces arising from the application of the ride or device in so far as it carries patrons or supports traffic as follows:

- (a) Patron mass for the purpose of calculations shall be not less than the following:
 - (i) Adults 75 kg.
 - (ii) Children 38 kg.

Where rides or devices are provided with single patron seats or equivalent confined zones, and the seats are independently supported, the designer shall consider the prospective loadings within the seat and supports in light of the likely spectrum of patron mass, cumulative damage and fatigue, and shall upscale the design mass to not more than 110 kg (approximately a load of 1 kN), where appropriate. Where patron positions are such that there is a limit to the possible patron mass, e.g. due to the width of a seat moulding, that mass shall be taken as the basis for the live load.

Where seats or confined zones are supported in pairs or are of bench design, or where patron masses are distributed in an ordered fashion, the designer shall take this into account so as to arrive at a rational nominal patron mass within the range of 75 kg to 110 kg.

The choice as to how patron masses are grouped shall be based on the most adverse condition, e.g. 2 adults are taken to be equivalent to 3 children unless seating arrangements preclude this.

- (b) The allowances for loading of areas by patrons shall be not less than the following:
 - (i) Walkways, access ways, platforms, stairs, and general areas open to groups of patrons boarding or exiting a device—4.0 kPa.
 - (ii) Aisles and contained walkways that form part of the experience of the system and where it is not possible to distribute the number of patrons with any accuracy—5.0 kPa.
 - (iii) Aisles, walkways, corridors and similar, where because of the operating conditions only one patron may pass at a time—1.0 kPa, together with 1 kN point loading at the most adverse position.
- (c) Forces for which direct application is not definable but which are due to the movement of patrons, out-of-level of the set-up or other factors, and which occur perpendicular to the gravitational loads in Items (a) and (b) above.

Such horizontal forces shall be estimated, by proportion, from the gravitational loads as follows, and shall be considered to act in the most adverse direction and in combination with other loads:

- (i) Where an accurate estimate of the horizontal components of live loads can be made, a minimum proportion of 2% of the (unfactored) vertical loads shall be added to those estimated loads.
- (ii) Where it is not possible to estimate with any accuracy the horizontally occurring live loads, a minimum proportion of 5% of the (unfactored) vertical loads shall be assumed.
- (iii) Lateral loading on handrails shall comply with AS/NZS 1170.1 for panic load situations.

2.3.4 Working loads

Working loads shall include the loads applied to or within the structure or its components due to the motional behaviour of the ride or device or due to the motion of patrons upon the surface or within the system. Typically, they are occasioned by release of potential or kinetic energy, acceleration, braking, rotational, translational, centrifugal, gyroscopic and Coriolis force effects.

A comprehensive analysis of the motional behaviour of a ride or device, including its foundation system, shall be made so that all forces and moments and their ranges of magnitude and direction are estimated for all the components and connections that make up the system.

The analysis shall consider the effects of partial loading and unbalanced loading, unless the design of the system precludes such events. In particular, the effects of emergency braking and any extraordinary motion thereby created shall be taken into account in the design.

The analysis shall consider the frequencies of all working loads and moments determined and shall link such frequencies to the magnitudes and ranges so that a check for fatigue may be made.

The following items deal with specific aspects of the estimation of working loads:

(a) *Coefficient of friction*

Where working loads are transmitted across an interface by virtue of friction, the design needs to take into account only the maximum value that will occur before slipping at the frictional contact occurs.

Coefficients of friction shall be as follows unless it can be demonstrated that a different value exists in some particular situation:

Interface	Coefficient of friction	
	Lower	Upper
Steel/steel—dry	0.20	0.35
Steel/steel—lubricated	0.05	0.15
Rubber/steel—dry	0.50	0.60
Rubber/steel—wet (water)	0.20 (static)	—
Fabric/resin—dry (polished)	0.20	0.26
Fabric/resin—wet (polished)	0.09	0.10
Steel/concrete—dry	0.16	0.33
Steel/concrete—wet	0.10	0.15
Steel/timber—dry	0.20	0.35
Steel/timber—wet	0.25	0.30
Timber/timber—dry	0.25	0.35

NOTES:

- 1 The above coefficients of friction have been derived from references and experience. They are typical figures and generally conservative. However, designers should base designs on specific references or experimental values wherever the magnitude of a frictional force is related to safety.
- 2 Unless otherwise stated, the coefficients are valid for slow movement at the interface. Static coefficients may be expected to be somewhat higher.
- 3 For design purposes, the upper range should be employed in estimating forces to be resisted structurally, while the lower range should be used in the estimation of parameters such as stability factors.

(b) *Effect of impact*

Where impact is a feature of the motion of an amusement ride or device, the effects of such impacts shall be catered for by the inclusion in the system of appropriate buffering elements of known characteristics from which the impact forces shall be estimated.

Where it is not possible to quantify the effect, such as an effect due to joints in rails on wheeled vehicles, it may be accounted for by the increase of the live load and dead load components of any gravitational working load by the following factors, depending on the class of the ride or device:

Class of device	Factor
1	1.05
2	1.10
3	1.15
4	1.20
5	1.20

(c) *Operator-induced effects*

Where an amusement ride or device can have its motion magnified or enhanced by the continuous adjustment of speed (or other parameters) by the operator, one of the following requirements shall be applied:

- (i) The control system shall be modified to preclude the 'operator enhance' effects.
- (ii) The motion, and thus the working loads, induced by operator interference shall be analyzed on the basis of a worst case being that of resonance.
- (iii) The motion of the system shall be modified by increased damping, the inclusion of limiting elements or functional brakes, or other appropriate means to shift the resonant frequency of the system beyond that attainable by the operator and controls. The ratio between the two frequencies shall be not less than 2:1.

(d) *Patron-induced effects*

Patrons can, in certain rides or devices, induce extraordinary motion by virtue of a shift in their centre of gravity or the like. The effect of such interference with the normal motion of the ride or device shall be analyzed and included in the working loads, or shall be reduced to be imperceptible by system modifications such as those described in Items (c)(i) and (c)(iii) above.

If it is not possible to properly estimate such effects, then the standard mass of the patrons (see Clause 2.3.3(a)) shall be increased by the following factors:

Class of device	Factor
1	1.05
2	1.10
3	1.15
4	1.20
5	1.20

NOTE: Both the patron's orientation and the basic type of ride affect the sort of self-acceleration that can be generated.

(e) *Excitation of static structures*

Where structures primarily of a static nature (e.g. sporting fixtures, park fixtures, playground ancillary devices) can be excited, by patrons or other agencies, into vibrations at frequencies of 1 Hz and less, an analysis of the prospective dynamic loadings shall be made and the design shall consider fatigue (see Table 2.3).

Alternatively, the structural concept shall be modified to change the characteristics of vibration to avoid damaging conditions such as resonance.

2.3.5 Wind loads

2.3.5.1 General

Loadings due to wind shall be considered under the headings of self-generated wind and environmental wind. In some circumstances, these two aspects of wind load may occur simultaneously and may have particular relevance as a summation to wind pressure sensitive elements of vehicles and the like and to the peak wind forces to be resisted by the structure and to be powered (or braked) by mechanical systems.

2.3.5.2 Self-generated wind

The significance of, and magnitude of, working loads deriving from the velocity of a ride vehicle or any structural support or part thereof shall be assessed according to the engineering principles of AS/NZS 1170.2. In particular, the basic wind pressure shall be calculated from the relevant peak velocity of the component(s) under consideration and the appropriate areas and aerodynamic coefficients adopted. Where locally (within a ride) self-generated wind may react with environmental wind, the resultant working wind forces shall be calculated, as above, based on the sum of the wind speeds.

2.3.5.3 Environmental wind

2.3.5.3.1 Fixed location rides and devices

Loadings applied to rides and devices by environmental winds shall be assessed according to AS/NZS 1170.2, taking into consideration the location in Australia at which the ride or device is to be established and the prospective wind speeds and directions likely at the site. AS/NZS 1170.2 predicts wind actions suitable for structural analysis according to ultimate limit state (ULS) methodologies and care is necessary where such results may not directly suit structural and mechanical analysis by permissible stress (PS) and general mechanical engineering principles. The relationship between ULS and PS wind speeds is—

$$V_p = \frac{V_u}{\sqrt{1.5}}$$

where

V_p = wind speed (PS)

V_u = wind speed (ULS) as per AS/NZS 1170.2

The minimum environmental wind speed to be considered for design, applicable to in-service (operation) of the ride or device, shall be 20 m/s relative to a height of 10 m at the site.

The minimum environmental wind speed to be considered for design, applicable to out-of-service conditions, shall be not less than the regional wind speed for an average recurrence interval of 500 years (V_{500}) for the site according to AS/NZS 1170.2 and all relevant factors (such as directional or height factors) shall be taken into consideration.

However, a relaxation may be permitted in one but not both of the following situations:

- (a) Where a ride or device is to be located in a particular fixed situation for a significant period but not approaching its design life, a lower out-of-service basic wind velocity may be satisfied by the designer on the basis of the agreement, in writing, of the purchaser and provided that the basis of the design is fully disclosed by the manual for the ride or device.
- (b) Where a designer/manufacturer proposes some reconfiguration of a ride so as to withstand the prospective out-of-service wind conditions, then such reconfiguration shall be—
 - (i) practical;
 - (ii) able to be accomplished in a timely manner considering both the unloading time for patrons and the time required to effect the reconfiguration;
 NOTE: In many parts of Australia, extreme storm winds can arise in very short periods and persist similarly with very little warning, frequently erratically. A period of only 30 min may be excessive to prepare a device to weather a storm.
 - (iii) agreed to by the purchaser; and
 - (iv) fully described in and documented by a procedure in the manual for the ride or device.

2.3.5.3.2 Mobile rides and devices

Loadings applied to mobile rides and devices by environmental winds shall be calculated according to the engineering principles of AS/NZS 1170.2 on the basis of wind velocities as follows:

- (a) Out-of-service 46 m/s.
- (b) In-service (operating) 20 m/s.

These wind speeds shall be taken to apply in any direction (relative to the ride) and to relate to obstructions up to a height of 10 m in terrain category 2 of AS/NZS 1170.2. For structures over 10 m, the analysis shall accommodate the velocity height profile for terrain category 2.

NOTE: The reconfiguration relaxation for out-of-service conditions in Clause 2.3.5.3.1 for fixed devices may be applied.

2.3.6 Seismic (earthquake) loadings

2.3.6.1 Fixed rides and devices

Loadings generated by earthquakes or seismic activity shall be considered in the design of amusement rides or devices that are fixed on a permanent foundation. Such loads, as they may act on the ride or device itself, shall be considered in the design analysis in combination according to Table 2.2. See also AS 1170.4 for the determination of notional loads. As AS 1170.4 determines the magnitudes for seismic loads for the evaluation of structural adequacy by ULS methodology, where these loads are to be evaluated by PS methodology, a factor of 1/1.5 shall be applied.

2.3.6.2 *Mobile rides and devices*

In the case of mobile or temporary unfounded rides and devices, the designer shall consider seismic activity and consequent loadings. The capacity of the device to withstand such actions while in its operational configuration shall be specified in the operation and maintenance manual for the device.

2.3.7 **Transport loads**

2.3.7.1 *General*

Mobile rides and devices are by definition structures that can be moved from place to place. Many are designed to incorporate a vehicle chassis within their operational structure with or without additional elements that may be dismantled and packed onto the chassis so as to be contained within an envelope suitable for road travel. Others may, in a dismantled form, be packed on trailers or containers for movement by independent prime movers or trucks; in some cases these may require their elements to be handled by cranes, forklifts and the like during assembly and dismantling (see Clause 2.3.8(f)).

A designer of an amusement ride or device shall—

- (a) consider the orientation, support and arrangement of the structure and mechanical elements of a ride or device in the travelling mode and account for the effects of travel generated accelerations acting on the dead weights of components in respect of strength and fatigue; and
- (b) consider any limitations that need to be placed on travel, in respect of the following aspects, and ensure that the manual for the ride or device provides appropriate warnings and advice:
 - (i) Speed of travel (possibly related to Item (ii)).
 - (ii) Roadway conditions (e.g. highway surfaces only).
 - (iii) Maximum (annual or otherwise) distance that has been allowed for in the design.
 - (iv) Any special requirements, such as for racking, dogging-down, cushioning.
 - (v) Any advisable checks or inspections prior to or following travel.
 - (vi) The type of suspension of trucks or trailers (where not inherent in the design of the ride or device) that is assumed in the design (e.g. steel spring or air) and any corrections to be made to the above items if a different type is used.

The literature can provide substantial information as to the accelerations generated by road and rail transport; however, much of this is related to packaging or driver safety. Designers may opt to access such data or may make allowances according to the guidelines and recommendations in Clauses 2.3.7.2 and 2.3.7.3.

2.3.7.2 *Strength*

Vibrational accelerations, such as could act in the dead load of ride structures attached to vehicle chassis members or supported by racking systems on vehicles, have magnitudes up to $\pm 3g$ on the rough roads that are typical of off-highway situations in Australia and can occur with frequencies in the range 2 Hz to 10 Hz.

2.3.7.3 *Fatigue*

Vibrational accelerations, such as may produce fatiguing stresses in ride structures and components, are produced by all road surfaces to some degree and have typical magnitudes in the range $\pm 0.15g$ to $\pm 0.8g$, with frequencies between 2 Hz and 30 Hz. Designers may include such loads in their prediction of fatigue life and thus account for them within their recommended limits for travel. Alternatively, inspection requirements may be specified to take account of travel, according to a log, so as to modify the frequency of visual and non-destructive testing, e.g. to require annual inspection or inspection after a specified distance such as 15 000 km, whichever occurs earliest.

2.3.8 Other special loadings

The following special loadings shall be considered, where relevant, in the design of an amusement ride or device, unless their occurrence is precluded by special provisions or by virtue of the basic arrangement of the system:

- (a) Loads due to expansion or contraction due to temperature changes.
- (b) Pretensioning effects on membrane structures and supports.
- (c) Ponding of rain or hail.
- (d) Snow (see AS/NZS 1170.3).
- (e) Differential settlement of foundations or improper founding at set-up.
- (f) Forces due to handling or erection.
- (g) Stresses developed by fabrication and assembly dimensional tolerance effects and load deformation ($P\Delta$) effects.
- (h) Forces due to unusual conditions, e.g. cyclic vibration.
- (i) Hydrostatic loads or wave forces.
- (j) Loads occasioned by soil pressures, water in soil pressures or both.
- (k) Test loads.

2.3.9 Load combinations

The device, its structure and its components shall be designed to be—

- (a) structurally sound;
- (b) serviceable without excessive flexure or deflection;
- (c) stable and safe against moving on blocking or on permanent footings; and
- (d) proof against failures due to the onset of metal fatigue prior to the expiry of the nominal design life.

The designer shall establish the load combinations to be used to represent the most adverse conditions presenting under the criteria listed in Items (a) to (d) according to rational analysis, based on published technical standards according to Clause 2.4.

NOTE: The combination of the loads derived from Clauses 2.3.2 to 2.3.8 may require vector summation, which should take place after the appropriate load factors have been applied.

TABLE 2.2
LOAD FACTORS

Type of loading	Load factors			
	Permissible stress design		Ultimate limit state design	
	Full load	Part load (no load)	Full load	Part load (no load)
Gravitational loads (dead loads) (forces due to mass of structure, mechanical components and appurtenances)	$\times 1.0$	$\times 1.0$	$\times 1.2$	$\times 1.2$
Live loads (forces due to the passengers and applied equipment or materials as developed by gravity action)	$\times 1.0$	As proportioned $\times 1.0$ (see Note 1)	$\times 1.5$	As proportioned $\times 1.5$ (see Note 1)
Working loads (see Clause 2.3.4) due to the motion acting on—				
Dead loads	$\times 1.0$	$\times 1.0$	$\times 1.5$	$\times 1.5$
Live loads	$\times 1.0$	As proportioned $\times 1.0$ (see Note 1)	$\times 1.5$	As proportioned (see Note 1)
Wind loads (see Clause 2.3.5)—				
In-service value	$\times 0.75$	$\times 0.75$	$\times 1.0$	$\times 1.0$
Out-of-service value	—	$\times 1.0$	—	$\times 1.0$
Seismic loads (See Note 2)				
Fixed rides—				
In-service	$\times 0.75$	$\times 0.75$	$\times 1.0$	$\times 1.0$
Out-of-service	—	$\times 0.75$	—	$\times 1.0$
Other (special) loads	$\times 1.0$	$\times 1.0$	$\times 1.3$	$\times 1.3$

NOTES:

- 1 'As proportioned' implies the full value computed on the basis of the proportional part load, e.g. on a circular ride of 20 vehicles—
 - (a) for stress and deflection—5 vehicles sequentially, fully loaded and the remaining 15 vehicles half-loaded; and
 - (b) for stability—5 vehicles sequentially, fully loaded and the remaining 15 vehicles unloaded (empty).
- 2 In zones of high seismic activity, loadings due to seismic activity should be determined according to the appropriate local Loading Code. The application of such loadings in the design of a ride or device should take account of the periods for which the ride or device may be subject to the seismic actions and the type of footing or foundation involved in the transmission of those actions to the structure of the device. The design of mobile rides that are located in one place on a permanent basis should take account of earthquake actions in the same manner.

2.4 BASIS OF DESIGN

2.4.1 General

The design or analysis (or both) of an amusement device shall be carried out by the designer. The designer shall undertake a process of hazard identification and analysis of risk and shall incorporate risk controls within the structural and mechanical aspects of the design in accordance with the provisions in Clauses 2.4.2 and 2.4.3. The designer, or a competent person nominated by the designer, shall be involved with all phases of the manufacture, construction, testing and commissioning of new equipment, where his or her responsibility shall be to ensure a level of supervision of the work such that there is no negation of any basic premise or assumption underlying the design.

As it is not possible to predefine whether a particular element should be considered primarily structural or mechanical in its response to loading, the designer shall choose the methodology for analysis.

In all cases, the designer should consider the following for each element to be designed:

- (a) The class of the device.
- (b) The danger to life and limb.
- (c) The nature of failure to which the element is prone, whether it be ductile deformation, the initiation of fatigue cracking, a brittle fracture or any combination of these problems.
- (d) The likelihood that day-to-day inspection of the device will reveal incipient failure before such failure has progressed to a stage where a real danger exists.

2.4.2 Structural design

2.4.2.1 General

The design of the structure of a ride or device shall be taken to include those components that provide the load paths between the patron support elements and ground and may include, for example, floor, seat, car/gondola, frames, vehicle frames and chassis, sweeps, booms, hubs, tracks, base, frames and stabilizers and, to the extent that pivot points and pins, static shafts and the like, enter into such structural systems, those parts. The design of structural elements shall proceed on the basis of appropriate technical standards or established engineering practices by the methodologies of either permissible (allowable) stress design, (PSD), or ultimate limit state design, (ULSD), some times known as load and resistance factor design, (LRFD).

The estimated loads for design according to Clauses 2.3.2 to 2.3.8 shall be combined according to Table 2.2, as determined by the methodology chosen.

The designer's risk analysis shall establish those structural elements that in the case of failure, could endanger life, the environment or property, and identify them as safety related.

The design of safety-related structural elements shall take full consideration of failure due to fatigue and shall be proportioned and detailed to achieve a life not less than that specified in Table 2.3 according to the class of the ride or device. Where the class of the ride has been determined precedent on 'intrinsic safety secured' according to Clause 2.1.6, any safety-related structural component or connection (whether welded or bolted) that is not fail-safe by virtue of a redundant load path, shall be designed and proportioned and shall be specified to be inspected during manufacture so as to achieve an infinite fatigue life.

Safety-related structural elements and connections (whether welded or bolted) shall be designed and arranged to be capable of inspection by means appropriate to determine their fitness for purpose at any time. Inspection shall be facilitated by means incorporated in the design.

The designer shall consider the effects of corrosion and, where possible, shall eliminate or minimize its occurrence by the appropriate selection of materials and detailing to avoid ingress and retention of moisture. Where corrosion cannot be overcome, the designer shall provide an allowance in the proportioning of structural elements, which shall be declared within the ride manual, together with comprehensive instructions as to inspection and maintenance.

NOTE: Appendix F gives guidance for the design and analysis of amusement devices subject to fatigue.

TABLE 2.3
MINIMUM LIFE VALUES AT FULL LOAD

Class of device (see Table 2.1)	Structure operating cycles	Mechanical operating hours
1	—	6 300
2	5×10^5	12 500
3	1×10^6	25 000
4	2×10^6	50 000
5	4×10^6	100 000

NOTES:

- 1 It is generally recognized that—
 - (a) the first inspection should be carried out before expiration of 10% of the calculated life;
 - (b) the second inspection should be carried out before expiration of 50% of the calculated life; and
 - (c) subsequent inspections should be carried out at intervals not exceeding 50% of the calculated remaining life.
- 2 A load spectrum analysis may be required to determine the equivalent full load number of cycles or operating hours attributable to part loading episodes. Out-of-balance part loading may account for a higher equivalent relative to certain elements in the design.

2.4.2.2 Design methodologies—Structural

Requirements and recommendations concerning the design of structural elements are provided in various Australian Standards, depending on the materials involved.

Similarly respected codes for structural design exist overseas and are used for the design of amusement rides and devices. For Australian design, Australian Standards are recommended; however, subject to verification by a competent person or organization, appropriate normal engineering practice or the use of reputable overseas Standards may be used on the basis that loading is properly assessed according to this Standard and appropriate load safety or stress safety factors are accounted for. The recommended Australian Standards are as follows:

- (a) For design by PSD (ASD)—AS 3990, AS/NZS 1664.
- (b) For design by ULS (LFRD)—AS 4100.

2.4.3 Mechanical design

2.4.3.1 General

Mechanical elements of a ride or device shall be designed according to technical standards, where they exist, or established engineering practices. In particular, the design shall take full consideration of the potential of mechanical components to fail as a result of fatigue and the limits that may apply due to fatigue and due to wear.

Fatigue prone mechanical components shall be designed and detailed to achieve a fatigue life not less than that specified in Table 2.3 for the class of the ride or device. Where the class of the ride or device has been determined precedent on intrinsic safety ‘secured’ according to Clause 2.1.6, any mechanical component other than proprietary equipment shall be designed, detailed and specified to be inspected so as to achieve infinite fatigue life.

In particular, the design of safety-related mechanical components that transmit power, shall achieve infinite fatigue life according to published technical standards, such as AS 1403 or equivalent.

The designer's risk analysis shall establish those mechanical components that, in the case of failure, could endanger life, the environment or property, are deemed to be safety related.

Mechanical components incorporated in a design shall be selected on the basis of strength and wear characteristics as published by their manufacturers. Where such equipment performs a safety-related function, the selection shall be based on a guarantee by the manufacturer for the required life according to Table 2.3, or the designer shall apply a factor of safety of at least 0.5 to published technical data related to strength and 0.7 to that related to life.

The loadings established as the basis for the design of mechanical components shall be derived from the worst case combination(s) under Table 2.2 giving due consideration to the load and combination factors that are given but that may not necessarily be valid for mechanical design methods.

2.4.3.2 *Design methodologies—Mechanical*

Australian Standards and other reputable overseas standards provide for the design of numerous elements in mechanical engineering under a variety of particularized codes, such as those for cranes and associated equipment. Generally, these standards are based on well-researched engineering principles but these are frequently directed by specialized formulae to the immediate subjects. Where relevant, designers of amusement rides and devices should make use of such standards directly or by virtue of the background theory. Standards of this type may include—

- (a) Australian Standards—AS 1418, AS 1403, AS 3569; and
- (b) overseas standards—DIN 15018 (series), DIN 15020 (series) and BS 2573 (series).

Where the mechanical design of safety-critical elements is progressed on the basis of applying a simple factor of safety on failure load (stress), test figures or test loads and published, guaranteed minimums for common components and manufactured elements, the minimum factors to be employed shall be as set out in Table 2.4, for the class of the ride or device. If there is no capacity for redundancy in a safety-critical component designed by simple factor of safety processes, the higher factor of safety within Table 2.4 shall be used. Design by this method is not intended to displace or supersede design for fatigue or wear determined by legitimate sources as outlined above.

2.4.3.3 *Fail-safe systems*

A fail-safe system (redundant) shall be applied for all safety-related mechanical components with limited fatigue life.

A fail-safe system shall include either a means to signal the primary fault (e.g. alarm, cessation of motion, shutdown, and similar) or shall incorporate a positive procedural arrangement involving inspections directed to the timely discovery of the primary fault where secondary (load-carrying) systems are involved, i.e. redundancy.

NOTE: Appendix C contains examples of fail-safe systems and additional information on failure to safety.

TABLE 2.4
FACTORS OF SAFETY FOR MECHANICAL ELEMENTS

Material of component	Minimum factor of safety	Higher factor of safety
Cast iron	10	15
Steel (any type)	6	8
Non-ferrous metals	7	9
Glass-fibre-reinforced plastics	10	15
Non-metals (in general)	10	12
Bolts and other screwed fittings	6	8
Wire ropes and fittings	10	12
Hemp/sisal ropes	10	12
Welded link chain	10	12
Roller chain	8	10

2.4.4 Inspection matters for consideration by the designer

The designer shall take the following into consideration:

- (a) Where the designer nominates an inspection requirement, the procedures for (and frequencies of) inspections shall be documented in the operation and maintenance manual.
- (b) Where any inspection reveals cracks or other signs of fatigue, the design shall be re-assessed by the designer or other competent person, and inspection intervals shall be adjusted accordingly.
- (c) Prescribed non-destructive testing methods may be any or all of visual, dye-penetrant, magnetic particle, ultrasonic and radiographic examination techniques specified according to the appropriate Australian or international Standards. Non-destructive testing shall only be carried out by competent persons.
- (d) The designer shall clearly identify details and components that are prescribed for non-destructive testing on drawings to be included in the operation and maintenance manual or other suitable document.
- (e) Where the designer prescribes fatigue-prone details or components for testing, the calculated fatigue life of such details shall dictate the maximum service periods permitted before such inspections take place.
- (f) Repairs to fatigue-prone details and components shall be carried out by competent persons under the supervision of the designer or other competent person.

2.4.5 Deflection

Unless designed to produce movement for ride effect, deflections under all conditions of maximum loading shall be minimized to preclude the following:

- (a) Excessive swaying of any structural component or of the whole device.
- (b) Unnecessary cyclic vibrations.
- (c) Excessive bounce or springiness underfoot.
- (d) Any movements tending to open gaps between components affecting the safety of retention pins or other fixtures.
- (e) Any tendency for base members or chassis footings to creep on their foundations or blockings.

In general—

- (i) deflections of simply supported beams shall not exceed one-five-hundredth (1 in 500) of their span; and
- (ii) deflections of cantilever beams and columns shall not exceed one-three-hundredth (1 in 300) of the unsupported or unbraced length.

2.5 STABILITY

2.5.1 General

The requirements for stability, where any loading tends to overturn the device or cause it to shift off its footings by lateral motion, shall be as set out in Clauses 2.5.2 and 2.5.3.

2.5.2 Overturning

The stabilizing moment under in-service conditions, considering all loadings as required by Table 2.2, shall be not less than 1.5 times the overturning moment. The overturning moment shall be calculated for the most adverse direction.

The stabilizing moment under out-of-service conditions, considering all loadings as required by Table 2.2, shall be not less than 1.25 times the overturning moment.

Where the stabilizing moment is provided in full or in part by permanent foundations, the connections between the ride or device and those foundations shall be designed to retain a factor of safety of 6 (against ultimate strength) under the condition of design stabilizing moment.

2.5.3 Lateral sliding

Where working loads (in particular those due to unbalanced loading, wind loading and similar) can cause a tendency for a ride or device to require restraint against lateral slippage with respect to its footings or packings, the following shall apply:

- (a) Where restraint is provided by friction alone, a margin against slippage of 1.5 times the lateral loading shall be maintained. Coefficients of friction as listed under Clause 2.3.4(a) shall be used unless other conditions can be proved.
- (b) Where restraint is provided by hold-down bolts or other direct connections to hold-down foundations—
 - (i) the strength of the bolted connection shall be calculated in bearing (i.e. no allowance for frictional grip due to bolt loading shall be considered), and a factor of safety of 6, in shear or bearing (against ultimate strength), shall be maintained; and
 - (ii) the lateral reaction bearing pressure for the embedded foundation (in soil) shall not exceed 50 kPa, unless a higher capacity is proved by test, or another construction such as piling is employed and designed to attain equivalent strength.

2.6 STRUCTURAL MATERIALS

2.6.1 General

Only materials appropriate to the requirements of structures, components and devices shall be used.

2.6.2 Identification

All materials shall be identified on construction drawings.

2.6.3 Bolted connections

2.6.3.1 General

The type of joint, based on its mode of load carrying (shear, tensile or combined), shall be determined, together with the magnitude of live and dead loads applicable to the joint. Guidelines and design methods provided in AS 4100 and AS 3990 should be used as appropriate. In addition, the requirements and guidelines in Clauses 2.6.3.2 to 2.6.3.8 shall be taken into account in the design of dynamically active joints (joints subject to cyclic service loads).

Whenever practical, bolted joints should be designed to act in shear.

An appropriate locking device should be considered to prevent vibration loosening.

NOTE: If the bolt pre-tension is less than 65% of the proof load, under certain vibration conditions it has the potential to loosen. This potential may be minimized by tightening the bolt in excess of 65% of the proof load provided the bolt has enough capacity left to carry the service loads.

Stress concentration due to threads should be considered when carrying out a fatigue analysis.

2.6.3.2 Shear joints

If the maximum design tensile load on the bolt is less than 8% of the ultimate tensile load or the maximum design shear load on the bolt is greater than six times the maximum design tension load on the bolt, the bolted joint shall be considered a shear joint.

Shear joints should be designed as follows:

- (a) A shear joint where the live shear stress on the bolt is more than 15% of the proof shear stress of the bolt should be designed as a friction grip joint (TF) as per AS 4100.
- (b) If the shear joint needs to be regularly assembled and disassembled, it should not be designed as a TF or TB joint in accordance with AS 4100 unless the bolts are discarded at each disassembly.
- (c) Where the live shear stress on a bolt is less than 15% of the proof shear stress of the bolt, the joint may be designed as a shear (pin) or tension bearing joint (S or TB as per AS 4100).*

NOTE: An S-type joint may require an appropriate thread-locking device if it has the potential for vibration loosening.

2.6.3.3 Tensile joints

If the maximum design tensile stress (dead plus live) on the bolt is greater than 30% of the ultimate tensile stress of the bolt, the joint shall be considered a tensile joint.

Tensile joints should be designed as follows:

- (a) A tensile joint should be designed in such a way that the clamping force between the two joining members always remains positive during the life of the joint, taking into consideration the effects of bolt and joint stiffness. The bolt should not yield under the service loads experienced during the life of the joint.
- (b) If the peak live component of the maximum design tensile stress is greater than 30% of the ultimate tensile stress of the bolt, a fatigue analysis taking into consideration the effects of the joint and the bolt stiffness should be carried out.

* FERNANDO, S. On the design and failure of high tensile bolt group joints subject to dynamic loading—Theoretical and experimental investigations, Case studies. *Proceedings of International Conference on Failure Analysis and Maintenance Technologies (ICFAMT)*. Brisbane, Australia. April, 2004.

- (c) If the maximum design tensile stress (live plus dead) on a bolt in the joint is greater than 30% of the ultimate tensile stress (UTS) of the bolt, a fatigue analysis taking into consideration the effects of the joint and the bolt stiffness should be carried out.

2.6.3.4 Combined shear and tensile joints

Joints not belonging to either shear joint or tensile joint classifications are classified as combined shear and tensile joints. Joints requiring regular assembly and disassembly belong in this classification.

Combined shear and tensile joints should be designed as follows:

- (a) Combined shear and tensile joints should be designed as friction grip joints if the live maximum shear stress (using Mohr's Circle) on a bolt due to combined design shear and tensile load action (dead plus live) is more than 15% of the proof shear stress of the bolt with a target pre-tension of not less than 65% proof load of the bolt.
- (b) Combined shear and tensile joints should be designed so the clamping force between two joining members always remains positive during the life of the joint taking into consideration the effects of bolt and joint stiffness. The bolt should not yield under the service loads experienced during the life of the joint.
- (c) A fatigue analysis taking into consideration the effects of the joint and the bolt stiffness should be carried out—
 - (i) if the peak live component of the maximum design principal (tensile) stress (using Mohr's Circle) on a bolt due to combined design shear and tensile live load action is greater than 40% of the total maximum design principal (tensile) stress (dead plus live); or
 - (ii) if the total maximum design principal (tensile) stress (using Mohr's Circle) on a bolt due to combined design shear and tensile dead and live load action is greater than 40% of the ultimate tensile stress of the bolt.

2.6.3.5 Use of dissimilar materials

The following requirements shall be applied:

- (a) Joint designs that require tightening of dissimilar materials and flexible or softer materials shall be given special consideration.
- (b) Effects of thermal loads shall be considered if the joint materials have different thermal expansion coefficients.
- (c) A stiffness-based joint analysis shall be performed in the design of safety-critical joints of this type.

2.6.3.6 Prevention against loosening

The design of the joint should minimize the need to use thread-locking devices.

If the joint has a potential to loosen then an appropriate thread-locking device shall be used. The designer shall fully specify the identification, compliance and re-usability of thread-locking devices, especially for thread-locking devices to be used in joints that are to be regularly assembled and disassembled.

Safety-critical pin-type joints formed by a bolt and nut shall be provided with a secondary means to prevent the joint from coming apart.

2.6.3.7 Stress corrosion cracking

Bolts that are subject to stress corrosion cracking (SCC), such as high tensile bolts (Class 10.9 and higher) and stainless steel bolts, shall only be specified for use after consideration of their susceptibility to SCC and the potential in the design for exposure to conditions that can cause SCC. The designer or manufacturer shall provide a diagrammatic scheme of the bolts in the device that are subject to SCC risks, together with details of a regular replacement program.

2.6.3.8 Complete specifications

The manual shall contain complete specifications for bolted joints and their components, covering the relevant topics in the following list:

- (a) The designer shall fully specify the details of the type of bolt, washer and nut (with reference to relevant standards), required finish, design pre-tension and the acceptable window of working pre-tension.
- (b) In addition, the method of achieving the desired design pre-load shall be provided. If tightening to a particular torque is the method of tightening, the relevant torque value and associated conditions (e.g. finish, coating, lubrication level (dry or oiled) or use of anti-seize) shall be specified.
- (c) The type and details of locking devices, where used, shall be specified, including the necessary frequency of replacement.
- (d) For multiple bolt group joints, the tightening sequence and steps shall be specified.
- (e) Advice that compliance certificates be obtained for any replacement bolts or bolt parts.

2.6.4 Tracks

Tracks and trackways shall be designed to facilitate correct laying and alignment.

2.6.5 Glass-fibre-reinforced plastics

Where glass-fibre-reinforced plastic is used in an application in which it is required to perform a structural function, appropriate factors of safety shall be applied (see Table 2.4), and consideration shall be given to the design and manufacturing requirements for glass-fibre-reinforced plastic in AS 1418.10.

Glass-fibre-reinforced plastic should be backed up by conventional structural materials and should not be used as the primary structural element of an amusement device unless such backup is incorporated.

2.6.6 Wire rope—Structural

Wire rope shall be selected and installed as appropriate to the requirements of the design. Wire rope grips (bulldog grips) shall not be used in safety-critical circumstances.

2.6.7 Combustibility

The combustibility of materials shall be in accordance with Clause 3.5.

2.7 ANCILLARY MATERIALS

The materials for components and accessories used in and around amusement rides and devices shall not be harmful to patrons, operating staff or the environment in which they are installed. These materials shall be capable of withstanding the installation stresses and intended use.

2.8 CONTAINMENT AND RESTRAINTS

2.8.1 General

2.8.1.1 Application

Containment and restraint of patrons shall be installed where, because of the nature and arrangement of the device, patrons can—

- (a) place themselves or others in jeopardy through not remaining within the confines of the designated riding position for the duration of the ride cycle;

- (b) be at risk of injury because of relativity of motion between the riding position and an adjacent structure;
- (c) be displaced suddenly or unexpectedly within the vehicle; or
- (d) be ejected from the designated riding position by the inherent motion of the device.

2.8.1.2 Risk assessment

The provision of containment and restraint and their type shall be determined by a risk assessment. This risk assessment shall be performed in accordance with this Clause and shall take into consideration the following:

- (a) The nature of the amusement ride or device.
- (b) The intended limits of physical characteristics of adult or child patrons based on appropriate anthropometric data.
- (c) Whether because of the nature of a ride, a safer outcome can be achieved by enabling the patron to part company with the vehicle in the event of a collision (e.g. toboggans), an inversion (e.g. of a child's canoe ride) or similar situations.

NOTE: Where the designer's risk assessment determines that a restraint is not appropriate, other risk controls relative to the operating environment may be required to address the consequences.

- (d) The accelerations applied to patrons and the arrangement and inclination of seats or patron positions (see Clause 2.8.1.3).
- (e) The need for latching, locking or interlocking functions when restraints are required.
- (f) The need to evacuate patrons from any foreseeable position or situation on the ride or device, including emergency stops and stops in unplanned locations and the appropriateness of individual or group release of restraints.
- (g) The status of restraints, if required, if affected by emergency stop or loss of power.
- (h) Any reasons for restraint other than those due to ride motion and seat geometry (see Clause 2.8.3).

2.8.1.3 Provision of restraints to counter the effects of acceleration and seat inclination

Restraint devices shall be provided in cases where it is reasonably foreseeable that patrons could be lifted or ejected from their seats or riding positions by the acceleration of the amusement ride or device, or by seat inclination, during the ride or device cycle and other reasonably foreseeable situations, e.g. the application of emergency brakes or vehicles stopped in inverted positions.

NOTE: Seat inclination may reduce the actuality of patrons being lifted or ejected. When this effect is quantifiable, acceleration in the X direction may be adjusted.

The coordinate system shown in Figure 2.1 shall be used as the standard reference for acceleration directions, including the application of the different means of restraint in accordance with the criteria of the acceleration diagram shown in Figure 2.2.

The acceleration diagram in Figure 2.2 shall be used as part of the risk assessment for determining if a restraint is required and, if required, what type. Figure 2.2 identifies and graphically illustrates five distinct areas of theoretical acceleration. Each of the five distinct areas may require a different type of restraint, as indicated in Clause 2.8.2. Figure 2.2 applies for sustained acceleration levels only. It is not applicable to impact accelerations.

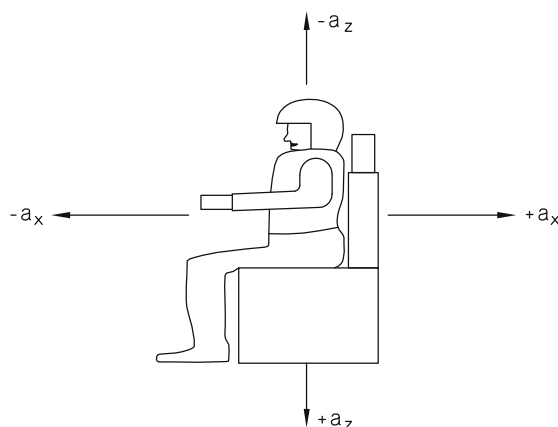


FIGURE 2.1 COORDINATE AXES REFERENCE FOR ACCELERATION DIAGRAM

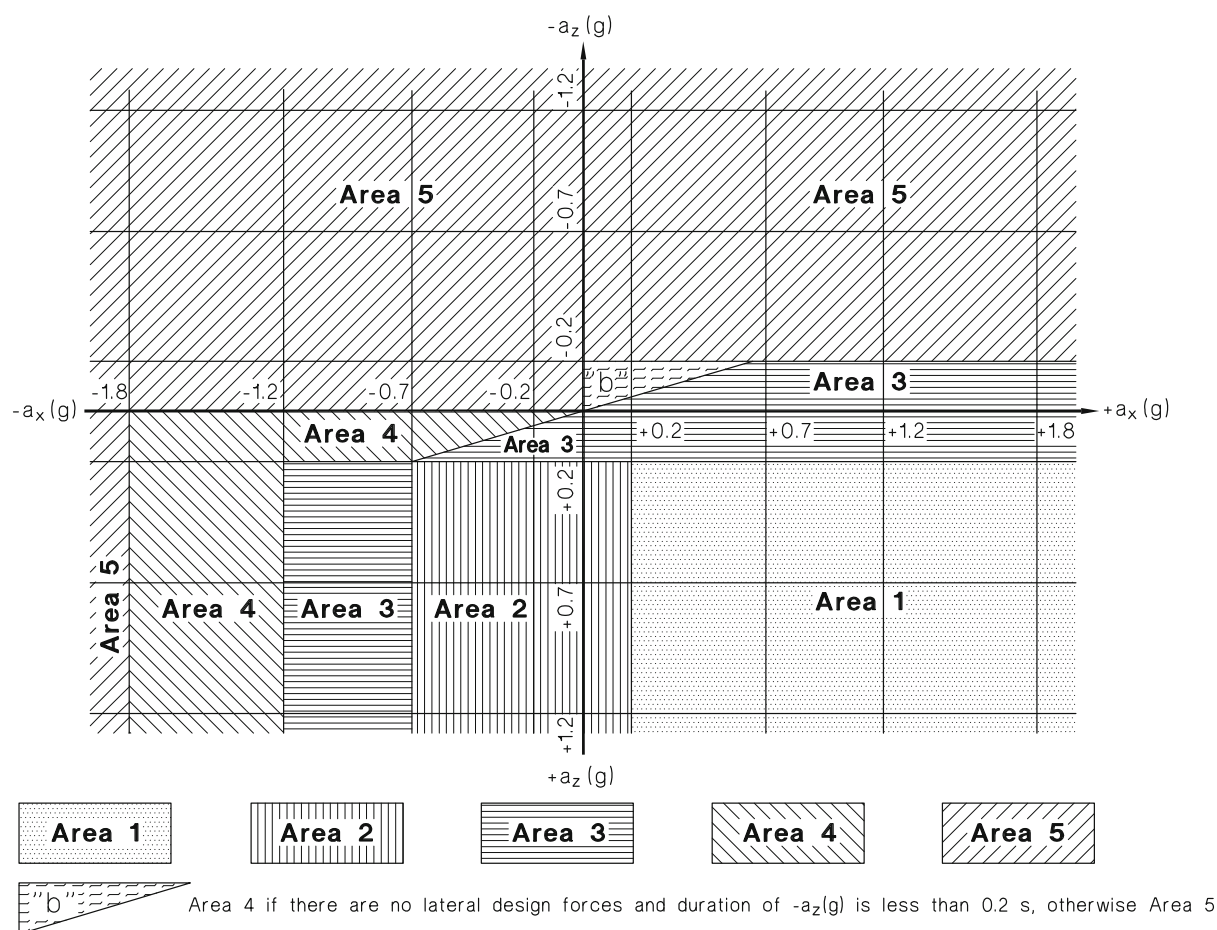


FIGURE 2.2 ACCELERATION DIAGRAM SHOWING RESTRAINT TYPE AREAS

2.8.2 Restraint criteria

2.8.2.1 General

With respect to Areas 1 to 5 in Figure 2.2, restraint Types 1 to 5 set out in Clauses 2.8.2.2 to 2.8.2.6 shall be used as a minimum unless modified in accordance with Clause 2.8.3.

2.8.2.2 Area 1

A Type 1 restraint is defined as unrestrained or no restraint at all.

Based solely on Area 1 dynamic forces, no restraint is required; however, other criteria in the risk assessment may indicate that a higher level of restraint is required.

2.8.2.3 Area 2

A Type 2 restraint is required unless patrons are provided with sufficient support and the means to react to the forces, e.g. handrails, footrests or other devices. A Type 2 restraint is generally defined as a latching restraint device for each individual patron or a latching collective restraint device for more than one patron.

Type 2 restraints are devices or systems of components that inhibit patrons from leaving the correct ride position under normal ride forces and ride conditions, however, patrons are not restricted from leaving this position if they choose.

Examples of Type 2 restraints include lap bars, seatbelts, and lap or waist chains.

A Type 2 restraint shall have at least the following characteristics:

- (a) *Number of patrons per restraint device* The restraint device may be for an individual patron or it may be a collective device for more than one patron.
- (b) *Final latching position relative to the patron* The final latching position may be fixed or variable in relation to the patron.
- (c) *Latching* The patron or operator may latch the restraint.
- (d) *Unlatching* The patron or operator may unlatch the restraint.
- (e) *Confirmation of status* The design shall allow the operator to perform a visual or manual check of the restraint each ride cycle.
- (f) *Means of activation* The restraint may be manually or automatically (e.g. motorized) opened or closed.
- (g) *Redundancy of latching device* Redundancy is not required.

2.8.2.4 Area 3

A Type 3 restraint is required. A Type 3 restraint is generally defined as a locking restraint device for an individual patron or a locking collective restraint device for more than one patron.

A Type 3 restraint shall have at least the following characteristics:

- (a) *Number of patrons per restraint device* The restraint device may be for an individual patron or it may be a collective device for more than one patron.
- (b) *Final locking position relative to the patron* The final locking position shall be variable in relation to the patron, e.g. a bar or rail with multiple locking positions.
- (c) *Locking* The patron or operator may manually lock the restraint or it may lock automatically. The manufacturer shall provide instructions requiring the operator verify that the restraint device is locked.
- (d) *Unlocking* The operator manually or automatically unlocks the restraint.
- (e) *Confirmation of status* The design shall allow the operator to perform a visual or manual check of the restraint each ride cycle.
- (f) *Means of activation* The restraint may be manually or automatically (e.g. motorized) opened or closed.
- (g) *Redundancy of locking device* Redundancy is not required.

2.8.2.5 Area 4

A Type 4 restraint is required. A Type 4 restraint is generally defined as a locking restraint device for an individual patron.

A Type 4 restraint is a device or system of components designed to ensure that the patron cannot leave the correct ride position either by (normal or unusual) forces exerted by the ride or self-movement. The patron cannot unlock the restraint while on the ride.

Examples of Type 4 restraint systems include individually adjustable lap bars, seatbelts, lap, waist and crotch straps and chains and over-shoulder restraints.

A Type 4 restraint shall have at least the following characteristics:

- (a) *Number of patrons per restraint device* A restraint device shall be provided for each individual patron.
- (b) *Final locking position relative to the patron* The final locking position shall be variable in relation to the patron, e.g. a bar with multiple locking positions.
- (c) *Locking* The restraint device shall be automatically locked.
- (d) *Unlocking* Only the operator shall manually or automatically unlock the restraint.
- (e) *Confirmation of status* The design shall allow the operator to perform a visual or manual check of the restraint each ride cycle.
- (f) *Means of activation* The restraint may be manually or automatically (e.g. motorized) opened or closed.
- (g) *Redundancy of locking device* Redundancy shall be provided for the locking device function.

2.8.2.6 Area 5

A Type 5 restraint is required.

A Type 5 restraint is a device or system of components specifically designed and provided to confine a patron to, and support the patron in, a unique position and an appropriate posture that, while retained, ensures that forces that are acting on the patron produced by the action of the ride in both normal and unusual (e.g. emergency) circumstances, do not cause the patron to be ejected from the ride. Patrons cannot unlock the restraint.

Examples of Type 5 restraint systems include lap and lap 'T' bars and over-shoulder devices with crushable bolsters, body harnesses and other systems and combinations associated, typically, with body contour moulded seats or beds where the restraint precludes the patron from moving from the designed position and posture.

A Type 5 restraint shall have at least the following characteristics:

- (a) *Number of patrons per restraint device* A restraint device shall be provided for each individual patron.
- (b) *Final locking position relative to the patron* The final locking position shall be variable in relation to the patron, e.g. a bar with multiple locking positions.
- (c) *Locking* The restraint device shall be automatically locked.
- (d) *Unlocking* Only the operator shall manually or automatically unlock the restraint.
- (e) *Confirmation of status* An interlock and external indicator is required. If the interlock system detects a fault in the monitored restraint device, the ride shall be brought to a cycle stop or cycle start shall be inhibited. The interlock system shall comply with Clause 2.8.8.
- (f) *Means of activation* The restraint may be manually or automatically (e.g. motorized) opened or closed.
- (g) *Redundancy of locking device* Redundancy shall be provided for the locking device function.

- (h) *Restraint configuration* Two restraints, e.g. shoulder and lap bar, or one fail-safe restraint device shall be provided.

2.8.2.7 Secondary restraints for Type 5

A Type 5 restraint configuration may be achieved by the use of two independent restraints or one fail-safe restraint. When two independent restraints are used, the secondary restraint device may be an individual locking restraint device or a collective locking restraint device. The secondary restraint device shall have at least the following characteristics:

- (a) *Number of patrons per restraint device* The restraint device may be for an individual patron or it may be a collective device for more than one patron.
- (b) *Final locking position relative to the patron* The final locking position may be fixed or variable in relation to the patron.
- (c) *Locking* Only the operator shall manually or automatically lock the restraint.
- (d) *Unlocking* Only the operator shall manually or automatically unlock the restraint.
- (e) *Confirmation of status* The design shall allow the operator to perform a visual or manual check of the restraint each ride cycle.
- (f) *Means of activation* The restraint may be manually or automatically (e.g. motorized) opened or closed.
- (g) *Redundancy of locking device* Redundancy is not required. The locking and unlocking of the secondary restraint shall be independent of the primary restraint.

NOTES:

- 1 Table 2.6 summarizes the various restraint types and their characteristics.
- 2 Latching restraints are those able to be released by patrons. Locking restraints are those requiring unlocking by the operator.
- 3 Secondary safety devices such as latching belts, straps or other devices that limit the travel of a primary restraint device are acceptable. When properly designed, these devices may be considered to be an indication of minimum closure of the primary restraint device.
- 4 The design of the patron restraint and patron containment system are interrelated and should be coordinated with each other while addressing the intent of the amusement ride or device. Generally a highly contoured seat and lateral support in combination with the restraints may be the most desirable design.
- 5 The term 'redundant restraint devices' means independent restraints in the sense that the secondary device, e.g. a lap bar or containment enclosure, is able to restrain the patron if the primary restraint fails.

TABLE 2.6
SUMMARY OF RESTRAINT SYSTEM TYPES AND CHARACTERISTICS

Characteristic	Type of restraint					
	1	2	3	4	5	Secondary 5
(a) Number of patrons per restraint						
No restraint required	●					
Individual or collective device		●	●			●
Individual restraint device for each patron				●	●	
(b) Final latching/locking position in relation to the patron						
Fixed or variable		●				●
Variable in relation to patron			●	●	●	
(c) Latching/locking						
Patron or operator manually latch/lock restraint or it is automatic. Operator required to verify it is latched/locked		●	●			
Restraint device is automatically locked				●	●	
Only the operator may manually or automatically lock the restraint						●
(d) Unlatching/unlocking						
Patron or operator may unlatch restraint		●				
Only operator manually or automatically unlatches/unlocks the restraint			●	●	●	●
(e) Confirmation of status						
Design allows operator to visually or manually check each cycle		●	●	●		●
Interlock and external indicator required. Failure stops or inhibits cycle start					●	
(f) Means of activation						
Manually or automatically opened/closed		●	●	●	●	●
(g) Redundancy of latching/locking device						
Redundancy is not required		●	●			●
Redundancy required for locking device function				●	●	
Redundancy not required. Locking and unlocking of secondary restraint to be independent of primary restraint						●
(h) Restraint configuration						
Two restraints, e.g. shoulder and lap bar, or one fail-safe restraint					●	

LEGEND:

● = Required characteristic

2.8.3 Other containment and restraint considerations

The application of Figure 2.2 is intended as a design guide. The patron containment and restraint risk assessment in Clause 2.8.1.2 or other factors or requirements in this Standard may indicate the need to consider another level of restraint (either higher or lower) or a form of containment. Any special situation shall be taken into consideration in designing the containment and restraint system. These may include—

- (a) the intended nature of the amusement ride or device, i.e. its intensity: