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Health and Safety executive

Safety of Amusement Devices: Design

ADIPS

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This guidance is issued by ADSC on behalf of the industry associations listed in the Foreword. It is endorsed by the Health and Safety Executive. Following the guidance is not compulsory and you are free to take other action. But if you do follow the guidance you will normally be doing enough to comply with the law. Health and safety inspectors seek to secure compliance with the law and may refer to this guidance as illustrating good practice.

Safety of Amusement Devices: Design

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Foreword

This guidance sets out what the Joint Advisory Committee on Fairgrounds and Amusement Parks considers are appropriate measures for those involved in design, and others in the industry, to work safely and comply with the law. The following industry associations, in alphabetical order, together with the Health and Safety Executive (HSE) are represented on the Committee:

- The **Amusement Catering Equipment Society** (ACES) 1 Delamere Road, Turf Hill, ROCHDALE, 01-16 4XD. Tel: 01706 869841

- The **Association of Independent Showmen** (AIS) 53 Lowick Gardens, Westwood, Peterborough, PE3 7HD

- The **Association of Leisure Equipment Suppliers of the United Kingdom** (ALES) 1st Floor, 74 Kilbury Drive, WORCESTER, WR5 2NG. Tel. 01905 360169 Fax. 01905 360172

- The **British Amusement Catering Trade Association (BACTA)** Alders House, Aldergate LONDON, EC1A 4JA Tel: 020 7726 9826 Fax: 020 7726 9822

- The **British Association of Leisure Parks, Piers and Attractions** (BALPPA) 57 - 61 Newington Causeway, LONDON, SE1 6613. Tel: 0207 7403 4455 Fax: 0207 7403 4022 www.balppa.org

- **Health & Safety Executive** (HSE) 375 West George Street, GLASGOW, G2 41-W. Tel: 0141 275 3000 Fax: 0141 275 3015 www.hse.gov.uk

- The **National Association for Leisure Industry Certification** (NAFLIC) PO Box 752, SUNDERLAND, SR3 1XX. Tel: 0191 5239498 Fax: 0191 5239498 www.naflic.org.uk

- The **Showmen's Guild of Great Britain** (SGGB) 41 Clarence Street, STAINES, TW18 4SY. Tel: 01784 461805 Fax: 01784 461732

- The **Society of Independent Roundabout Proprietors** (SIRPS) 66 Carolgate, RETFORD, DN22 6EF. Tel: 01777 702872

This publication has been written taking into account the contents of the European Standard EN 13814: 2004, modified where necessary to conform to British legislation and the amusement industry's agreed and accepted practices (see Appendix 3).

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Chapter 1

Design risk assessment

General

1. Design Risk Assessment (DRA) is the process of assessing the hazards that the design of a piece of fairground equipment[1] may pose, the likelihood of those hazards causing a risk and the control measures that are necessary to adequately control those risks[2]. Designers should assess the significant risks that arise from its subsequent assembly/disassembly, transport, inspection, maintenance and operation. This Chapter has been prepared as guidance for designers and others, such as persons importing or supplying amusement devices, on what information a DRA should contain.

2. Effective safety management emphasizes the need to assess and control risk. In Great Britain this principle is laid out in the *Management of Health and Safety at Work Regulations 1999* and in the accompanying Approved Code of Practice and Guidance.

3. The Regulations require employers and self-employed persons to carry out assessments of risks to the health and safety of themselves (in the case of self-employed), their employees, and others.

4. In addition to this general duty to assess risk, there is also an explicit duty placed upon those who design fairground rides to ensure that they are safe[3]. Safe in this context means safe for the operators, attendants and those who inspect and maintain an amusement device as well as the members of the public who ride them. Bearing in mind that risks are typically heavily dependent on decisions made at the design stage, the process of design risk assessment is crucial to confirming the safety integrity of the ride.

5. The Health and Safety Executive and fairground industry associations in Great Britain have produced guidance "Fairgrounds and Amusement Parks – Guidance on Safe Practice (HSG175)". This introduced the idea of "Design Review" for amusement devices. This is the process where an inspection body registered with ADIPS, and independent of the original design, reviews the safety critical aspects to ensure the integrity of the design

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[1] An "article of fairground equipment' means any fairground equipment or any article designed for use as a component in any such equipment.

[2] A "Hazard" means anything that can cause harm (e.g. chemicals, electricity, working at height, machinery, etc). The "Risk" is the chance, high or low, that somebody will be harmed by the hazard.

[3] The legal duty to ensure that the design of a fairground ride is safe is contained within The Health and Safety at Work etc Act 1974 (as amended by the Consumer Protection Act 1987), and associated Regulations which apply in Great Britain. In particular in Section 6(1A) & 2 of the Act, which states:

(1A) It shall be the duty of any person who designs, manufactures, imports or supplies any article of fairground equipment' —

a. to ensure, so far as is reasonably practicable, that the article is so designed and constructed that it will be safe and without risks to health at all times when it is being used for or in connection with the entertainment of members of the public;
b. to carry out or arrange for the carrying out of such testing and examination as may be necessary for the performance of the duty imposed on him by the preceding paragraph;
c. ……….
d. ……….

(2) It shall be the duty of any person who undertakes the design or manufacture of an article for use at work or of any article of fairground equipment to carry out or arrange for the carrying out of any necessary research with a view to the discovery and, so far as is reasonably practicable, the elimination or minimisation of any risks to health or safety to which the design or article may give rise."

assumptions (see Chapter 13).

6. If a designer does not directly arrange for "Design Review" to be done, the industry agreed guidance HSG 175 makes it clear that it will be necessary for him to provide adequate data to the manufacturer, importer or supplier as appropriate so that they can have it done. The designer's risk assessment is a crucial element of this data.

7. Fairground equipment is largely excluded from European Directives and is specifically excluded from the Machinery Directive. There are however a number of helpful European and International Standards dealing with issues of hazard and risk which have been used as source material in the following paragraphs of this Chapter. The principle of making use of such sources is to maintain some consistency with other types of machinery and structures, where this is justifiable.

8. The advice in this publication is based in part on the (British and) European Standard EN 1050[4] - Safety of machinery. Principles for risk assessment. This is a Standard which many European designers of fairground equipment consider to be appropriate when designing amusement devices. Risk assessment principles for machinery are also developed in ISO 141214[5]. Much of the content of these Standards can also be satisfactorily applied to other equipment such as structures, although it is recognized that some variations are necessary in the application of machinery standards to amusement devices.

9. For international terminology relating to hazard, risk and related matters, ISO/IEC Guide 735[6] provides definitions.

More than one Designer - Responsibilities

10. It is normal for an amusement device design to combine a number of different technical disciplines (e.g. structural, mechanical, hydraulics, electrical, lighting, and control systems) which may involve input from different designers. Even within one discipline there may be good reason for more than one designer to be used (e.g. some work may be subcontracted). There may even be more than one designer associated with each single component - for instance, one designer may prepare a passenger containment layout, another may do the structural calculations, and yet another may carry out the ergonomic assessment of it.

11. Where multiple designers are used effective assessment of all relevant risks will need effective management to ensure completeness.

12. Responsibilities are determined, at least in part, by allocation down the contractual chain or chain of command. For instance, where subcontracts (which are often verbal) are placed to carry out parts of the design or modifications to an amusement device, each person in the chain needs to consider what risks relate to his specific undertaking and what needs to be done to control them. The extent of the risk assessment work that each of these various subcontractors needs to undertake depends on the extent of their contracts or instructions.

13. This duty is created and its limits defined by The Health & Safety at Work etc Act 1974 S6, subsection 6(7), which says that:

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[4] EN 1050 Safety of machinery. Principles for risk assessment
[5] ISO 14121 Safety of machinery. Principles of risk assessment
[6] ISO / IEC Guide 73 Risk management. Vocabulary. Guidelines for use in standards.

(a) "Any duty imposed on any person by any of the preceding provisions of this section shall extend only ... to matters within his control."

14. For example, in the case of a single component (in the absence of specific instructions to the contrary) it would not be expected that the designer would have to assess risks that only arise when the component is combined with other components which were designed elsewhere. But as the individual components come together there is a responsibility on the person higher up the contractual chain or chain of command who brings these items together to ensure that the associated risks are properly assessed and controlled. He, since he may not personally have the required expertise, is at liberty to allocate or subcontract the risk assessment of the combined assemblage of components, but he may not avoid the responsibility for ensuring that it is done.

15. The intricacies of the relationships and the allocation of responsibilities may be complex where amusement devices are concerned. Subsection 6(8) of the HSW Act recognizes this complexity and the limits of responsibility :-

(a) "*(8) Where a person designs ... an article of fairground equipment and does so for or to another on the basis of a written undertaking by that other to take specified steps sufficient to ensure, so far as is reasonably practicable, that the article will be safe and without risks to health at all such times as are mentioned in paragraph (a) of subsection (1) or, as the case may be, in paragraph (a) of subsection (1) or (1A) above, the undertaking shall have the effect of relieving the first-mentioned person from the duty imposed by virtue of that paragraph to such extent as is reasonable having regard to the terms of the undertaking."*

16. This means that a person higher up the contractual chain or chain of command may take responsibility (in writing) for the safety of work that he has undertaken to do on behalf of another which would otherwise have fallen on that person. But note the words "to such extent as is reasonable having regard to the terms of the undertaking." The intent is not to avoid safety responsibilities but to clarify the process when more than one person is involved. Furthermore, there will remain a duty on the first person to pass adequate information about his work up the chain.

17. HSG 175, Appendix 2 outlines that, in managing the design process it may be relevant to "identify the people, departments and organisations responsible for carrying out and reviewing safety-related activities". Bearing in mind subsection 6(8) of the HSW Act quoted above, it may be necessary for this, or some of it, to be in writing - it would certainly be good practice.

18. It may be appropriate for a person commissioning design work, or a person who imports or supplies an amusement device, to appoint a person to co-ordinate the work (which may be himself if he has appropriate competence) and to inform the relevant parties in writing. That person should check the way in which the elements of the design combine and have the final responsibility for making sure that every safety-related aspect has been covered

Amusement Devices - Risk Assessment in Great Britain

19. The information in this Chapter draws on knowledge and experience of design, operation, incidents, accidents and resultant harm associated with fairground and amusement park machinery and structures. Some known hazards are identified for consideration in a standardised assessment process, but any DRA may need to take into account additional hazards not mentioned here.

20. As noted at the beginning of this Chapter, the term “hazard” means anything that has the potential to cause harm (e.g. , electricity, working at height, machinery, chemicals, etc). Risk is the probability, high or low, that somebody will be harmed by the hazard.

21. The Court of Appeal, in R v. Board of Trustees of the Science Museum[7] held that the term "risk" in s.3, HSWA, means the possibility of danger rather than actual danger. In the case in point a failure to adequately chemically disinfect a water cooling tower had potentially exposed the public to legionella bacteria and a risk of contracting legionnaire’s disease. The question of whether or not there had been actual harm imposed (e.g. exposure to legionella bacteria) was found to be irrelevant. Designers should bear this in mind when considering the risks that their design may pose to others in the DRA.

22. When there is significant hazard potential for serious injury, the designer will be expected to demonstrate suitably low risk. It is at the design stage that most can be done to ensure that persons are adequately protected.

23. A designer is expected to consider as far as reasonably practicable hazards that may occur as a result of his design. Decisions on whether or not additional measures are required to mitigate the hazard should be based on an assessment of the severity of the possible harm associated with the hazard and the probability of its occurrence (the risk).

24. The term “reasonable practicability” may raise questions amongst designers who are uncertain as to how far they need to go to comply with their duty. A designer must balance the level of risk against the measures needed to avert the risk, whether in money, time or trouble. A key British criminal case which provides a steer on this matter is Edwards V National Coal Board[8] . In this case, the Court of Appeal considered whether or not it was reasonably practicable to make the roof and sides of a road in a mine secure. They concluded that;

- *"... in every case, it is the risk that has to be weighed against the measures necessary to eliminate the risk. The greater the risk, no doubt, the less will be the weight to be given to the factor of cost."*

and

- *"'Reasonably practicable' is a narrower term than 'physically possible' and seems to me to imply that a computation must be made by the owner in which the quantum of risk is placed on one scale and the sacrifice involved in the measures necessary for averting the risk (whether in money, time or trouble) is placed in the other, and that, if it be shown that there is a gross disproportion between them - the risk being insignificant in relation to the sacrifice - the defendants discharge the onus on them."*

The Risk Assessment process

25. The technique of risk assessment formalizes the intuitive process by which designers and safety engineers use their experience to identify hazards, estimate risk and select appropriate control measures.

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[7] R v Trustees of the Science Museum [1993] 3 All ER 853,
[8] Edwards V National Coal Board [1949] 1 KB 704; [1949] 1 All ER 743

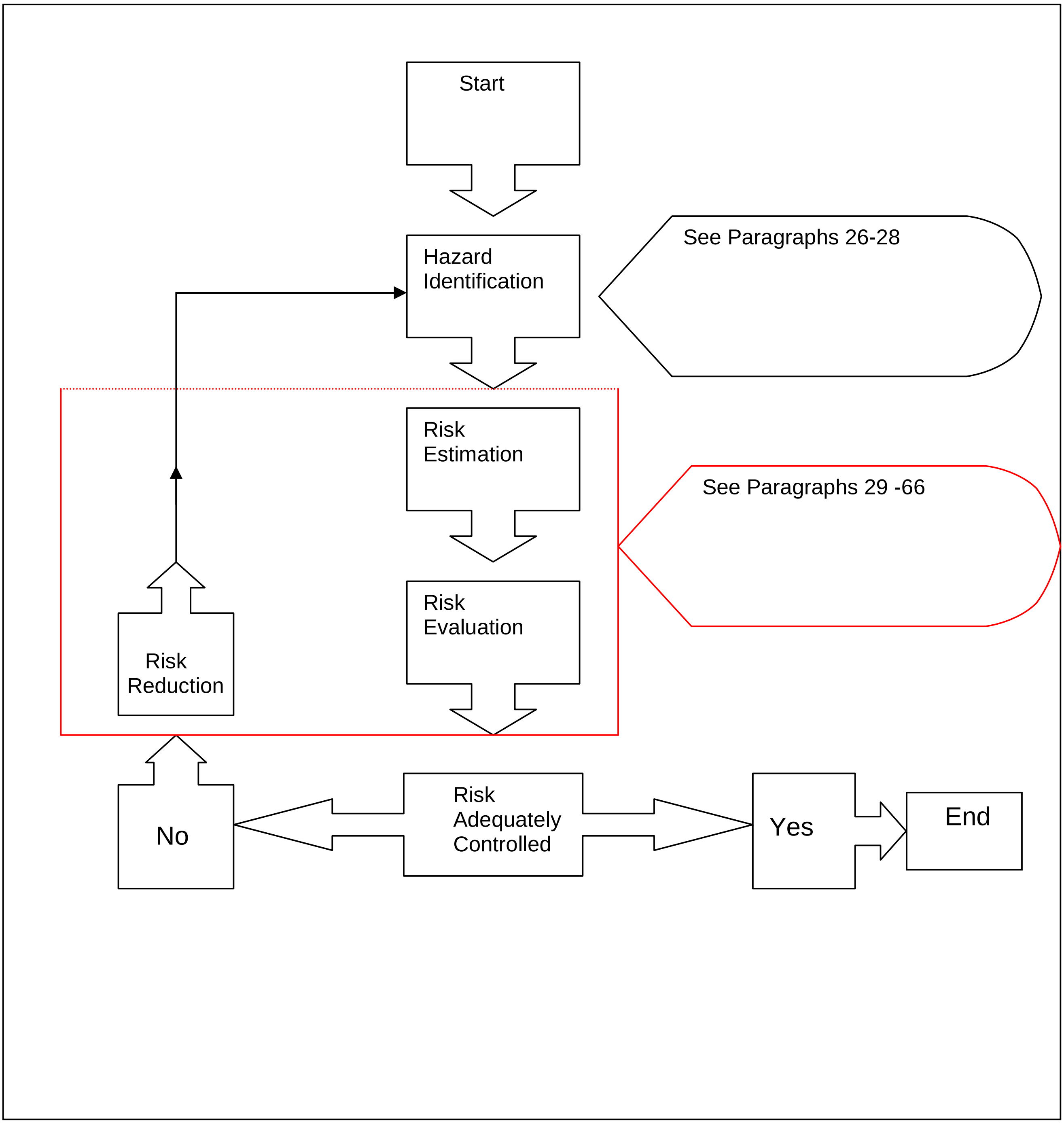

Figure 1.1 the design risk assessment process

Hazard identification

26. Because of the nature of fairground rides some of the hazards encountered in amusement devices are different from those associated with machinery in general, such as those shown in Table A.1 of EN 1050: 1996. For example the fact that the public interact with amusement devices changes the normal design procedure of removing people from machinery proximity. A list of some of the more common hazards encountered in

fairground and amusement park machinery and structures is shown in Table A.1 (Appendix 1).

27. A designer should consider the hazards posed by the limits of the amusement device e.g.:

(a) the different aspects of the amusement device's life (e.g. build-up / pull down, maintenance, inspection, test and operation for use by the public);

(b) The effectiveness of measures to ensure that the motion envelope does not pose a hazard to passengers or others.

(c) foreseeable wear and tear and the effects that may have on integrity;

(d) the intended use (both the correct use and operation of the machinery as well as the consequences of reasonably foreseeable misuse or malfunction);

(e) the full range of reasonably foreseeable uses (and abuses) of the amusement device by passengers identified, as appropriate, by sex, age limit, height limit, and limiting mental and physical abilities. (Human reliability analysis techniques may be usefully applied to fully understand the range of uses and abuses possible);

(f) reasonably foreseeable exposure of other members of the public (e.g. passers by) to the hazards of the amusement device.

28. The following chapters provide advice on many of the hazards identified in Table A.1, and where they are mentioned the associated Chapters and paragraphs are identified in the right hand column of the Table. However, amusement park devices and structures are diverse and the extensive variants precludes specific advice on them all within this guidance. Hazards which are identified and which are not listed in Table A.1 should also be assessed in accordance with the procedures described in this Chapter. Particular care should be taken in identifying non-standard circumstances and assessing whether control measures are needed.

Risk Estimation

29. Risk estimation should be carried out for every potential consequence or accident that is reasonably foreseeable from each identified hazard by assessing the two elements of risk

(a) The severity of the harm

(b) The probability of the occurrence of that harm

30. The severity of harm is normally measured by the likely severity of injuries (i.e. slight, serious or fatal) in combination with the extent of harm (i.e. the number of persons that would be harmed if the hazardous event were to happen). The probability of occurrence of the harm is a function of the frequency and duration of the exposure of persons to the hazard, the probability of occurrence of the hazardous event, and the technical and human possibilities to avoid or limit the harm.

31. Information for risk estimation and any qualitative and quantitative analysis should include the following, as appropriate:

(a) limits of the amusement device (see paragraph 27);

(b) design drawings or other means of establishing the nature of the amusement device;

(c) information concerning sources of energy;

(d) any accident and incident history (where available).

32. Comparisons between similar hazardous situations associated with different types of amusement device are often possible, provided that sufficient information about hazards and accident circumstances in those situations is available. The absence of an accident history, a small number of accidents or low severity of accidents for a particular model of amusement device should not be taken as an automatic presumption of a low risk.

33. For quantitative analysis, data from data bases, handbooks, laboratories and manufacturers' specifications may be used provided that there is confidence in the suitability of the data. Uncertainty associated with this data should be identified in the completed documentation. Data based on the consensus of expert opinion derived from experience may be used to supplement qualitative data.

34. Several methods are available for the systematic analysis of these elements in relation to complex combinations of events (this only applies to a small number of hazardous events associated with amusement devices). Examples are given in Annex B of EN 1050:1996.

35. When estimating the probability of occurrence of harm the frequency and duration of exposure to risk can be influenced by :

(a) need for access to the danger zone (e.g. for normal operation, maintenance or repair);

(b) time spent in the danger zone

(c) the proportion of time for which the danger exists

(d) the number of people requiring access

(e) the frequency of access

36. However to avoid high risk situations becoming hidden by rigid application of the "time at risk" argument it is generally accepted that risks for such activities should be presented both with and without the application of time at risk factors, to enable the full implications of the arguments to be properly considered. An example of this is where a lift door might only affect someone passing through it for a very brief moment; however due to the high hazard nature and the number of affected persons, the time at risk has little relevance.

37. The accuracy of estimation of the probability of occurrence of a hazardous event, whether of a technical nature or resulting from human behaviour, may be improved in some circumstances if:

(a) there is applicable reliability and other statistical data available;

(b) there is relevant accident history;

(c) risk comparison with similar situations is possible).

38. If the probability distribution of time-to-failure is non-linear, there may be a need to carry out more than one estimate of the probability of occurrence of a hazardous event in order to determine the worst relevant case.

39. Two failure modes in particular, i.e. early mortality failures (often associated with initial defects), and aging or wear failures, may require more than one estimate of the probability of occurrence of a hazardous event.

40. The third main failure mode, random failure, should be treated in accordance with the principles of probability theory. (e.g. an extreme wind load is equally likely to occur at any point during the lifetime of the device, as are many electrical / electronic component failures, particularly when combined in circuits involving many components)

41. The possibility of avoiding or limiting harm may be influenced by matters such as:

(a) staff training;

(b) public awareness of risk enhanced by general information, by direct observation, or through warning signs and indicating devices;

(c) the human possibility of avoidance or limiting harm (e.g. reflex, agility, possibility of escape) - this may be possible, possible under certain conditions, or impossible;

(d) by practical experience and knowledge of the machinery, or of similar machinery (although the lack of such experience should be the default assumption).

42. Risk estimation should take into account all persons exposed to the hazards. This includes members of the public (including passengers on rides), operators, attendants, inspection / maintenance staff, installers of fixed equipment, those involved in build-up / pull down of travelling devices, and any other persons for whom it is reasonably foreseeable that they could be affected by the amusement device.

43. The estimation of the exposure to the hazard under consideration requires analysis of, and should account for, all modes of operation of the amusement device and methods of working. In particular this affects the need for access during build-up / pull down, training, passenger loading / unloading, cleaning, fault finding and maintenance. Risk estimation should account for situations when it may be necessary to suspend or override safety functions (e.g. during maintenance).

44. The relationship between an exposure to a hazard and its effects should be taken into account. The effects of accumulated exposure and synergistic effects shall also be considered. Risk estimation when considering these effects shall, as far as practicable, be based on appropriate recognized data. Note that accident data may be available to indicate the probability and severity of injury associated with the use of a particular type of amusement device with a particular type of safety measure.

45. Human factors can affect risk and shall be taken into account in the risk estimation. This includes, for example:

(a) interaction of persons with the amusement device;

(b) interaction between persons;

(c) psychological aspects;

(d) ergonomic effects;

(e) capability of persons to be aware of risks in a given situation (e.g. in relation to ride operators or maintenance staff) depending on their training, experience and ability.

46. The estimation of the ability of exposed staff shall take into account the following aspects:

(a) application of ergonomic principles in the design of the device;

(b) natural or developed ability to execute the required tasks;

(c) awareness of risks;

(d) level of confidence in carrying out the required tasks without intentional or unintentional deviation;

(e) temptations to deviate from prescribed and necessary safe working practices.

47. Training, experience and ability might reduce the risk but none of these factors should be used as a substitute for risk reduction by design or safeguarding where such safety measures can be reasonably practicably implemented. Due to the exposure of large numbers of members of the public, inappropriate reliance should not be placed on ride operators / attendants having to develop an unreasonable degree of skill or acquired knowledge to ensure public safety.

48. Risk estimation should take into account the reliability of components and systems.

49. When more than one safety-related device or system is to be provided to give a degree of redundancy, consideration needs to be given to dependent or common mode failures .

50. When safety measures include:

(a) work organisation,

(b) correct behaviour,

(c) diligence,

(d) application of personal protective equipment,

(e) skill or training,

The relatively low reliability of such measures, as compared to proven technical safety measures, should be taken into account in the risk estimation. Where it is reasonably practicable to employ technical and or physical safety measures this should be done in preference to relying upon those measures listed above.

51. Risk estimation may need to take into account the likelihood that safety measures might be defeated or circumvented. for example where:

(a) the safety measure slows down throughput, or interferes with any other activities or preferences being carried out;

(b) the safety measure is difficult to use;

(c) the safety measure is not recognized as such, or is not accepted as suitable for its function.

Risk Evaluation & Reduction

52. Risk evaluation should be carried out to determine if risk reduction is required or whether safety has been achieved.

53. If risk reduction is required, then appropriate safety measures should be selected and applied, and the procedure repeated (see figure 1).

54. The following hierarchical principles of prevention should be considered when evaluating risk:[9]

(a) Avoiding risks

[9] *Management of Health and Safety at Work Regulations 1999, Schedule 1 General Principles of Prevention as set out in Article 6(2) of Council Directive 89/391/EEC)34*

(b) Evaluating risks which cannot be avoided

(c) Combating risks at source.

(d) Adapting to technical progress

(e) Replacing the dangerous by the non-dangerous or the less dangerous

(f) developing a coherent overall prevention policy which covers technology, organisation of work, working conditions, social relationships and the influence of factors relating to the working environment

(g) giving collective protective measures priority over individual protective measures; and

(h) giving appropriate instructions to employees

55. During this process, it is important for designers to check whether additional hazards are created when new safety measures are applied. If additional hazards do occur, they should be added to the list of identified hazards and the risk reassessed.

(a) Where control measures include safeguarding (provision of guards, barriers, restraints, etc.) then the assessment should consider if :-

(b) the safeguarding selected provides a safe situation for the intended use;

(c) the type of safeguarding selected is appropriate for the application in terms of:

i. probability of defeat or circumvention;

ii. severity of harm;

iii. hindrance to the execution of the required task (in the case of hazards affecting staff);

56. If after risk reduction, some residual risk remains, further mitigation measures required should be clearly communicated to the ride controller.

Documentation of Design Risk Assessment

57. At the end of the design process there is a need to record some information about the design risk assessment, not least so that others having a legitimate interest may see what has been done and what the residual risks might involve.

58. The risk assessment document should include when relevant:

- details of the amusement device design for which the assessment has been made (e.g. unique reference numbers, specifications, limits, intended use);
- any relevant assumptions which have been made (e.g. loads, strengths, safety factors) which differ from or are additional to recommendations in this publication;
- the hazards identified.
- The control measures and any further action required
- Residual risks.

59. In Great Britain, this information - the documented design risk assessment - has to go forward to the process known as Design Review carried out by an ADIPS Registered Inspection Body. More details of what this should include, and information to be provided to others, are given in Chapter 13.

Relevant Standards & Other Publications

ISO/IEC Guide 73: 2002 ISO 14121	Risk management - Vocabulary - Guidelines for use in standards Safety of machinery. Principles of risk assessment
EN 1050	Safety of machinery. Principles for risk assessment
HSC13REV1	Health and Safety Regulation: A short guide. HSE Books; 2003.
HSG 175	Fairgrounds and Amusement Parks - Guidance on Safe Practice HSE Books; 1997.
R2P2	Reducing Risks, Protecting People (HMSO; first published 2001)
	Review of Fairground Safety, Report to the Health and Safety Commission; August 2001

Chapter 2
Principles of Dynamic Analysis

General

1. Many amusement devices may be considered dynamic devices. They are specifically designed to cause the passenger to experience changes in position, velocity and acceleration.

2. The loads thus imposed are examples of dynamic loads. The dynamic response of a structural system depends on the load, natural frequency and damping and the participating mass of the system.

3. Variations in acceleration, cause variations in forces and component stresses which can lead to fatigue. Indeed experience shows that most structural failures and damage occurring in dynamic amusement devices result from fatigue. Experience also shows that there are common failings in the methods and accuracy of dynamic analysis of amusement devices - hence the need for this part of the Guidance.

4. Special methods are required for the fatigue analysis of particular design features and these influence the requirements of dynamic analysis. The calculation of fatigue life requires a knowledge of the stress history of the design detail; i.e. the variation of the stress must be calculated. This, of course, means that the dynamic forces and moments should, in general, also be evaluated as functions of time.

5. If the forces, moments and stresses are not calculated as functions of time then worst case stress magnitudes and ranges will need to be justified and demonstrated to be suitably pessimistic. The designer will be aware that this can lead to over-elaborate structures and mechanisms.

Vector Analysis

6. Since velocities, accelerations and forces are vector quantities, i.e. having both magnitude and direction, the principles of vector analysis should be applied. Many amusement devices involve motions in three space dimensions and the use of three dimensional Cartesian (or other) vector notation is often the only realistic means of ride analysis.

Rigid Body Dynamics

7. The basis of dynamic analysis is Newton's Laws of Motion. In their simplest form these laws apply to particles having finite mass but infinitesimal size. But amusement devices contain components of finite size and the extensions of Newton's Laws into Rigid Body Dynamics must be used. That is to say that, for many ride components, moments and products of inertia are important.

8. While it is sometimes true that reasonable results may be obtained by approximating ride components by a reduced set of point masses, it is also true that, in other instances, large errors may result. Thus, if the moments and products of inertia of a ride component are not used (in determining its rate of change of angular momentum) it is important that an error estimation be carried out to justify the approximation.

Devices having One or More Degrees of Freedom

9. In amusement devices, as with other dynamic systems, the input controls impart known time or position dependent variations to the dependent variables. So, for instance, one might specify the time history of a rotational speed in a simple rotating device, or the release position and velocity of a roller coaster train.

10. In the simplest devices (e.g. Twist), once the input parameters are specified, the accelerations and forces may be calculated using basic differential calculus. In more complicated devices there may be additional degrees of freedom (e.g. Matterhorn car swing) which require the solution of complex differential equations of motion before all of the required force and moment vectors can be calculated.

11. In many of these more complicated devices the additional degrees of freedom have been deliberately introduced and are an important feature of the ride. As such the variations in the dependent variables are not small in magnitude and the differential equations are non-linear containing time and position dependent coefficients. Differential equations of this type exhibit regions of instability. Indeed the feature of many rides of this type is that they operate in regions of instability or near-instability in order to achieve the desired effect (e.g. the spinning of Octopus cars or the large swing angles of Matterhorn cars).

12. Realistic modelling of most devices of this type is unlikely to be achievable without the use of rigid body dynamics and appropriate computer software. The analytical assessment of component fatigue lives is, of course, dependent on the dynamic model and its solution being of sufficient accuracy.

Devices having Zero Degrees of Freedom – General

13. The analysis of simpler amusement devices not requiring the integration of differential equations also has some common pitfalls. The design engineer must remember that gyroscopic moments are dependent on the angle between the two interacting axes. So, for instance, on a Trabant the angle between the rotor spin axis and the vertical is relevant. Another occasional error is to reverse the direction of a gyroscopic moment vector, which will affect the stress analysis of some of the dependent components.

14. An even simpler class of amusement device has zero degrees of freedom (i.e. no differential equations to solve) and all motions remaining parallel to a plane (i.e. two dimensional motion). A typical example would be a Twist. Although simpler methods can often be employed for rides in this class they are not without their pitfalls. Two typical errors result from making assumptions about the position of a rigid body's instantaneous centre of rotation from the position diagram; and ignoring or miscalculating Coriolis accelerations. The first of these snags can be avoided by drawing the velocity and acceleration diagrams. The second is avoided only by careful procedure as with the calculation of other components of acceleration.

Unwanted Vibrations

15. The large swinging motion of, for example, a Matterhorn car is a designed-in vibration. However, there is often a need to design light, economical structures which are, as explained above, subject to varying positions, velocities, accelerations and forces. These variables may excite unwanted, small amplitude, structural vibrations.

16. Vibration is particularly likely to be a problem at or near resonance when a periodic excitation occurs at a frequency close to a structural natural frequency. In order to avoid

problems it is necessary to form an approximation, to be refined if necessary, of the excitation frequencies and any natural frequencies likely to be significantly excited. So, for instance, in track-following rides excitation may arise from passing over track supports or rail joints and in rotating rides the basic rotational frequency may be the source of excitation.

17. These are, perhaps, obvious sources of excitation but it is important to remember that, as Fourier Series expansion will show, the dynamic excitations in many rotating amusement rides can contain higher harmonics of rotation speed. The designer must therefore be aware that sub-harmonic resonances can occur and structures may need stiffening to make the lowest natural frequency much higher than the basic rotational frequency.

18. An often mentioned source of vibration, and hence additional dynamic forces, is the motion of wheels over rail or tram joints. In this connection it is worth noting that, while slight gaps between adjacent rails are not of great significance, any misalignment causing an effective "step" up or down which the wheel must climb may cause significant vibratory dynamic loading. At very slow speeds this loading becomes small, but otherwise and when the tyre provides the only flexibility the maximum additional load is given by the step height multiplied by the tyre stiffness of a complete axle (i.e. normally four tyres). Clearly calculation of this additional load may be used in assessing component strength, but it also may be used as a guide in the selection of tyres or the setting of misalignment tolerances.

19. Further dynamic magnification results from lateral track to side or guide wheel clearance on roller coasters. It is very common for designers to underestimate this magnitude at the design stage and, if subsequent accelerometer or other measurements are not used for confirmation purposes, it may be necessary to presume that wheel cluster and axle fatigue will occur and that a regular inspection programme for such components must be specified.

Use of Dynamic Analysis Software Packages

20. Designers should ensure that the software is suitable for the purpose for which it is employed.

21. When using such software it is important that the specification of the input motions is realistic. For instance, the designer may use an input data assumption of constant acceleration, from start-up, followed by steady motion at maximum speed, when this may be unrealistic after due consideration of the torque / speed characteristics of the drive and control system.

22. Dynamic analysis software may include options to analyse natural frequencies of vibration. This having been said, it is common practice for designers to account for vibration by use of nominal, non-specific, factors. The latter are not always conservative however and, if it is thought that significant natural frequencies might exist, the designer should consider carrying out the extra analysis offered by the software package.

23. For the reasons expressed in the preceding 3 paragraphs, and for other reasons, output results can be significantly affected by the input assumptions. It is therefore important that the designer ensures that a full record of input data is associated with any set of output results. This would be essential for archiving purposes, but also essential for others (such as inspection bodies carrying out design review) who might have to make subsequent reference to the results.

Chapter 3

Calculating loadings

1. This part deals with the calculation of loadings for use in other assessments, e.g. fatigue lives.

Foreseeable loadings

2. These will include:

(a) **Static loadings.** - These should include the weights of both the static and moving parts of the structure (BS 6399-1 and EN 1991-1-1 include advice on weights of materials). The weights of passengers should also be included (see below). Table 3.1 shows typical values which may be assumed, in the absence of more specific data, in relation to the loading of floors and barriers. (Special consideration needs to be given if extreme crush loading can occur. It is not included in the table).

Table 3.1 Imposed loadings on floors and barriers etc.

Location	Vertical imposed loads	Horizontal imposed loads	
		Top rail	Intermediate rail
Floors, stairways. landings, ramps, entrances, exits of rides and structures	3. 5 kN/m^2	0.5 kN/m	0.1 kN/m
Grandstands (including stairways etc.) and parts of rides / structures subject to dense crowds	5.0 kN/m^2	1.0 kN/m	0.15 kN/m
Moving & fixed platforms of rides walked on during loading and unloading but not subject to queues or crowds	The least favourable of 2.0 kN/m^2 or 2 x full passenger load distributed over a realistic area	03 kN/m	0.1 kN/m
No public access	The least favourable of 1.5 kN/m^2 or 1.5kN point load	0.3 kN/m	0.1 kN/m

(b) **dynamic loadings** - (taking account of operating speed, frequency, magnitude and direction of load cycles and the effects of braking, including emergency braking). See also Chapter 2 on Principles of dynamic analysis.

(c) **bracing loads** - resulting from passengers bracing themselves against restraints and other parts of the containment (e.g. footrests).

(d) **out of balance loadings** - (from foreseeable misuse). In the absence of more specific data the unbalanced loadings for use with rotating devices (or parts of devices) may be considered as follows :

i. General stress analysis (as well as considering full load): - A sector comprising 1/4 or 3/4 of the circle occupied;

ii. Overturning analysis: - A sector comprising 1/6 of the circle occupied;

iii. Fatigue analysis: - A sector comprising 1/6 or 5/6 of the circle occupied.

(e) **environmental loadings** (e.g. wind, snow). Useful guidance is given in :

i. Snow loads: BS 6399 -3 & DD ENV 1991-1-3:2003

ii. Wind loads: BS 6399 -2 & DD ENV 1991-1-4:2005

Assessments should consider both in-service and out-of-service conditions. The windiest geographic and topographic locations should be considered when assessing out-of-service conditions. A suitable reduced wind gust speed (at 10 m above ground) of 15 m/s may be assumed for in-service calculations.

(f) It will normally be appropriate to ignore wind loading when calculating fatigue lives, however there are some occasions when wind loading might invoke fatigue loading, particularly for static devices.

3. The minimum passenger weights for calculating static and dynamic loadings should be:

(a) 1.0 kN for each device or part designed to carry one person (except for fatigue calculations). When designed to carry more than one person, or when carrying out fatigue calculations, at least 0.75kN should be used.

(b) 0.40 kN may be used where devices are designed specifically and solely for persons under 1400mm in height and provided this limitation is clearly stated in both the design specification and the Operations Manual.

4. Loads resulting from passengers pushing / pulling or bracing themselves need to be taken into account when designing passenger restraints and other parts of the containment (e. g. footrests), railings and bracing devices within the passenger unit. All significant situations during the ride cycle including loading, unloading and emergency situations may need to be considered.

5. The magnitudes of maximum bracing forces are dependent upon the detailed design of the containment and its relationship to the passengers' body positions and the parts of the body which are exerting force. However, if strength data is not to be taken from a reputable source, bracing forces used in any calculations should never be less than 500 N per person without additional justification.

Wind loading assessment

General;

6. In general wind loads should be based on DD ENV 1991-1-4:2005 or BS 6399 -2. For certain countries outside Europe with extreme meteorological conditions there may be additional local requirements to be taken into account.

7. It should be remembered that the geographical location of an amusement device of nearly any type is not fixed throughout its lifetime. Calculations will normally need to be based on the British (or European) locations having the highest average wind speeds. In the terminology of EN 1991-2-4, an appropriate value for $v_{ref,0}$ is 28 m/s for the reference wind

velocity (i.e. the mean velocity at 10 m above ground of terrain category II averaged over a period of 10 minutes, and having an annual probability of exceedance of 0.02 - commonly referred to as having a mean return period of 50 years). For devices or parts of devices which clearly cannot be re-located an appropriate lower value of reference wind velocity may be abstracted from the Standard.

8. For rides or structures which are less than 20 metres high, if either

(a) the associated risks are not severe; or

(b) a scheme for temporary on-site protection, strengthening or sheltering is specified and verified by the designer for inclusion in the Operations Manual; then

the basic value of the reference wind velocity may be modified by the assumption of a 5 year return period and a reduced temporary factor, i.e

(c) $v_{ref}(p) = 0.85\ v_{ref,0}$ and;

(d) $c_{TEM} = 0.80$

9. For the normal case when the ride or structure (or the particular component being assessed) is not susceptible to dynamic response a value of $c_d = 0.90$ may be used.

10. Where the conditions in the two preceding paragraphs apply, the modified pressures q,,f shown in Table 2.2 result for

(a) $c_{DIR} = 1.0$

(b) $c_{ALT} = 1.0$

(c) $c_t = 1.0$

(d) terrain category III

Wind loads may then be evaluated using the following formula

(e) $Fw = \bar{q}_{ref} . c_f . A_{ref}$

Table 3.2

Pressure $\bar{q}_{ref} = q_{ref} \times c_e(z) \times c_d$ **(kN/m²)**

	for ref wind speed	
Height of the structure	$v_{ref} \leq 15$m/s (in service)	$v_{ref,0} \leq 28$ m/s (out of service)
0 ≤8 m	0.21	0.35
8 ≤ 20 m	0.29	0.50
20 ≤ 50 m	0.40	0.95

11. For rides or structures where:

(a) the associated risks may be severe; and

(b) an adequate scheme for temporary on-site protection, strengthening or sheltering has not been specified and verified by the designer for inclusion in the Operations Manual

the values in Table 3.2 may need to be revised.

Revision will also need to be considered for locations for which:

(a) the basic value of the reference wind velocity exceeds 28 m/s; or

(b) the ride or structure (or the particular component being assessed) is susceptible to dynamic response; or

(c) height above sea level is such that the altitude factor exceeds 1.0; or

(d) topography is affected by an isolated hill, escarpment, valley or feature causing funnelling effects; or

(e) the terrain category exceeds III, such as at exposed coastal or open sites.

12. Since pressure increases with height above ground z, overall forces and overturning moments will need to be calculated either by integration over the surface area or by a suitable piecewise approximation based on pessimistic assumptions. For instance, the total force on an area is safely overestimated by using the wind force per unit area calculated at the highest point of this surface. A corresponding safe overestimate of the overturning moment is found by multiplying this force by the height above ground of the centroid of the surface.

Reduced Wind Loads

13. If the primary assessment shows that the device is not stable or structurally sound under extreme conditions of wind loading then reduced wind loads may be acceptable in the calculations, depending upon the provision of temporary protection or strengthening to the device. These must be demonstrated to be capable of resisting the full wind loading. Instructions regarding this protection strengthening should be included in the Operations Manual

14. It will be necessary to calculate a limiting value of mean wind speed for the device at which the protection / strengthening scheme must be invoked. Advice on recognising or measuring the danger limit should be given.

In Service Wind Loads

15. Parts of some amusement devices may be exposed to more significant wind loading whilst giving rides to the public (e.g. the overturning moment caused by wind loading on the seating unit of a Miami Trip is worse when it is at top dead centre than at bottom dead centre). Since it is customary to close down operations when winds become high, reduced values of wind load may be applied to those configurations which are only experienced in service.

16. In-service conditions may be calculated using a value of 15 m/s for v_{ref} (the reference wind velocity).

(a) This is approximately the mid point of Force 7 on the Beaufort scale (Moderate Gale) when whole trees will be in motion and inconvenience is felt when walking against the wind.

The associated modified pressures $\bar{q}_{ref}$ shown in the middle column of Table 3.2 apply in these circumstances.

Relevant Standards and Other Publications

EN 1991	*Eurocode 1. Actions on structures*
EN 1991-1-1	*Eurocode 1. Actions on structures. General actions. Densities, self-weight, imposed loads for buildings.*
EN 1991-1-3	*Eurocode 1. Actions on structures. General actions. Snow loads.*
EN 1991-1-4	*Eurocode 1. Actions on structures. General actions. Wind actions.*
BS 6399	*Loading for buildings.*
BS 6399-1	*Loading for buildings. Code of practice for dead and imposed loads.*
BS 6399-2	*Loading for buildings. Code of practice for wind loads.*
BS 6399-3	*Loading for buildings. Code of practice for imposed roof loads.*

Note: When using Eurocodes designers should ensure that they refer to the current UK national annexe. Eurocodes should not be used unless a current UK national annexe is available.

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Chapter 4
Assessment of fatigue

1. Many amusement devices are designed with the purpose of subjecting the passengers to significant variations in acceleration. This means that lots of safety-critical structural and mechanical ride components experience significant stress fluctuation such that fatigue is the dominant failure mode. For this reason, for such components it is essential that the assessment of fatigue is realistic. It is conventional in Britain, because all equipment is subject to a regime of annual third-party inspections which may involve NDT, to assess fatigue lives. On the basis of the fatigue life, designers and inspection bodies may ensure that component inspection programmes are sensibly tailored

Fatigue life assessment

2. The safety assessment should determine fatigue lives, in terms of ride operating hours, of individual safety critical components which will be repeatedly subjected to stress fluctuations of a magnitude and frequency which could result in fatigue damage.

3. Information on fatigue life assessment is given in:

Table 4.1 Fatigue Standards	
BS 7608	for steel structures
ENV 1993 1 9	
BS 8118-1 EN 1999-2	for aluminium structures
BS 2573-2 (=ISO 4301/1)	for machined components

4. In these Standards, to aid fatigue analysis, many welds and other physical features have been grouped into classes according to their construction.

5. Fatigue lives may be determined either by calculation (for those features covered by a suitable method) or by accelerated life tests. When the detail is not identical to one of the standard types, Finite Element Analysis may be a useful technique for calculating stress in complex structural details. [If doubt about the accuracy of calculated stress magnitudes or frequencies in a safety-critical component remains, the designer may need to consider confirmation by test]. Fatigue lives associated with these calculated stresses for non-standard details may then be derived using the "geometric stress range" or "hot spot stress range" as appropriate.

6. An appropriate inspection programme must be devised for all safety critical component details which do not have a fatigue life at least twice the foreseeable operating life of the device. Alternatively, component replacement at or before half of the fatigue life may be specified - however, the designer may need to consider the risks associated with non-compliance.

7. As a guide, fatigue calculations will be needed where the stress magnitude in a component varies with time by more than 10% and the number of repetitions of this variation during its design life is likely to be greater than 20,000. In such cases, the designer may need to take account of:

(a) the maximum value of the nominal principal stress and whether it is compressive or tensile,

(b) the minimum value of nominal principal stress and whether it is compressive or tensile,

(c) the number of times the stress will vary between these extreme values per operating hour.

8. If the same component is also likely to have a significant number of repetitions in one or more smaller stress ranges, the designer should carry out a statistical analysis to determine the effect these smaller stresses is likely to have on the component's fatigue life.

9. The additive effects of different stress cycles should be considered.

10. Since fatigue life is calculated in cycles, a means of readily identifying the number of in-service stress cycles should be specified. (Cycle counters are on the market). Any such system should be tamper-proof and either measure stress cycles directly or provide information from which stress cycles can be easily calculated. Conversion factors for relating cycles to operating hours should be provided.

Designing to increase fatigue life

Minimising stress concentration

11. Fatigue strength is a local rather than a systemic property of a component. Abrupt changes of section should be avoided, particularly in pins and shafts as they act as stress raisers and significantly reduce fatigue life. If a change of diameter or section is unavoidable, it should be made gradually with large fillet radii or run out (15 degree max) to limit the stress concentration.

12. The following are important, but do not make up an exhaustive list of measures to consider when designing to reduce stress concentration:

(a) Mechanical components which have to abut a shoulder with a fillet radius may be provided with a chamfer to eliminate contact with the radius. The chamfering alleviates stress concentration and fatigue damage from fretting.

(b) Slots and grooves e.g. keyways and lubrication grooves may be provided with generous run-out radii, with fillet radii in all corners. Accordingly keys and splines should have chamfers to avoid damaging the radii.

(c) Lugs, brackets, clips, holes, etc. for transportation, stowing, carrying pipes, cables and similar services should be specified at the design stage and positioned to minimise their effect on fatigue life. All effects of these attachment points on fatigue life should be determined.

(d) Other factors to be considered include surface/weld profile, joint configuration, threads etc.

13. Potential stresses involved in frequent erection, dismantling and transportation of mobile devices should be taken into account. Where necessary, the assembly procedure should be specified to reduce the risk of overstressing structural and other components through using inappropriate assembly sequences or practices

14. The importance of, and reasons for, these features should be emphasised and the features toleranced accordingly. For mechanical components the designer should calculate for each design feature a theoretical stress concentration factor value (K_t). Data sheets

giving K_t values for many fundamental geometric parameters such as diameters, fillet radii etc are available (see bibliography)

Specifying surface finish

15. Smooth surfaces may improve the fatigue life of components. Therefore surface finish should be considered in the designer's calculation of fatigue life and may need to feature in the specification. For instance where flame cut blanks are to be used in fatigue-sensitive areas, the specification may not only require the edges to be ground but might also identify the type and direction of the finish required because the direction of grinding can affect fatigue life.

Protecting against corrosion

16. Defects caused by corrosion may act locally as stress concentrators and / or may initiate and accelerate crack propagation. The design should therefore seek to minimise the effects of the environment. Corrosion due to the retention of rainwater or salt water can be reduced by providing drainage and alerting end users to clear drainage areas and holes where necessary.

17. Corrosion may be limited by provision of protective coatings. See, for instance, ISO 12944 and ISO 14713.

18. In some instances, electro-deposition of metals (e.g. hard chrome plating) or hot dip galvanising onto medium and high tensile steels can lead to reduction in fatigue life of the parent metal. The loss in fatigue strength can be largely avoided by shot-peening the material before plating. It is essential that the necessary pre- and post- stress relieving treatments are done whenever there are such risks.

19. The fatigue properties of the materials required and the fabrication techniques to be used should be considered at an early stage in the design process. Materials with outstanding fatigue resistant properties cannot compensate for a poorly designed product. However, the fatigue resistant properties of an otherwise superior design can be undermined by an incorrect choice of material.

20. Where fatigue is a dominant design criterion, which is very often the case with amusement ride components, the specification should take account of material properties such as ductility and notch sensitivity, together with their effect on crack propagation.

21. When British and European Standards relating to fatigue are employed, such as those listed in Table 3.1, conditions on the selection of materials are incorporated and should be followed.

22. For machined components a wider selection of materials is available and the designer should choose one with a (proof stress)/(tensile strength) ratio optimally at 0.75, low notch sensitivity, and adequate elongation, usually not less than 10%

Choosing the fabrication method

23. Fusion welds e.g. gas flame or metal-arc can reduce the fatigue life of components when, for example:

(a) the weld is a cast structure and may have fatigue properties inferior to the parent metal;

(b) the parent metal microstructure can be affected by a wide heat affected zone each side of the weld (Some stainless grades of steel may suffer from weld decay, depletion of chromium at the grain boundaries, which can reduce the physical or corrosion resistant properties);

(c) both the weld metal and the surrounding material may be prone to defects e.g. hot cracks, slag inclusions if the welding process used is inappropriate or incorrectly performed ;

(d) the thermal gradients induced can cause residual stresses leading to reduction in fatigue strength;

(e) the shape of the weld and connected parts may act as a geometric stress raiser, locally increasing stresses.

24. Where welded assemblies may be subject to repeated stresses, careful consideration may need to be given to the siting of welds because welded joints will have shorter fatigue life. The designer may need to specify post-weld heat treatments in order to minimise the effects of welding on fatigue life. The designer should consider having safety-critical components made from a single piece of parent material where it is practicable to do so. The Standards listed in Table 4.1 incorporate more advice on these issues.

Making it easy to examine and test safety-critical components in-service

25. Good design should make it easy to inspect and maintain an amusement device in safe condition once it has entered service. The designer should therefore consider very carefully how it is to be examined, tested and maintained. It is particularly important that safety-critical component details, particularly those having calculated fatigue, corrosion or wear lives less than twice the specified replacement life of the component, are:

(a) **accessible** - there have been many unacceptable cases where safety-critical components have not been examined, tested or maintained because of the amount of dismantling needed to reach them. In some instances, they have been housed inside welded structures

(b) **clearly identified** in the Operations Manual with lifespan and all requirements for maintenance, examination and testing precisely specified. For visual examination and NDT this should include:

i. the maximum period before first examination or test

ii. the subsequent frequency of examination or test

iii. the purpose of the test (type of defect to look for and its likely location);

iv. significant acceptance/rejection criteria.

v. Additionally for NDT this should include:

vi. method and relevant technique;

vii. specification of any initial NDT to be done by the manufacturer to provide reference material in the Operations Manual, e.g. ultrasonic traces or x-ray results showing the original condition of components or structures.

26. While even the best designed devices may have component details which require NDT to give assurance of their continued fitness for purpose, the need for frequent or extensive NDT may indicate a lack of attention to fatigue prevention, or an over-reliance on

tolerance rather than prevention.

Relevant Standards & Other Publications

ISO 12944	*Paints and varnishes. Corrosion protection of steel structures by protective paint systems*
ISO 14713	*Protection against corrosion or iron and steel in structures. Zinc and aluminium coatings. Guidelines.*
EN 1993-1-1	*Eurocode 3. Design of steel structures. General rules for buildings.*
EN 1999-1-1	*Eurocode 9. Design of aluminium structures. General rules. General rules and rules for buildings.*
BS EN 13001-2	*Crane safety. General design. Load effects*
BS 7608	*Code of practice for fatigue design and assessment of steel structures.*
BS 8118-1	*Structural use of aluminium. Code of practice for design.*
Note:	When using Eurocodes designers should ensure that they refer to the current UK national annexe. Eurocodes should not be used unless a current UK national annexe is available.

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Chapter 5
Specifying materials

Steels

1. Supporting frameworks should be made from weldable structural steels to BS 7668, EN 10025; or EN 10210. If other steels are used, they should have properties at least comparable to those Standards. Design recommendations for the use of structural steel in buildings are given in BS 5950 and ENV 1993 and their supplements and addenda. These, when used in conjunction with fatigue standards (see Chapter 4) contain useful guidance which is relevant to fairground structures.

2. The deterioration of steel components may be inhibited by providing protection against corrosion using one of the methods described in ISO 12944 or ISO 14713. Hollow section structural steel will be subject to internal corrosion, and the designer should specify what internal corrosion allowance has been used. He should consider whether to specify that the ends be permanently closed to prevent ingress of corrosive fluids. Where excessive corrosion could weaken safety critical parts of the structure, the designer should specify the recommended method and frequency of inspection and this should be entered in the Operations Manual.

Aluminium alloys

3. Particular care should be taken when specifying aluminium alloys for structural use, including decking and lighting features. BS 8118 and ENV 1999 give recommendations for the use of aluminium in all types of structure, including advice on material, loading, design, testing, fabrication and erection, and protection. Suitable weldable alloys are included.

4. The strength of some popular alloys is highly dependent on the heat treatment to which it has been subjected and can be severely diminished by application of heat in the manufacturing process. For safety critical components the designer should specify any restrictions to be applied during manufacture.

5. The designer should keep a record of which alloy has been specified for each component in case repair or replacement is required.

6. Care should be taken when using aluminium with steel because of cathodic corrosion. BS 8118 and ENV 1999 give advice.

Timber

7. Structural use of timber for safety critical components should be limited to the species listed in BS 5268-2 or EN 1995. Both of these Standards also contain design recommendations. Bearing in mind the trade-off between material choice and resistance to decay, the designer needs to take into account where the structure is to be located. He should also advise on categories of materials suitable for repair.

8. Bracing should be provided to ensure that transverse deflections under load do not cause secondary bending stresses in structural members.

9. Connections using nails should not be made in any location where load magnitude or fluctuation is significant. Joints in main trestles and for the secondary members between trestles should be bolted. The holes in the timber should be the same size as the bolts, which should be driven home to ensure a tight fit to minimise water penetration which can

lead to rot.

10. Timber guard rails should be designed to BS 6180.

Plastics and composites

11. Plastics and composites are used, particularly in passenger units, because they give the designer the freedom to make complex shapes.

12. Designers will be aware of the difficulty of designing (and confirming the design safety of) plastic composite safety critical components for structural applications. It is therefore usual to base the design of such components on a steel (or other) framework. If the strength of the framework can be shown to be sufficient on its own, no structural analysis or testing of the plastic shell is required. However, the design specification should, where necessary, allow access for inspection of the framework.

13. The designer may need to take account of:

(a) the properties of the material;

(b) the likely variability created by the manufacturing method, particularly if the composites are hand-laid;

(c) the likely deterioration in the material in service;

(d) the thermal expansion properties (which are relatively large for composites);

(e) the design of the supporting structure to prevent excessive loads at the points of support, taking loading and expansion into account;

(f) the type of fastening most appropriate to the composite used e.g. bolts, rivets, moulded-in inserts or adhesive bonding;

(g) the likely effects of corrosion on attached or moulded-in reinforcing

(h) the possibility of fatigue where there are fluctuating loads.

14. The strength and fatigue properties of plastics are increased by reinforcement. The strength of a composite depends on the strength, orientation, proportion and type of fibre and resin. For instance, the addition of 30% of glass fibres may increase the strength twofold. The maximum fatigue resistance is obtained using laminates with unidirectional fibres. Lesser improvements are achieved with (in order of decreasing effectiveness) 85% unidirectional, cross ply, glass fabric, random short fibre. BS 4994 gives useful guidance for specifying reinforced plastic structures.

15. Plastics and composites differ from metals in a number of significant properties. In particular, they can be significantly affected by both time and temperature, while their visco-elastic nature makes their behaviour under stress more complex. Unreinforced plastics usually have non-linear stress-strain curves up to the yield point while glass reinforced plastics (GRP) are practically linear up to 0.3% strain. Plastics also have much higher creep than metals. Therefore, components under constant load should be designed against creep strength rather than yield strength.

16. The designer should obtain adequate information on the plastics, additives and reinforcements to be used and if necessary consult the manufacturer or another authoritative source of information on the properties of the materials before finalising the specification.

17. Where components made of composites are safety-critical, the designer should make clear that they should only be fabricated by manufacturers who have the facilities,

personnel and procedures to maintain the necessary quality. In particular, the process needs to be adequately specified and controlled to ensure consistent properties in the finished article. The requirements for initial and in-service examinations also need to be specified at the design stage. Particular attention should be given to points of potential high stress created by the shape of the structure and the presence of fittings.

Relevant Standards and Other Publications

ISO 12944	*Paints and varnishes. Corrosion protection of steel structures by protective paint systems*
ISO 14713	*Protection against corrosion or iron and steel in structures. Zinc and aluminium coatings. Guidelines.*
EN 1993	*Eurocode 3.Design of steel structures*
EN 1995	*Eurocode 5. Design of timber structures.*
EN 1999	*Eurocode 9. Design of aluminium structures.*
EN 10025	*Hot rolled products of non-alloy structural steels. General delivery conditions.*
EN 10210	*Hot finished structural hollow sections of non-alloy and fine grain steels. Tolerances, dimensions and sectional properties*
BS 4994	*Specification for design and construction of vessels and tanks in reinforced plastics.*
BS 5268-2	*Structural use of timber. Code of practice for permissible stress design, materials and workmanship.*
BS 5950	*Structural use of steelwork in building.*
BS 6180	*Barriers in and about buildings. Code of practice.*
BS 7668	*Weldable structural steels. Hot finished structural hollow sections in weather resistant steels. Specification.*
BS 8118	*Structural use of aluminium.*

Note: When using Eurocodes designers should ensure that they refer to the current UK national annexe. Eurocodes should not be used unless a current UK national annexe is available.

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Chapter 6
Designing foundations, supports and structures

General design requirements

1. The following paragraphs refer to a number of British and European Standards which are normally the most appropriate for use in the UK. The designer may need to consider other national standards and codes for structural design, of which there are many.

2. General information on designing structures is given in ENV 1991, BS 5950 and EN 1993 for steel; and BS 8118 and EN 1999 for aluminium; BS 8110 and EN 1992 for concrete; BS 5268 and EN 1995 for timber.

Foundations

3. Where there are to be purpose made foundations, the designer should consult the prospective controller to determine the siting of the structure. From that he may establish appropriate site-specific loading and environmental conditions. The designer will need to decide the extent of any site investigations. The designer should calculate the direction and magnitude of the forces which will be applied to the ground by the supporting structure. The foundations shall be designed, in accordance with BS 8004 or EN 1997-1, to withstand these forces. Where the designer and foundation constructor are from different countries, account must be taken of potential confusion from different units of measurement, drawing projections and other conventions (e.g. compass bearings).

Support and Stability

4. Outriggers or other means may need to be used to maintain the stability of the device. Calculations and / or tests should demonstrate, in the worst operational and non-operational conditions including during erection, the ability to resist overturning, sliding and lifting. (Suitable calculation loads are given in Chapter 3 above). Advice, to be included in the Operations Manual, on minimum ground bearing areas for each designated point of support should be based on the above calculations taking into account likely ground conditions.

5. The designer should supply information on the designated positions at which pressure is to be transferred from the device to the ground and on the size and direction of the forces imposed. He should also give recommendations for levelling, packing and securing of the device as appropriate. These matters should form part of the instructions for safe erection, to be included in the Operations Manual.

6. The use of packing should be minimised. Where it is permitted, the maximum packing height at various points should be specified, together with any necessary precautions. Calculations (and subsequent tests) should investigate the likelihood of movement of the device off its packing. Where this could be a problem, advice on precautions, e.g. anchorage, should be included in the Operations Manual.

7. Hydraulic jacks should not be used as supports, except during buildup, unless compensation for leakage can be guaranteed. The permissible out of level tolerance should be specified by the designer and included in the Operations Manual, together with the other advice given above.

8. Where a trailer with road wheels and running gear forms part of the device, provision should be made to ensure that no part of the dead, imposed or dynamic loads is

transmitted to the foundations by the wheels or running gear.

9. Where a vehicle or trailer chassis forms all or part of the stationary framework, the designer should make sure that it will withstand both the static and fluctuating stresses imparted during erection, use, dismantling and transportation. The fatigue life of critical chassis components should be established and the methods and frequency of examination specified.

Structures

10. The designer should calculate the fatigue lives of all safety critical components of the structure. Recommended methods and frequencies of examination should be based on the calculated fatigue lives and included in the Operations Manual.

11. Normal structural design methods should be used for those parts which are not dominated by fatigue.

Ancillary equipment

12. The design should ensure that ancillary equipment and structures will be safe under foreseeable operating conditions. For example, calculations should demonstrate that backdrops and lighting displays will be strong and serviceable enough to withstand predictable wind loadings, wear and tear associated with regular assembly and dismantling where appropriate, and capable of being adequately secured at all times. Guidance on the assessment of wind effects is given in Chapter 3, paragraphs 5 to 15.

Joining the parts

Non-welded joints

13. Bolts for structural connections should conform with EN 1993-1-1.

14. The designer should determine the maximum loads arising in bolted joints and specify on the assembly drawings and maintenance schedules the pre-load torque to which they should be tightened. This is particularly important for load-bearing rotating assemblies such as slewing rings. Nuts on critical assemblies should have a suitable locking device.

15. Safety critical bolts which are subjected to repeated stress fluctuations should be assessed with respect to fatigue life. Recommended methods and frequencies of examination and / or replacement should be based on the calculated fatigue lives and included in the Operations Manual. (Bolts, studs and rivets are difficult to inspect by NDT in situ and replacement is a safer way of ensuring continued suitability for service).

Welded joints

16. Load-bearing welds in steel structural parts should be designed in accordance with BS 7608 or EN 1993-1-9. Where fluctuating loads are not significant BS 5950 may be used. Welding of steels not covered by these Standards, e.g. wear-resistant or hardenable steels used in specific applications, such as pins, shafts and tracks should not be specified unless consideration has been given to the metallurgical effects. Where the resultant quality of a welded joint in steel could be significant then ISO-25817 could be relevant.

17. Load-bearing welds in aluminium structural parts should be designed in accordance with BS 8118 or ENV 1999. Where the resultant quality of a welded joint in aluminium could

be significant then ISO-10042 could be relevant.

18. Weld specifications (certainly of every safety critical component) should always be shown on manufacturing drawings. Symbolic representation should comply with EN 22553.

19. Welding procedures, when safety critical components are involved, should be approved in accordance with ISO 15607 - ISO 15614 and welders approved in accordance with EN 287-1 or ISO 9606-2.

Relevant Standards & Other Publications

ISO 5817	*Welding. Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded). Quality levels for imperfections.*
ISO 10042	*Arc-welded joints in aluminium and its weldable alloys. Guidance on quality levels for imperfections.*
EN 287-1	*Qualification testing of welders. Fusion welding. Steels*
EN 1991	*Eurocode 1. Actions on structures.*
EN 1992	*Eurocode 2. Design of concrete structures.*
EN 1993	*Eurocode 3. Design of steel structures.*
EN 1993 -1-1	*Eurocode 3. Design of steel structures. General rules and rules for buildings.*
EN 1995	*Eurocode 5. Design of timber structures.*
EN 1997-1	*Eurocode 7. Geotechnical design. General rules.*
EN 1999-1-1	*Eurocode 9. Design of aluminium structures. General rules. General rules and rules for buildings.*
EN 22553	*Welded, brazed and soldered joints. Symbolic representation on drawings.*
BS 5268	*Structural use of timber.*
BS 5950	*Structural use of steelwork in building.*
BS 7608	*Code of practice for fatigue design and assessment of steel structures.*
BS 8004	*Code of practice for foundations.*
BS 8110	*Structural use of concrete.*
BS 8118	*Structural use of aluminium.*
Note:	When using Eurocodes designers should ensure that they refer to the current UK national annexe. Eurocodes should not be used unless a current UK national annexe is available.

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Chapter 7
Mechanical systems

Hydraulic and pneumatic

General

1. The designer should assess all modes of failure which could affect passenger safety, taking particular account of all the forces acting on cylinders, hoses and other components during normal use, erection, dismantling, maintenance and repair.

(a) Advice on hydraulic systems is given in ISO 4413 and EN 982.

(b) Advice on pneumatic systems is given in ISO 4414 and EN 983

(c) Principles and presentation for mechanical, hydraulic, pneumatic and other diagrams are given in BS 5070-3.

(d) Graphic symbols and circuit diagrams for fluid power systems (both hydraulic and pneumatic) and components should be in accordance with ISO 1219-1 (identical to BS 2917-1) and ISO 1219-2.

2. The design specification should meet the following general requirements where necessary:

(a) all components should operate within the manufacturer's specification

(b) all parts of the system should be protected against overpressure

(c) components requiring maintenance should be accessible

(d) where operating pressures and flow rates are safety critical they should be specified by the designer and set by the manufacturer so that they can only be adjusted within a pre-set range

(e) pressure gauge ports (or gauges protected from in-service damage) should be fitted in order to allow monitoring of the system

(f) flexible hoses should be of suitable length to prevent over-stress and should be protected from accidental damage

(g) fluid level indicators should be fitted.

Specific requirement for hydraulic systems

3. The risk of fluid contamination and heat build up should be minimised by carefully siting pumps, enclosing fluid reservoirs and providing efficient strainers, filters and coolers.

4. Hose rupture valves or restrictor valves should be provided directly on the support side of all cylinders where a rupture could affect the safety of the device, particularly where hydraulic pressure is used to raise any part of it. Hose rupture valves should not cause shock loads which could overstress the structure.

5. Other facilities should be provided to allow the elevated part to be lowered safely after operation of a hose rupture valve.

Specific requirements for pneumatic systems

6. Pneumatic systems operating above 0.5 bar over atmospheric pressure may fall within the scope of the Pressure Equipment Regulations 1999 or the Pressure Systems Safety Regulations 2000. There is an Approved Code of Practice to the Regulations and HSE has also published guidance. The Simple Pressure Vessels Regulations 1991 (amended in 1994) may also be relevant.

7. Where necessary on safety-critical circuits a filter, drain, regulator and lubricator should be provided in the supply line and additional drain taps provided where condensate can be collected and released safely.

8. Where necessary, pressure relief valves, hose rupture valves and / or air fuses should be provided to protect the system from over-pressurisation. The operation of these valves should not lead to unsafe operation of the device or to other danger.

9. Exhaust ports should be positioned or fitted with silencers such that the escaping air does not lead to danger.

Couplings

Rotating shaft couplings

10. These should have an adequate service factor to transmit the design power reliably. This should take account of the anticipated daily operating hours together with any foreseeable shock loadings. A torsional analysis should be made before specifying couplings which may be subject to substantial shock, vibration or torque fluctuations.

11. Where proprietary flexible couplings are used, the specification should be consistent with the manufacturers' instructions.

12. Suitable protective devices should be provided if failure of a coupling could lead to injury - for instance, covers should be provided if there is a risk of ejection of parts or entanglement.

13. Where the calculated risk of a coupling failure which could cause loss of control of a passenger unit is unacceptable, a secondary system may be fitted or an inspection and replacement programme specified. Any secondary system should not come under load during normal operation and should be designed to withstand any breakaway loadings which may result from the coupling failure.

Hinge pin pivot couplings

14. Where a coupling consists of a pivot pin (or shaft), the pin should be an interference fit in one of the components only, allowing the other components(s) to rotate on the fixed pin. This has the advantage that one of the components does not need a bearing surface. (For ISO limits and fits see ISO 286). Alternative means (i.e. other than by an interference fit requiring some precision) of stopping pin rotation with respect to one of the coupled components may be used.

15. If the risk of coupling failure cannot be reduced to an acceptable level, other secondary means (e.g. a back up retaining device) should be provided.

16. All bearing surfaces should be provided with a means by which the bearing can be adequately lubricated.

17. A pivot pin supported at both ends experiences smaller bending stresses than in a

cantilever design. In both types the detail of the design should be carefully considered and calculation of bending as well as shear stresses should be carried out. Fluctuating stresses need to be assessed for fatigue life. This recommendation also applies to wheels of track guided rides which are likely to be mounted on stub axles and to be subjected to large forces. (EN 1993-1-8 gives advice on bending stresses in pin joints).

18. If failure of a single axle on a track guided ride would result in a passenger unit leaving the track, the specification should ensure (either by providing adequate design life, by an inspection and replacement programme, or otherwise) that failure in service cannot occur.

Ball and socket couplings

19. Many of the proprietary ball and socket couplings available are designed for towing trailers behind vehicles. However, some manufacturers have test data covering fatigue loading in a variety of circumstances. Before using proprietary couplings, the designer should check with the manufacturer supplier that they will be suitable for the intended use.

20. If the risk of coupling failure cannot be reduced to an acceptable level, other secondary means (e.g. a back up retaining device) should be provided.

21. Couplings should be designed to have provision for effective lubrication of the bearing surface.

22. When replacing ball and socket couplings, the complete assembly should be renewed to prevent the possibility of mismatch due to wear or incorrect sizing.

23. Some proprietary ball and socket couplings have in-built, readily visible, wear gauges. Where using types in which this is not present, the designer should specify the safe wear limits and the means and frequency of checking them.

Relevant Standards and Other Publications

ISO 286	ISO system of limits and fits
ISO 1219-1	Graphic symbols and circuit diagrams for fluid power systems and components. Specifications for graphic symbols.
ISO 1219-2	Fluid power systems and components. Graphic symbols and circuit diagrams.
ISO 4413	Hydraulic fluid power. General rules relating to systems.
ISO 4414	Pneumatic fluid power. General rules relating to systems.
EN 982	Safety of machinery. Safety requirements for fluid power systems and their components. Hydraulics.
EN 983	Safety of machinery. Safety requirements for fluid power systems and their components. Pneumatics.
EN 1993 -1-8	Eurocode 3. Design of steel structures. Design of joints.
BS 5070-3	Engineering diagram drawing practice. Recommendations for mechanical/fluid flow diagrams.

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Chapter 8
Controls: general requirements

1. All operating controls should be:

   (a) clearly visible to the Operator

   (b) easily distinguishable from each other

   (c) readily accessible to the Operator

   (d) easy to operate

   (e) clearly marked to show the function and mode of operation. All markings should be permanent and conform to recognised standards. Written markings should be in a language agreed between the user and the supplier.

2. The Operator's working position should be:

   (a) be safe (and have safe access)

   (b) make it easy to control the ride

   (c) have adequate illumination

   (d) give, where possible, an unobstructed view of all areas of operation.

   (e) take into account environmental aspects e.g. temperature, vibration and noise

3. The design also should take account of any need for the operator and attendants to communicate, between themselves and where necessary with the public e.g.

   (a) visibly

   (b) by phone/ intercom

   (c) public address

   (d) through the ride control system (such as 2-button operating systems).

4. Controls designed to be operated by passengers should:

   (a) be clearly marked, in a language agreed with the controller, to show their functions;

   (b) be accessible to all passengers within the designated size limits;

   (c) not present a risk to passengers through their positioning or use.

   (d) should not be foreseeably capable of causing injury to passengers either directly (e.g. by trapping hands or fingers, electric shock, etc) or by causing any controlled device to malfunction or operate inappropriately

   (e) only be operable by passengers when it is safe for them to do so

   (f) never override an operator selected control input where it would be unsafe to do so.

   (g) Be able to be muted or over-ridden by the operator if necessary.

5. The designer should anticipate how controls could fail or be misused as well as the possibility of operator error and ensure that there is no significant risk from such events.

6. The design should indicate how equipment is to be protected, installed and operated to prevent danger.

7. Controls located in public areas and accessible to the public should be tamper -

proof where necessary to prevent misuse.

8. Any necessary diagrams and instructions should be provided in the Operations Manual.

9. Guidance on control panels, displays etc. is given in EN 894.

10. Design of stop controls is given in Chapter 9.

Relevant Standards & Other Publications

EN 894-1	*Safety of machinery. Ergonomics requirements for the design of displays and control actuators. General principles for human interactions with displays and control actuators*
EN-894-2	*Safety of machinery. Ergonomics requirements for the design of displays and control actuators. Displays*
EN 894-3	*Safety of machinery. Ergonomics requirements for the design of displays and control actuators. Control actuators*

Chapter 9

Safety-related control systems

Introduction

1. Most amusement devices contain control systems, the fundamental elements of which are input sensors such as switches and proximity devices, control logic for processing input signals and determining output signals, and output actuators such as brakes and motors. Many of these control systems perform functions such as emergency stop, interlocking on passenger restraints and access gates, block-zone control, and braking.

2. A control system in an amusement device should be regarded as being safety-related if its correct functioning contributes to reducing any risk to a tolerable level, or is necessary to maintain or achieve safety. The functions carried out by a safety-related control system are therefore termed 'Safety Functions'. Generally, safety functions maintain or achieve a safe state by preventing the initiation of a hazardous situation, or by detecting its onset and initiating an appropriate response .

3. This aspect of overall safety associated with a control system operating correctly in response to its input signals is known as 'Functional Safety'. It is distinct from safety associated with exposure to the energy source (e.g. electricity) used in the control and power systems of an amusement device,

4. Safety-related control systems should be designed and configured to:

(a) perform the safety functions that are necessary to maintain or achieve a safe state (or mitigate the consequences of a hazardous situation) ; and

(b) perform each safety function with sufficient integrity (bearing in mind the consequences of any failure)

5. The principles covered by this Chapter apply to safety-related control systems implemented in a range of technologies, including electrical, electronic, programmable electronic, mechanical, pneumatic, hydraulic and manual systems. It describes the general principles that should be adopted in the design of safety-related control systems, and also discusses application of the following relevant standards:

(a) IEC 62061 – Safety of machinery – Functional safety of safety-related electrical, electronic and programmable electronic control systems

(b) EN 954 –1 – Safety of machinery – Safety-related parts of control systems – Part 1. General principles for design.

(c) IEC 61508 – Functional safety of electrical/electronic/programmable electronic safety-related systems (Parts 1-7)

6. Brief reference is also made to the future ISO 13849-1 – Safety of machinery – Safety-related parts of control systems – Part 1: General principles for design, which was being developed at the time of publication.

7. Regardless of which particular standard is applied, the designer should take full account of the level of risk reduction that the safety-related control system is required to achieve. This is because the required level of risk reduction will have a significant influence on the design techniques needed to ensure that the performance in terms of reliability and tolerance to faults is adequate.

8. Failures that occur in a safety–related control system can be classified as either random hardware failures or systematic failures. Random hardware failures arise as a result of degradation mechanisms within the hardware, which as their name suggests occur at an unpredictable point in time. Systematic failures on the other hand are associated with deficiencies built in to the hardware or software, typically caused by errors in the requirements specification, or due to inappropriate selection, design or implementation of hardware or software. As systematic errors are deterministic to a certain cause, simulating the failure cause should repeatedly induce them.

General Principles

9. The design characteristics for reliability and fault tolerance of a safety-related control system should stem from the design risk assessment carried out on the amusement device in accordance with Chapter 1. This assessment will identify aspects of the device's operation that create risks that may need to be reduced to a tolerable level.

10. Designers may implement a range of protective measures to reduce the risk, many of which will not involve the use of safety-related control systems. For example, the physical dimensions of passenger restraints are important factors in minimizing the risk of passenger ejection, and the provision of platforms and walkways will reduce the risk of falls from height. However, in many cases risks cannot be reduced to tolerable levels without incorporating safeguards that rely on the correct operation of safety-related control systems. In this case, the designer needs to understand and assess the amount of risk reduction that these systems are required to contribute, and their consequential reliability and fault tolerance capability.

11. The more critical the role played by a safety-related control system, the more reliable and resistant to faults it should be. This property is described as the 'Safety Integrity' of the system, which is an indication of the degree of assurance or confidence that it will perform the required safety function(s) under all stated conditions within a stated period of time. An adequate level of safety integrity may be achieved by a combination of:

(a) the reliability of the hardware, software, and human operator; and

(b) the way the parts are combined in the design of the control system; and

(c) the use of diagnostic and proof testing techniques; and

(d) the use of other design techniques that avoid systematic failures and/or control systematic faults.

12. The designer should identify all safety functions that are to be performed by the safety-related control systems and then determine the required safety integrity of each. This specification is known as the 'Safety Requirements Specification' and is fundamental to the achievement of safety by design. The overall process is illustrated in Figure 9.1

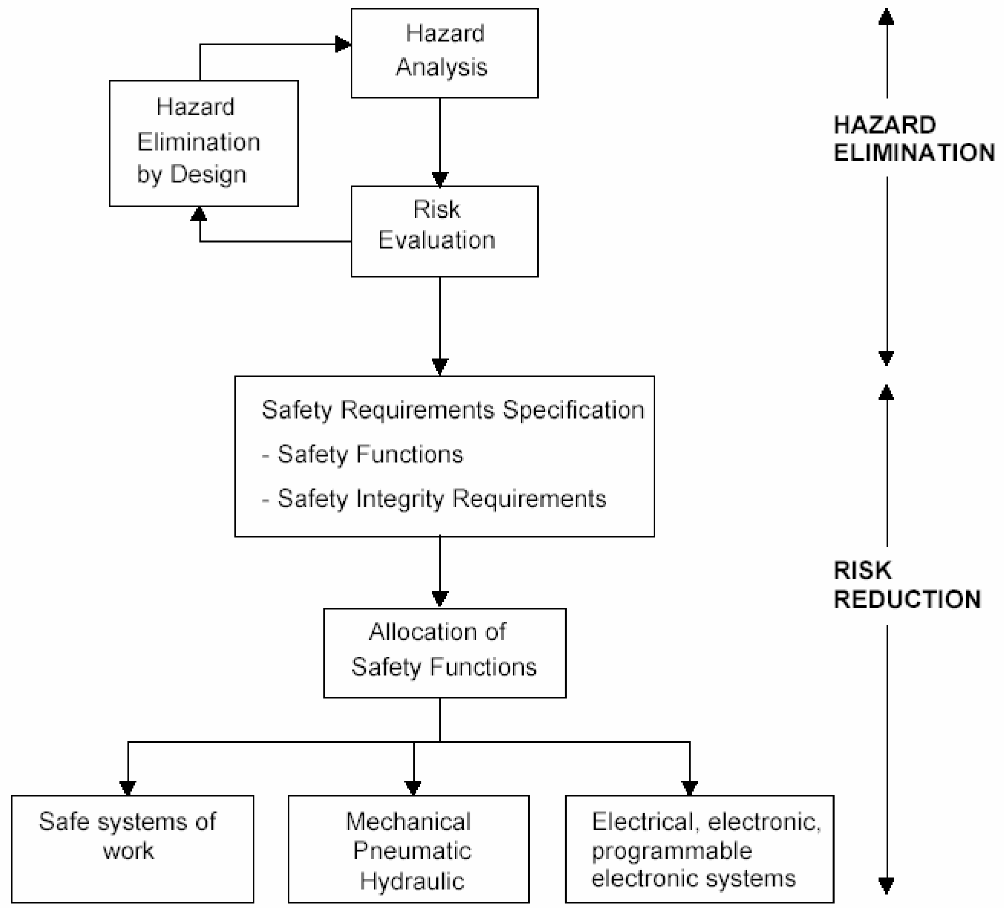

Figure 9.1 The risk control process

13. In designing a safety-related control system to achieve a level of safety integrity that is commensurate with its required contribution to risk reduction at the amusement device, the following require consideration:

(a) The reliability of the equipment and any human actions that form part of the safety-related control system;

(b) Use of techniques such as redundancy, diversity, monitoring, and automatic diagnostics – these are design techniques that can often be an effective means of achieving adequate safety integrity;

(c) How to prevent, as far as possible, systematic faults being introduced during the specification, design or manufacture of hardware and software (e.g. software 'bugs', incorrectly specified components or faulty wiring);

(d) The design of any human interfaces;

(e) How to incorporate design features which may help the control system to recover from faults during operation (e.g. program sequence monitoring);

(f) The behaviour of the safety-related control system under fault conditions (failure modes);

(g) How to test the safety-related system(s) initially to show, as far as possible, that there are no design, manufacturing or installation faults before the amusement device is put into operation;

(h) How to design periodic test and inspection procedures for the safety-related control system(s) for the lifetime of the amusement device to show that no part (including both hardware and software) has changed or deteriorated beyond reasonable limits.

14. These issues should be taken into account for all elements of the safety-related control system, including hardware, software, the way that parts are combined during integration, and any humans on whom the functionality of the system may rely. It should be recognised that all these elements may contribute towards the safety integrity of the individual safety functions and the performance of each element therefore needs to be considered when assessing safety integrity.

15. The following points aim to assist in the process of designing safety-related control systems for amusement devices. They are applicable to new devices, devices being refurbished to present day standards and to older devices being reassessed for the purpose of improving safety.

(a) Identify the hazards occurring at the device, taking into account the hazards that arise in normal operation, during maintenance, and in foreseeable abnormal conditions such as break-down.

(b) Assess the risks from the device. If the risks are determined to be unacceptable, consider designing them out. If this is not possible, determine the risk reduction measures required to reduce the risks to a tolerable level (see Chapter 1).

(c) Allocate safety functions to appropriate combinations of risk-reduction measures, such as positioning, fixed guards, passenger restraints, speed and acceleration control, anti-collision mechanisms, and emergency stops.

(d) Determine which of these risk reduction measures require a safety-related control system.

(e) For each safety function, determine the contribution required from the safety-related control system to achieve the necessary level of risk reduction.

(f) Draw up the safety requirements specification that assigns a required safety integrity to each of the safety functions. The required safety integrity is a measure of the target dangerous failure rate, which is based on the tolerable risk determined as part of the risk assessment process.

(g) Design the safety-related control system. The design process should include consideration of the consequences of failures, which may require the application of reliability analysis techniques such as Failure Mode and Effects Analysis (FMEA), reliability block diagrams, cause consequence analysis, and fault tree analysis. The design should consider failures within purpose built control units, such as electronic motor drives, as well as those in circuitry external to the drives.

(h) Validate the design to ensure that it meets the requirements of the Safety Requirements Specification. Document the process so that anyone who needs to can understand how and why the system meets the safety requirements.

16. Designers should provide information on an appropriate in-service maintenance regime incorporating inspections, tests and any required component replacement schedules. To maintain safety integrity, all safety-related control systems should be tested regularly as part of a preventative maintenance strategy.

17. For any particular safety-related control system, the frequency of testing should be

determined taking into account:

(a) the safety integrity requirements;

(b) the target dangerous failure rate;

(c) the reliability of the component parts;

(d) the degree of fault tolerance; and

(e) the diagnostic capabilities of the safety-related control system.

Programmable Safety-Related Control Systems

18. Some amusement devices have control systems that incorporate programmable electronic systems such as programmable logic controllers (PLC), embedded microcontrollers and microprocessors, and smart sensors. The cost, flexibility and configuration advantages of using such devices are well known, but considerable care should be taken if it is proposed to use programmable electronic systems for implementing safety functions.

19. As with any safety-related control system on an amusement device, those that incorporate a programmable electronic system need to perform the required safety functions with a suitable degree of safety integrity. This will be influenced to a large extent by the programmable electronic system's susceptibility to random hardware failures, and also to systematic failures within its hardware and software (operating and application).

20. As the failure modes of programmable electronic systems are not well defined and their behaviour under fault condition cannot be readily determined, safety-related control systems incorporating such technology must be regarded as complex systems. This classification is a fundamental factor in the selection of which standard to apply to the design of the safety-related control system (see fig.8.2).

21. Although they may be adequate for performing non-safety-related control functions on amusement devices, general-purpose programmable electronic systems such as PLCs should not be assumed to be suitable for use in safety-related control systems. To determine their suitability for implementing safety functions, the performance of the overall safety-related control system would need to be assessed against relevant standards, which might indicate that the required safety integrity can only be achieved by adopting additional measures to protect against failure of the hardware and software of the programmable electronic system. Alternatively, the safety functions could be performed by supplementary control circuits that do not depend on the correct operation of the PLC.

22. In the absence of additional measures being used, the safety integrity of any PLC or similar programmable electronic system used in a safety-related application should equal or exceed to that of the most critical safety function that it performs. This also applies to the application software (e.g. ladder logic, function blocks) or configuration of such devices.

23. Programmable electronic systems are available that have been specifically designed and assessed for use in safety-related applications by following a rigorous and systematic design approach such as that offered by IEC 61508 . Their designs typically incorporate enhanced redundancy, diagnostic and monitoring techniques to reduce the likelihood and impact of random hardware failures, and diversity to reduce the likelihood of systematic errors inducing common cause failures.

24. Measures should be taken to ensure that software for programmable electronic systems used in safety-related applications does not contain systematic faults. Since it is

generally recognised that software cannot be tested with sufficient confidence to detect all such faults, software developers should minimise the likelihood of errors being introduced during the specification and development of the software by ensuring that the project is well managed within a structured framework. This will include progressive verification, validation and testing of the software components throughout the development cycle including any final development work during commissioning activities. Compliance with IEC 62061 and IEC 61508-3 (Software requirements) will demonstrate that good practice has been followed.

25. Within this framework, the accuracy and completeness of the initial specification for the requirements for safety performance in the control system is of fundamental importance - if the initial specification is deficient, the follow-on stages in the development cycle may not prevent systematic faults from being inadvertently introduced.

26. If the end-user has the facility to alter the application software, rigid procedures to control, assess and validate any changes are crucial. Although programmable electronic systems can make the physical task of modifying a safety-related control system relatively easy compared to wiring modifications in a hard-wired safety-related control system, skills and competencies in machinery safety issues are still vital. Modifications should only be undertaken by persons who possess the competencies that enable them to understand the implications of their actions.

27. If a field-bus system is to be incorporated into a safety-related control system, the overall system should satisfy the safety integrity requirements of each safety function. Field-bus systems suitable for transmitting safety-related data would have typically been designed and assessed for use in safety-related applications by following a rigorous and systematic design approach such as that of IEC 61508. The safety integrity capability of a field-bus system should equal or exceed that of the most critical safety function for which it transmits safety-related data.

28. Although a programmable electronic system that has been designed and assessed specifically for use in a safety-related control system may be certified to a particular safety integrity, it is the risk reduction capability of the overall safety-related control system that should be checked against the Safety Requirements Specification during validation. A component part intended for use in a safety-related control system is only effective if the overall system has been appropriately designed, integrated and validated, all of which require specific competencies.

29. It is essential that work on the specification, design and development of programmable safety-related control systems takes full account of the concepts of capturing safety requirements; safety validation; safety-related system architecture design, hardware and software realisation; and project safety assurance.

Non-Programmable Safety-Related Control Systems

30. This type of safety-related control system does not contain programmable electronic systems, although it is recognised that systems implemented in non-programmable technologies can actually be quite complex in nature. They include electromechanical relay-based systems, hydraulic and pneumatic systems, and mechanical systems that can be assessed using deterministic principles.

31. The general principles for the design of these systems are similar to those used for programmable electronic systems. This is because the requirements should be based on a fundamental assessment of the risks created by the device and the extent to which the

safety-related control system is needed to reduce those risks to a tolerable level, taking into account all other measures taken to control the level of risk.

32. In many cases a safety-related control system based on programmable electronic systems will also comprise non-complex electrical and electronic parts such as interlocking switches and interposing relays. Prior to integrating such parts, the system designer must be able to fully determine whether their application will achieve the appropriate level of safety integrity.

Use of Standards for Safety-Related Control Systems

33. Guidance on the processes and procedures appropriate to the design and development of electrical, electronic and programmable electronic (E/E/PE) technology based safety-related control systems is set out in the basic safety publication IEC 61508, which is regarded as the authoritative good practice in this field. It uses the Safety Lifecycle model to indicate the measures that should be applied from the conceptual design phase through to decommissioning, describing both quantitative and qualitative methods of control system analysis. Although IEC 61508 has been formally adopted across Europe, it is not actually harmonised to a specific Directive.

34. As a basic safety publication, IEC 61508 is intended to be used by IEC technical committees during the development of sector or product standards that have E/E/PE safety-related system considerations. IEC 62061, which is a machinery sector implementation of IEC 61508, provides a framework for designers of E/E/PE safety-related control systems for machines to achieve functional safety. The scope of IEC 62061 is applicable to E/E/PE safety-related control systems of any complexity, including high complexity systems that incorporate programmable electronic systems. As with IEC 61508, it has also been adopted across Europe, but in addition it has been harmonised under the Machinery Directive.

35. EN 954–1, which is also harmonized under the Machinery Directive, provides criteria by which the safety-related parts of control systems based on all operating media can be categorised according to their fault resistance and behaviour under fault conditions. Although the scope of EN 954-1 does not exclude complex safety-related control systems such as those incorporating programmable electronic systems, the standard is most applicable to low complexity safety-related control systems, i.e. those in which the failure modes of components are well defined and the behaviour of the system under fault conditions can be completely determined.

36. Further justification for restricting the application of EN 954-1 to low complexity systems is based on the fact that it does not consider systematic failures, which tend to be increasingly significant in complex systems. Also, it does not provide information on validation techniques for when programmable electronics are used in the design of safety-related parts of control systems, instead referring to other standards such as IEC 61508.

37. Although the exclusion of amusement devices from the scope of the Machinery Directive means that harmonised standards such as EN 954-1 and IEC 62061 have no formal status, they are nevertheless a useful source of guidance for the design of safety-related control systems for amusement devices. Amusement device designers should therefore decide on the appropriate standard that can be applied to the safety related control circuits, with the flow chart in Figure 8.2 aiding this decision.

EN 954-1

38. This Standard categorises safety-related control systems, in total or in part,

according to their resistance to faults and their subsequent behaviour in the fault condition. The resistance to faults is determined by the reliability of component parts and the way in which they are combined in the design. The structural arrangement governs the ability of the safety-related control system to perform its safety function(s) after a fault has occurred

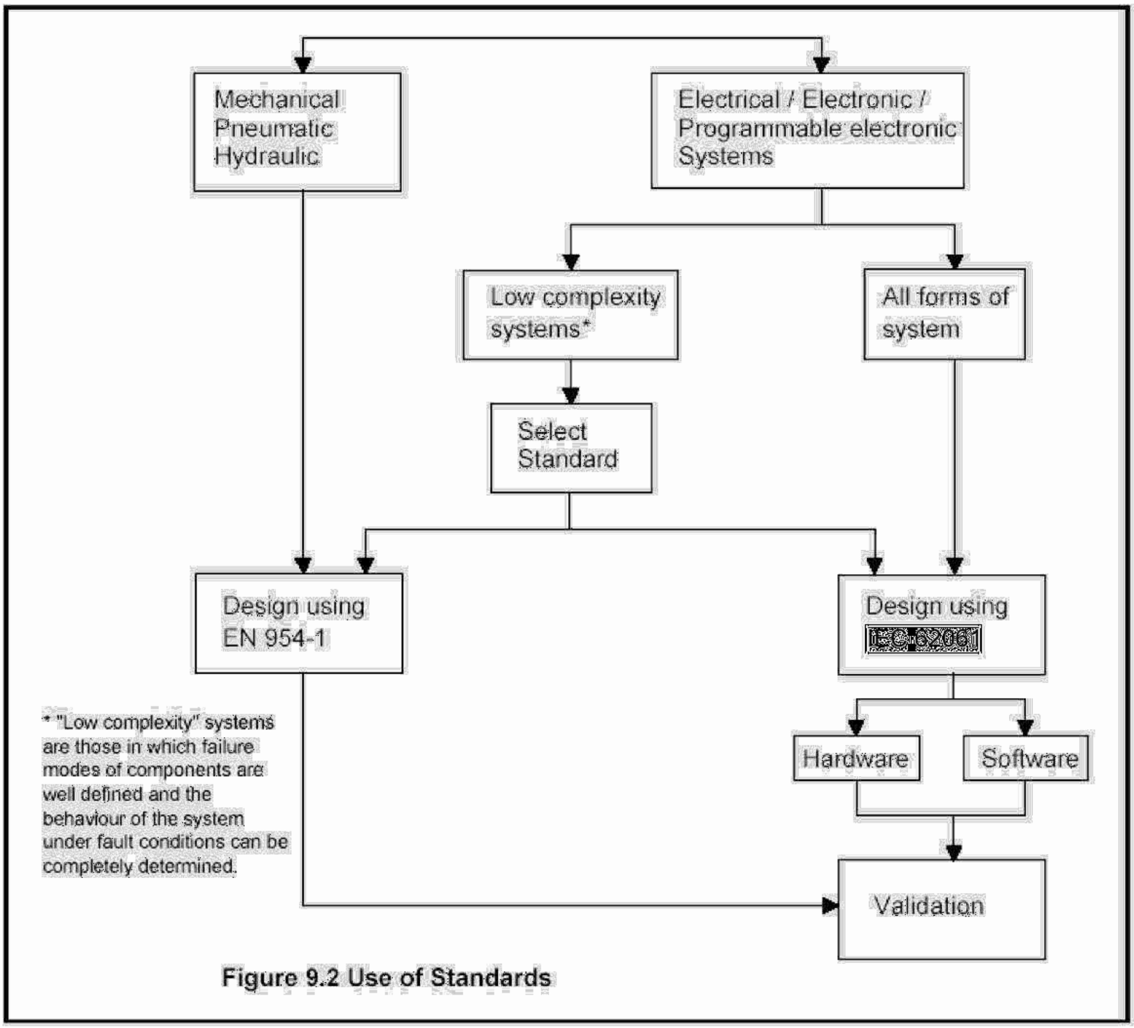

Figure 9.2 Use of Standards

Categories of control systems used in EN 954-1

39. There are five main categories of performance of safety-related parts of control systems in accordance with the standard, which are summarised in Table 9.1 below:

Table 9.3 EN 954-1 Safety Categories	
Category	Basic Requirements (For full requirements see clause 6 of EN 954-1: 1996)
B	Use of good engineering principles
1	Use of well-tried components and principles (reducing the probability of failure)
2	Incorporates a safety function check at machine start-up and may also be checked periodically (safety monitoring) A single fault may lead to the loss of the safety function
3	A single fault will not cause the safety function to fail (redundancy of hardware)

Table 9.3 EN 954-1 Safety Categories	
4	A single fault will not lead to a loss of the safety function. The single fault is detected at or before the next demand upon the safety function, or an accumulation of faults will not lead to a loss of the safety function.

Application of EN 954-1

40. It is important to bear in mind that safety-related parts of control systems may not neatly fit into a single category, particularly if they use different energy sources - a control system can incorporate electrical, electronic, programmable electronic, pneumatic or hydraulic devices.

41. Categories should not be regarded as hierarchical with regard to safety. For example, a single positively operated safety switch element that has been manufactured to a published safety standard might, itself, meet the requirements of Category 1, but not the criteria for higher categories. However, its level of safety performance could be considered at least as high as technologies with structures that meet Categories 2 and 3, but for which the component reliability is inferior in comparison. The selection of categories for the safety functions listed in the rest of this Chapter is therefore a matter of judgment that should be part of a risk assessment (see Chapter 1) and failure analysis.

42. The technical report PD CR 954-100: 1999 provides further guidance on use and application of EN 954-1, whilst ISO 13849-2 (effectively part 2 of EN 954) covers the process of validation of the safety-related parts of control systems of the machine.

Future of EN 954-1

43. EN 954-1 will at some point in the future be replaced by ISO 13849-1, which also applies to safety-related parts of control systems based on all operating media.

44. ISO 13849-1 introduces the concept of a ‘Performance Level’, which is a hierarchical and quantitative measure of the ability of a safety-related part of a control system to perform its associated safety function.

45. There are 5 discreet performance levels (a-e), each corresponding to a range of probability of dangerous failure per hour of the safety-related part of the control system.

46. The Performance Level of a safety-related part of a control system is a function of several parameters, including structure (EN 954-1 category classification), component failure rates and diagnostic capability.

IEC 62061

47. Guidance on the processes and procedures appropriate to the specification, design and validation of machinery safety-related control systems implemented in E/E/PE technologies is published in IEC 62061, which applies the principles of IEC 61508 to machinery applications.

48. IEC 62061 contains advice on the system hardware and software architectures aimed at achieving an adequate level of safety integrity. A quantitative analysis concept that was first introduced in IEC 61508 is that of Safety Integrity Levels (SILs), which specify the target failure values in terms of probability of a dangerous failure per hour and probability of failure to perform on demand.

49. Although IEC 61508 considers SILs ranging from SIL1 to SIL4, the scope of IEC 62061 does not extend to SIL4 - the highest level of safety integrity - as it is not considered relevant to the risk reduction requirements normally associated with machinery.

50. Furthermore, IEC 62061 quantifies SILs solely in terms of a failure rate (for continuous mode and high demand rate safety functions) and not in terms of a probability of failure on demand (for low demand rate safety functions), since the low demand mode of operation is not considered to be relevant for machinery applications.

51. Table 9.4 shows the range of probability of dangerous failure per hour for each value of SIL relevant to IEC 62061.

Table 9.4 IEC 62061 Safety Integrity Levels	
SIL	Probability of a dangerous failure per hour
4	Not applicable
3	$\geq 10^{-8}$ to $<10^{-7}$
2	$\geq 10^{-7}$ to $<10^{-6}$
1	$\geq 10^{-6}$ to $<10^{-5}$

52. The required SIL of a safety function is determined by the initial risk assessment, the analysis of the amusement device safety requirements and the level of risk considered tolerable in the specific application. The safety function will need to have a SIL value that reduces the initial risk to a level that is at least as low as this tolerable risk. It is essential that this analysis is undertaken by a competent person.

53. Examples of methods for assigning SILs to safety functions can be found in IEC 62061 (Annex A) and IEC 61508-5. When applying techniques such as these, it should be remembered that the acceptable probability of occurrence for a particular hazardous event is specific to the application. Determining the tolerable risk for a particular situation therefore requires many factors to be considered. It is only when this tolerable risk has been decided that the SIL required to adequately reduce the risk to this level can be determined.

54. A SIL is assigned to each safety function in a safety-related control system and has a strong influence on the requirements that have to be taken into account during the design and integration of a safety-related control system. These measures, together with the calculation of failure rates for the safety-related control systems, are an integral part of the process of achieving a safe design.

55. Central to IEC 62061 are the Safety-Related Electrical Control System (SRECS) and the Safety-Related Control Function (SRCF). These relate to the E/E/PE elements of a machine's safety-related control system and the control function to be performed by it.

56. A SRCF will be specified in terms of its particular role or function and the safety integrity associated with the performance of this function. Where a SRECS is used to implement one or more SRCFs, its hardware and software must achieve a SIL consistent with the highest safety integrity requirements of the individual SRCFs.

57. The SIL that can be claimed for a SRECS consisting of one or more subsystems will be constrained by the lowest SIL Claim Limit of any subsystem and by their combined probability of dangerous random hardware failure. The SIL Claim Limit of a SRECS

subsystem determines the maximum SIL that can be claimed in relation to its architectural constraints and its systematic safety integrity (extent to which systematic failure avoidance measures have been applied). For a SRCF to achieve a particular SIL, the SIL Claim Limit of each SRECS subsystem must therefore equal or exceed it, and their combined probability of dangerous random hardware failure must not exceed the target failure value for that SIL. The example of a SRECS design covered by Annex B of IEC 62061 illustrates this concept.

Comparing SILs and Categories

58. The fact that categories in EN 954-1 and SILs in IEC 62061 both share allocated numbers 1 to 3 does not mean that there is a direct relationship between them. Both standards are written from different perspectives and so SILs and Categories are not comparable measures. Categories are not to be assumed as hierarchical measures for all applications" with "a hierarchical measure across technologies, whereas SILs are hierarchical because they relate to probabilities of failure.

59. A safety-related control system comprised entirely of components meeting the requirements of EN 954-1 category 4 may reasonably be expected to meet the target failure value (probability of dangerous failure of the SRCF per hour) associated with SIL 3 . However, no assumption should be made about the target failure measure achieved by safety-related systems which include components to EN 954-1 categories B, 1, 2 or 3, because EN 954-1 has no quantified requirements on the likelihood of dangerous failure for these categories. Whereas the category of a safety-related control system relates chiefly to its structure, and therefore its hardware fault tolerance, its SIL is based on its probability of dangerous random hardware failure and the constraining effect of the maximum SIL Claim Limit (see para. 57).

60. For low complexity subsystems that have been designed in accordance with EN 954-1 and validated in accordance with ISO 13849-2 (effectively part 2 of EN 954), IEC 62061 provides a methodology for integrating them into a SRECS. The Category, Safe Failure Fraction[10] and Diagnostic Coverage[11] of the subsystem are used to derive a maximum SIL Claim Limit based on architectural constraints only, and a threshold value for probability of dangerous failure. Consideration of the systematic safety integrity aspects enables an overall maximum SIL Claim Limit to be determined.

61. This maximum SIL Claim Limit based on architectural constraints is a function of the category (hardware fault tolerance) and Safe Failure Fraction combination, whilst the threshold value for probability of dangerous failure is determined by the combination of category (hardware fault tolerance) and Diagnostic Coverage. Consideration of the systematic safety integrity aspects enables an overall maximum SIL Claim Limit to be determined, which in conjunction with the probability of dangerous failure indicates the SIL for a complete safety-related control system.

62. The Performance Levels used by ISO 13849-1, which are derived in part from EN 954-1 categories, will be more comparable with SILs, as they are both quantitative and hierarchical measures of performance.

Safety Functions and Detailed Requirements for Amusement Devices

[10] Fraction of the overall failure rate of a subsystem that does not result in a dangerous failure.
[11] Percentage decrease in the probability of dangerous hardware failures resulting from the operation of the automatic diagnostic tests.

Stop and associated functions

63. When necessary (as decided by the risk assessment) the safety-related control system should provide the facility for, safety stopping and emergency stopping of the amusement device. Operational stopping, for example for loading and unloading passengers, is implemented by the primary control system

64. Stop functions should have priority over related start functions.

65. Stop functions may be provided in separate systems or in a single system depending upon the risk.

Safety stop function[12]

66. This function is intended to avert actual or impending danger and may be activated either manually or automatically. It should stop the relevant parts of the amusement device so as to reduce the overall risk to an acceptable level as quickly as possible.

67. A safety stop function should override operational stop functions but not emergency stop functions.

68. After a safety stop has been initiated, a restart may not take place until the cause for the stop has been removed.

69. The relevant parts of the amusement device should reach standstill in the shortest time commensurate with avoiding hazardous conditions with due regard to all safety requirements including:

(a) general integrity of the machine and structure;

(b) safe accommodation of passengers; and

(c) decelerations.

Emergency stop function

70. Provision should be made, where indicated by the risk assessment, for a manually initiated emergency stop. The emergency stop should conform with the requirements of EN 418 and should function as either a stop category 0 or stop category 1 as defined in EN 60204 -1, depending upon the outcome of the risk assessment.

(a) A category 0 stop is caused by immediate removal of power

(b) A category 1 stop is a controlled stop with power available to the machine actuators to achieve the stop and then automatic removal of power when the stop is achieved.

71. Manual emergency stop actuators should be placed in positions that are easily accessed by appropriate operators, attendants, maintenance personnel, and in some circumstances passengers, who may need to stop the device for safety reasons.

72. Subject to risk assessment and operational considerations, the amusement device should reach standstill in the shortest time commensurate with avoiding hazardous conditions with regard to all safety requirements including:

(a) general integrity of the machine and structure;

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[12] In some applications, a safety or emergency stop may result in such problems as difficult recovery of passengers and / or restart. If a stop could arrest the ride in other than the normal operating stop position, means should be provided, e.g. by fixed platform, so that the passengers may be disembarked safely

(b) safe accommodation of passengers; and

(c) decelerations.

73. After an emergency stop has been initiated, a restart may not take place until after the cause for the stop has been removed. An emergency stop may be over-ridden to allow the safe recovery of passengers by trained personnel who should follow a safe system of work, but this should not allow the ride to be operated in normal operational mode while the recovery operation is taking place

Other safety functions

74. Single mechanically-actuated sensing devices (e.g. limit switches) on interlocking and / or monitoring systems should be actuated in the positive mode or where this is not reasonably practicable be monitored so that any failure that may lead to danger is detected and acted upon to ensure safety as determined by risk assessment.

(a) Subject to risk assessment, unmonitored negative mode devices should not be used.

(b) The risk assessment may also determine that positive mode switches may still need to be monitored so that any failure that may lead to danger is detected

75. Where the risk assessment shows it to be necessary, interlocking and monitoring devices should be selected and positioned so that they are not easily or accidentally defeated or interfered with by persons riding in or on the amusement device.

76. In block zone systems any paired (providing redundancy) sensors should normally be configured so that:

(a) For entry to the block either one sets the block as occupied (OR in logic terms).

(b) For exit from the block both are required to reset the block to free (AND in logic terms).

77. The designer should specify, for inclusion in the Operations Manual, the limits of any adjustments and any necessary checks and / or tests needed to confirm the correct adjustment and operation of the interlocking and / or monitoring system.

Safety related parameters

General

78. Means should be provided to ensure that the values of the safety related parameters stay within predetermined levels defined by the risk assessment. A safety-related parameter is a variable which may be adjusted manually or as part of normal operation and which, if it moves outside predetermined boundaries, may lead to danger.

Speed

79. Speed is an important safety critical parameter for amusement devices where accelerations, and consequently forces, are dependent on the speed of amusement ride elements. Therefore, speed control can prevent hazardous effects on structures and passengers.

80. The following speeds should be considered.

(a) **Minimum operational speed:** The minimum speed necessary to ensure, for a stated operational condition, the safe containment of passengers and the intended function and the integrity of the amusement device.

(b) **Normal operational speeds:** Speeds at which the device will normally run and which will be between the minimum operational speed and the maximum operational speed. The speed may vary during the ride cycle.

(c) **Maximum operational speed:** The maximum speed at which, for a stated operational condition, the safe containment of passengers and the intended function and the integrity of the amusement device are ensured during repeated or sustained use.

(d) **Maximum achievable speed:** The maximum value of speed achievable by an amusement device element, without any restriction of control.

81. For a particular part of the ride cycle there may be different operating speeds. In particular, subject to the penultimate sentence of this paragraph and paragraph 54 below, the following safety functions should apply to prevent the amusement device operating outside the design parameters.

(a) The control system should control the speed between the minimum and maximum operational speeds for that part of the ride cycle.

(b) If the device either fails to achieve a minimum operational speed after a predetermined time, or the speed falls below the minimum operational speed, then the control system should perform a safety stop.

(c) If the speed of the device rises above the maximum operational speed, then the control system should perform a safety stop.

In some cases, risk assessment may show that one or more of these safety functions is not required. In others, it should be used to justify the safety category or safety integrity level.

82. The risk assessment should evaluate the effects on the structure and/or machine and passengers due to any achievable speeds.

83. If the maximum achievable speed is lower than or equal to the maximum operational speed, the control system does not require additional speed limiting circuits. But if the maximum achievable speed is greater than the maximum operational speed, taking into account foreseeable fault conditions, additional means may be necessary to ensure that the maximum operational speed is not exceeded. Also if the machine does not reach, or falls below, the minimum operational speed, additional means may be needed to ensure that the minimum operational speed is achieved or a safety stop is performed.

84. In some amusement devices (e.g. those in which a multiple passenger unit is made to swing and/or rotate about a horizontal axis) the instantaneous positions, speeds and accelerations may be very dependent upon the design of the control circuits. Full details of control, including feedback characteristics, need to be available for use in the stress analysis.

Passenger restraint device status and behaviour

85. Where a control system is involved in the operating, interlocking or monitoring of passenger restraint devices, its safety function and required safety integrity should be determined from the risk assessment.

86. Guidance on the principles for the design and selection of interlocking devices is published in EN 1088, and guidance on their incorporation into safety related control systems is also available in BS PD 5304. These two standards relate specifically to guarding of machinery. However they do contain some useful advice applicable to interlocking systems on amusement devices. Interlocking systems are not always necessary, appropriate, or practical to be installed on an amusement device.

87. The following guidelines should be taken into account. Any departures from these guidelines should be detailed and justified in the risk assessment.

(a) Positioning for starting

i. Closure and locking of restraints should be confirmed either by personnel or automatic systems before starting the ride cycle.

ii. This confirmation need not be automatic.

(b) Enabling of release

i. Control systems should not allow the release of the restraint devices unless it is safe to do so or unsafe not to do so.

(c) Alarms and warnings

i. Where an operator relies on audible alarms or visible indications as evidence that restraint devices are locked in the closed position, such alarms or indications should have the necessary safety integrity as indicated by the risk assessment in accordance with Chapters 1 and 10 of this Guidance.

(d) Loss of power supply should not:

i. allow the automatic release of restraint devices unless such release would not endanger the passengers or a suitable system of work is in use to ensure passenger safety.

ii. prevent the intentional release of restraint devices when required to ensure the safety of the passenger or for operational purposes, e.g. manual release.

(e) Monitoring of position

i. The need for the monitoring of the position of passenger restraint devices and their interlock latches should be determined by the risk assessment in compliance with Chapters 1 and 10 of this Guidance.

Inhibiting or bypassing of safety functions

88. The inhibiting or bypassing of safety functions should not result in any person being exposed to hazardous situations. When safety functions are inhibited or bypassed, safe conditions should be provided by other means. Removal of inhibits or bypasses should result in all safety functions of the safety-related parts of the control system being automatically reinstated.

89. If it is necessary to manually suspend safety functions, e.g. for set up, adjustments, maintenance, and repair, the following criteria should be applied:

(a) reinstatement of the safety functions of the safety-related parts of the control system before normal operations can be continued;

(b) effective and secure means to prevent manual suspension in those operating modes where it is not allowed;

(c) depending upon the risk assessment, consideration should also be given to the provision of a mode selection device or means capable of being secured (e.g. locked) in the desired mode so as to prevent automatic operation. In addition, consideration may need to be given to the provision of one or more of the following:

   i. initiation of motion by a hold – to - run device or by a similar control device;

   ii. a portable control station (e.g. pendant) with an emergency stop device and, where appropriate, an enabling device. Where a portable station is in use, motion may be initiated only from that station;

   iii. limitation of the speed or the power of motion.

Control modes

90. Control systems should have one or more control modes relevant for their application. Control modes can be divided into:

(a) pre-operating modes (without passengers) such as for setting, adjustment, programming, testing, cleaning, maintenance, trouble shooting and repair;

(b) operating modes such as manual, semi-automatic and automatic cycle, for operation with passengers. There may be variations and combinations of operating cycles;

(c) non operating modes where the pre-operating or normal operating mode is not possible due to abnormal circumstances.

Change of control mode

91. A change of control mode should not cause a hazardous condition. It may be necessary to:

(a) bring the ride to a stop, requiring an operator start command to restart the ride, following a change of control mode;

(b) prevent inadvertent change of control mode, including unexpected start-up; or

(c) bring a change of control mode to the attention of the operator.

92. The following requirements should also be adopted where necessary:

(a) the appropriate mode selector should be so located that it can be operated safely;

(b) when a hazardous condition can result from a mode selection, such selection should be prevented by suitable means (e.g. key operated switch, access code);

(c) mode selection by itself should not lead to initiation of motion of any passenger unit – a separate action should be required;

(d) safeguarding should remain effective for all operating modes;

(e) indication of the selected operating mode should be provided (e.g. the position of a mode selector, the provision of an indicating light, a visual display indication).

Pre-operating mode

93. When in pre-operating mode the amusement device should operate only by a

separate action of the operator. The following conditions should be met:

(a) An authorised person should be in overall control.

(b) Depending on the risk assessment, the control of more than one subsystem which could cause a hazard should either be prevented by the safety-related control system or be under the sole control of a single operator.

(c) Depending on the risk assessment, safety functions should either continue to operate or be under the sole control of a single operator.

(d) All system emergency stops should remain effective.

Operating modes

94. There may be more than one operating mode. The amusement device should operate only after an initiation by the operator or under his supervision.

95. These modes are the only control modes which are allowed for normal operation with passengers, and all the safety functions should be in use.

96. In general, operating modes can include:

(a) manual, if all operating cycles are under the control of the operator;

(b) semi-automatic, if part of the operating cycle is controlled by means of one or more automatic program;

(c) automatic, if all operating cycles are controlled by means of one or more automatic program.

97. In operating modes, the following requirements should be met;

(a) The cycle should be initiated by the operator apart from special cases, such as continuous loading and unloading, and providing the risk assessment allows it;

(b) Means should be provided if necessary to prevent the ride time exceeding a predetermined value based on passenger discomfort;

(c) The selection of other operating modes or programs should not cause a hazard;

(d) During passenger loading or unloading mode, when the ride is at rest, it should not be possible for the ride to start, or move inadvertently, unless the operator has signalled the control system to do so. The required safety integrity level of this safety function should be determined from the risk assessment.

(e) Amusement devices in which loading and unloading occur without the device coming to a stop should be provided with a built-in device or procedures to ensure that the operator maintains his supervision of the ride. The speed of the device during loading and unloading should be treated as a safety-related parameter.

Non-operating mode

98. The amusement device, either whole or in part, is considered to be in a non-operating mode if, for example, any of the following occurs:

(a) Loss of power

(b) Restoration of power

(c) Actuation of an emergency stop

(d) Initiation of a safety stop

99. The safety related control system should ensure that:

(a) at any point in time, the state of the amusement device in non operational conditions does not lead to a hazard; and

(b) any safety critical parameters and data in the control system (preset or otherwise) should be maintained even during the course of operation resulting from safety or emergency stop or an equivalent event. If this is not possible, alternative means should be specified in order to ensure safety.

100. During the slowing and the stopping of the ride:

(a) a safe sequence of events should be followed; and

(b) the constraints set by the minimum operational speed and/or deceleration forces, applicable at the time, should be complied with.

101. Where loss of power could result in a dangerous condition, a reserve of energy should be available to provide the power necessary to enable the ride to be brought to rest and remain at rest, or other means should be provided to ensure safety.

102. Any reinstatement of power after a power loss should not automatically restart the ride without a command by the operator.

103. In the non-operational mode the following conditions should be met in addition to those required for the pre-operating mode:

(a) Operations, whose combination could simulate the operating mode or could lead to hazardous conditions, should be allowed only in confirmed discrete steps by the safety-related control system. Suitable means should be provided to ensure that each separate operation is deliberately actuated.

(b) Notwithstanding a) above safety functions should remain effective in those operations where, if overridden, a more hazardous condition could occur.

(c) If the only way to recover passengers is to use the built-in override of a safety function, this special procedure should be performed by an authorized operator and be visually monitored either by that operator or by a subordinate in good communication with him.

Collision prevention by control systems

104. Where required by a risk assessment a means of preventing unintentional collisions should be provided. An example of such means, a block-zone system, is provided.

Block-zone control system

A block-zone control system consists of the partial or complete subdivision of the ride circuit into sections, called block-zones, each of which should not be occupied by more than one passenger unit or train at the same time, except as allowed below.

The number of block-zones into which the ride circuit is subdivided should be sufficient to prevent unsafe collisions. In some devices dependent on the risk assessment more than one passenger unit may be allowed into, or to overlap into, one or more of the block-zones with safety being assured by other means. For example, speed may be restricted and / or buffering may be provided to allow passenger units to come into contact with each other at station areas or immediately before a lift in a log flume.

A block-zone control system normally includes the following elements:

- a means of signalling the occupied status of a block-zone e.g. occupancy sensors;
- a means of signalling the clear status of a block-zone (clearance sensors);
- control logic;
- devices which can stop the passenger unit when necessary within the required distance to prevent collisions (e.g. stopping devices).

Subject to risk assessment, the control system should perform a safety stop in the case of equipment failure which could lead to an increase in the risk to passengers; e.g. the failure of one out of a set of redundant sensors, or loss of power. The risk assessment should determine whether it is safer to allow unaffected passenger units, such as those ahead of a failed sensor, to carry onwards to a suitable disembarkation point, or even the normal disembarkation point.

On restoration of power (including electrical, hydraulic or pneumatic), if there is no automatic system to ensure the safe restart of block-zone operation, the system should prevent the opening of brakes or the initiation of movement except under a manual system of work. If an automatic restart is provided, it should be initiated manually.

In any block-zone, clearance sensors should be so located that if the passenger unit stops for any reason as soon as it leaves the block-zone, the following unit should be prevented from colliding with it even if stopped in the most unfavourable condition possible.

Sensors should be so located and / or control logic designed such that a block-zone is recognised as occupied before the previous block-zone is cleared.

Requirements for stopping devices

105. All brake or stopping systems should conform to the following requirements:

(a) The total required number of stopping units within a group should be determined by risk assessment.

(b) For a group of redundant brakes or stopping units, loss of power from or component failure of any brake or stopping unit, or a defined number of units as decided by the risk assessment, should not reduce the ability of the remaining stopping units within the group to bring a passenger unit to a safe halt.

(c) Stopping devices should be located so that, after a stop, the passenger unit, in normal conditions, can be restarted safely.

(d) The brake system should operate, when demanded to do so for safety reasons, within a time that will enable a ride to be brought to a halt within the required distance, no matter what the environmental or operational conditions.

(e) The control of final actuating systems of stopping devices (whether electrical, electronic, mechanical, pneumatic or hydraulic) should either:

i. cause the passenger carrying device to stop within safe limits in their de-energised state; or

ii. if any elements are energised to cause the stop, then an adequate level of safety should be provided by means such as redundancy and/or diversity.

106. Powered lifting or shifting devices may be used as stopping devices under the following conditions:

(a) The device should have the ability positively to halt the passenger unit or train in such a position that it is not possible for any external influence such as environmental conditions or change in load to cause it to continue.

(b) The device should be de-energised by suitable means, such as contactors, and the passenger unit or train effectively should be prevented from reversing in a dangerous manner by an anti-rollback device.

(c) An electronic device may be used to bring any device or motor speed to zero. However, if the speed does not reduce to zero within a safe distance, or if the electronic device restarts, then the supply to the final actuator or motor should be physically interrupted, e.g. by means of contactors, or other diverse means.

(d) The device, as well as any control circuits, whether electrical, electronic, pneumatic or hydraulic, should either:

i. cause the passenger carrying device to stop within safe limits in de-energised states, or

ii. if any elements are energised to cause the stop, then an adequate level of safety should be provided by means such as redundancy and/or diversity.

107. When a device is used to trim the speed of the passenger unit or train and also as a stopping device and if the trimming or stopping function has safety implications, then the sensors, control logic and the devices should be considered as part of the safety-related system and treated accordingly. In cases where trimming has no safety implications this part of the control system need not be safety-related.

Relevant Standards & Other Publications

EN 418	*Safety of machinery: Emergency Stop Equipment.*
EN 954-1	*Safety of machinery – Safety Related Parts of Control Systems Part 1: General Principles of Design*
ISO 13849-2	Safety of machinery – Safety-related parts of control systems – Part 2: Validation
PD CR 954-100	*Safety of machinery – Safety-related parts of control systems – Part 100: Guide on the use and application of EN 954-1:1996*
EN 1050	*Safety of machinery – Principles of Risk Assessment.*
EN 1088	*Safety of machinery – Interlocking devices associated with guards. Principles for design and selection*
PD 5304	*Safe use of machinery.*
EN 60204-1	*Safety of machinery – Electrical equipment of machines. Specification for general requirements*
IEC 61508	*Functional safety of electrical / electronic / programmable electronic safety-related systems*
IEC 62061	*Safety of machinery – Functional safety of safety-related electrical, electronic and programmable electronic control systems*

Chapter 10

Passenger Units and Containment

General principles

1. The passenger units[13] should be designed to contain safely all passengers for whom the Operations Manual states that the ride is suitable. To achieve this the designer needs to specify the target population for the ride, e.g. maximum and minimum size / weight and other physical limitations.

2. The sizing criteria for passengers should be such that they can be measured and distinguished easily by the ride attendants with minimal or no ambiguity.

3. The designer needs to provide secure and safe accommodation for passengers at all stages during the ride cycle and foreseeable emergency situations e.g. the application of emergency brakes.

4. Safe and secure accommodation includes minimising the risk of injury from the following causes:

(a) physical injury within the confines of the passenger unit

(b) injury due to forces that result in adjacent passengers being pushed together

(c) moving[14] into a position of danger, i.e. from where there is an unacceptable risk of passengers falling or being injured by contact with static or moving parts

(d) injury on boarding or leaving ejection

(e) injury from powered restraints

5. Some of the potential risks are discussed in the following paragraphs.

Passenger Accelerations

6. The accelerations and higher derivatives of velocity experienced by the target passenger range needs to be calculated by the designer and subsequently confirmed by measurement. Bearing in mind that there can be significant variations from passenger to passenger (e.g. according to position in a roller coaster train), it may be necessary to carry out these calculations and measurements for head, stomach and foot positions for each passenger, in each seat, of each car.

7. The variations of acceleration over the ride cycle should be such that they do not cause significant nausea, skeletal injury, etc.

Safety Envelopes

8. The design should specify the "safety envelopes" for the ride i.e. the minimum spaces around the moving parts necessary to prevent any part of a passenger or spectator from coming into contact with anything that could cause injury. This could be a moving part

[13] Passenger unit - Any car, carriage or other fixture, on which a person sits, stands, etc., being part of an amusement device.

[14] Whilst the above is intended primarily to deal with involuntary or unintentional movement, risk assessment may demonstrate the need for measures to control foreseeable, intentional movement.

of the ride or a stationary part which is too close to a moving part, e.g. barriers and items of themeing. The most important envelope to consider is that around the path of the passenger units.

9. The dimensions of safety envelopes should be based on anthropometric data, taking into account the style of containment. An example demonstrating changes in reach distances in relation to containment is given below. Where appropriate, the envelopes should be based on dynamic rather than static measurements since passengers or spectators may try to reach towards places of danger.

10. The type of object that is likely to be collided with may also alter the risk, as for example an extended hand or finger coming into contact with a soft or rounded structure might present a lower level of hazard than the same extremities colliding with a sharp or square object. The collision speed will also be a factor in determining the risk of injury.

11. Whenever design situations involve a real risk of injury and depending on the findings of a risk assessment, the extreme percentile dimensions indicated by anthropometric data may be used to calculate safe clearance envelopes.

12. Additional safety tolerances may also need to be added to the bare reach distances to ensure absolute clearance.

13. As examples of extreme percentiles (99.99th %iles) that might be used given the risk of an irreversible injury, and with no mitigating control measures the following anthropometric data may be useful.[15] These measurements do not contain any added safety tolerances as suggested in paragraph 10 above.

(a) Overhead fingertip reach – sitting (from base of seat to highest reach point)

   i. 99.99th %ile 1626 mm

(b) Sideways fingertip reach – Shoulder[16] (acromion) to furthest reach point sideways

   i. 99.99th %ile 930 mm[17]

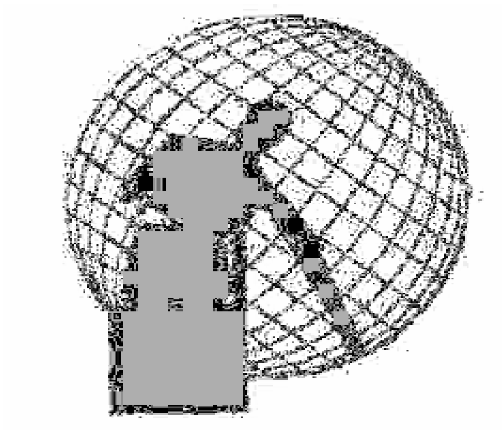
Unrestrained upper body, **raised seat side**.
Reach envelope for adult leaning over

Example as used in para. 11(b) page 72

[15] US adults 18 to 64 – PeopleSize 2000 - Open Ergonomics Ltd.

[16] Due to scarcity of relevant anthropometric data the measurement given here is from the acromion (the bony tip of the shoulder) rather than the underarm.

[17] This measurement assumes no unrestrained ability to reach further out due to low seat sides.

	Unrestrained upper body, **low seat side**. Reach envelope for adult leaning over

Examples of dynamic anthropometry reach envelopes given differing seat arrangements (These examples are not to scale)

Counterweighted Passenger Units

14. Where parts of the moving structure have counterweights to balance the passenger units, the designer should make sure that the passenger unit cannot move under the action of the counterweight unless it is safe to do so. This is likely to involve provision of suitable parking brakes and may involve interlocking.

Passenger Containment

15. The containment system shall be designed around the target passenger population. The designer shall consider how the following factors could affect passenger safety:

(a) **static factors** - the relationship between the dimensions of the passenger and the dimensions of the containment system

(b) **dynamic factors** - the relationship between the forces imposed on the passenger by the ride motion and the voluntary and involuntary responses of the passengers to those forces

(c) **psychological factors** - the passengers' likely perceptions of the ride and responses to it. As well as normal use, passenger behaviour which could reasonably be expected should also be considered[18]

16. In specifying the form of the containment the designer needs to :

(a) determine the size and direction of forces which will be exerted by elements of containment on the passengers (and vice versa)

(b) assess the risks arising from the forces

(c) identify the parts of the passengers' bodies which require support for each

[18] The following footnote is based on an extract taken from *Community legislation on machinery – Comments on Directive 98/37/EC; 1999 Ed: European Commission*
The designer is required to foresee only "reasonable" situations, i.e. based on logic, rational usage, and common sense. In any event, the concept of "reasonably foreseeable" precludes the irrational (e.g. drying the cat in the microwave). The foreseeability of the danger includes evaluating the complexity and plausibility of the combination of circumstances which would need to occur for the potential of harm to be realised. Consideration will need to be given to foreseeable situations in which the passenger's expected actions, as a result of not being able to fully perceive the danger, may expose him to an increased risk

anticipated force

(d) using body size data appropriate to the target population[19], identify the maximum and minimum dimensions of the containment system necessary to contain passengers safely.

(e) lay out the design so as to contain safely all passengers who will be permitted by the Operations Manual to use the ride.

17. Any component that plays a role in directly protecting a riding passenger from the hazards identified in paragraph 3 (above) shall be considered part of the containment system. The following examples should be taken into account along with any others that might present a hazard:

(a) Loads resulting from passengers bracing themselves when designing passenger restraints and other parts of the containment (e. g. footrests), railings and bracing devices within the passenger unit.

(b) The potential for injury due to inertial forces that result in adjacent passengers being forced together. This could be particularly likely in the case of rotating equipment and exacerbated by inappropriate (i.e. low friction) seat materials

(c) All significant situations during the ride cycle including loading, unloading and emergency situations. The magnitudes of maximum bracing forces are dependent upon the detailed design of the containment.

18. All passengers within the size limits specified in the Operations Manual shall be able to reach comfortably all parts of the containment system necessary for their safety. Typical parts and their requirements are :

(a) **seating** - shall be based on ergonomic criteria and provide support for all body parts susceptible to injury

(b) **footwells** - shall permit all passengers to brace themselves using their feet where the risk assessment shows this to be necessary

(c) **grab-rails** -shall be suitably designed and positioned for use by the target population. Where a risk assessment shows that there is a foreseeable risk of injury caused by contact with the grab-rail (e.g. during an emergency stop), the designer should consider the need for re-design, padding or restraints

(d) **head rests or head restraints** - appropriate to the ride motion should be included in the design where there is a foreseeable risk of whiplash injury

(e) **restraint systems** - shall be designed as an integral part of the containment system.

19. Where passengers ride in a sitting position, the seat is one of the most important parts of the containment system. Besides considering the size and shape of the seat, the designer should consider carefully the materials to be used for the surface.

(a) Hard materials, e.g. fibreglass, wear well but offer little comfort or protection to the passenger. Also they often have a smooth surface which provides minimal friction between the passenger and the seat. This can allow passengers to slide on the seat as the unit changes direction.

[19] Tables 10.1 to 10.3 indicate some of the important dimensions. Published anthropometric data for children is based on age, while it is normal to restrict use of amusement rides on the basis of passenger height. British data converted to a height basis is given in Table 10.4

(b) Hard finishes should only be specified if they do not put passengers at significant additional risk. If they are specified, the designer may need to consider techniques for reducing the likelihood of passengers sliding.

20. On rides carrying standing passengers the designer should take account of how the passengers are to be contained e.g.:

(a) standing and restrained

(b) standing and unrestrained

(c) held in place by ride forces

21. Depending on the containment requirements for standing passengers, the designer may need to take account of:

(a) the positions of passengers' centres of gravity

(b) the forces they are subjected to and the reaction forces they are expected to exert

(c) their gripping reach.

22. Where the risk assessment shows it to be necessary, the containment should be designed to prevent ejection and to prevent passengers from being able to move bodily about on the device except where it is stationary or where there is a clear intention for the passengers to move. Under such conditions the design should ensure that risk of injury is low and ample bracing and handholds should be provided.

23. The designer should ensure that he provides adequate information about the height (or other) limits on which the risk assessment and the design of the containment system are based. This will need to be included in the Operations Manual supplied with the ride.

Structure of passenger units

24. The design should specify how the passenger units will be secured to the main part of the device and demonstrate that the attachment will be strong enough to withstand the forces and moments which will be imposed. Where the risk assessment has identified the need for a secondary means of holding the unit if the main attachment fails, it is necessary to demonstrate that this secondary attachment is capable of withstanding the loadings (including "snatch" loadings) which may result from the failure of the main attachment.

25. Every passenger unit should be strong enough to withstand the forces imposed. It is normally reasonably pessimistic to ignore plastic or composite materials and base structural design calculations on the underlying steel framework. However, the localised strength of such shells may still need to be assessed.

26. All equipment involved in passenger containment, including bars, belts, harnesses, handholds, footrests, locks, catches, hinges and other attachment points should be of good construction and adequate strength to withstand the forces likely to be placed upon them by passengers (for example when bracing themselves) as well as by the ride forces.

27. All parts of the containment system should be free from sharp edges, projections and obstructions. Fixtures and fittings should not cause injury e.g. armrests should be smooth and continuous with the rest of the seat wherever possible.

28. Appropriate padding should be used on any part of the containment system against which the passenger may be forced by the motion of the ride to the extent that is necessary to adequately control the risk. This particularly needs to be assessed in relation to fittings

which may also benefit from careful positioning and adjustment.

29. Materials which will not become dangerous in use, e.g. through splintering, are preferred for passenger units. This is particularly important on slides where the whole running surface forms the passenger unit. The alternative is expensive inspection and maintenance programmes which the designer should specify.

30. Any running gear (e.g. wheels, rollers etc.) should be designed to absorb all forces likely to lead to derailment or lift-off. Devices to prevent lift-off should be designed to support loads equal to at least 50% of the fully loaded unit unless calculations indicate that greater forces or fatigue may be involved.

Passenger restraints

31. Normally the following principles will apply to the provision of passenger restraints on new rides.

(a) Where the risk assessment indicates that a restraint is required, it should be of appropriate design and construction (see Figure 10.2), with safety critical components accessible for maintenance.

(b) Where the risk assessment indicates that a restraint is required, there should be confirmation of safe closure, by personnel and / or by automatic systems.

(c) Where the risk assessment shows it to be necessary, the release should not be operable by the passengers unless the ride is in a suitable state for disembarkation. (This permits those catches which can be opened by passengers only when the unit is stopped in the unloading position)

i. The principle in the above may be achieved by releases which are shrouded, out of reach, or remote (e.g. electrical).

(d) The risk assessment should decide whether the restraint should be designed to be fail-safe open (or openable) or fail-safe locked. (For example, it is generally thought better, because of fire risk, for restraints to fail open, or openable, in the case of Ghost Train types in enclosed structures).

Restraint Construction

32. Some of the design / construction implications of the above may be :

(a) springs which have not been designed with infinite fatigue life;

(b) wear of latches and plungers;

(c) fatigue of restraint bars and other structural and mechanical components, for instance in the locking mechanism;

(d) short circuits and cross-talk in control systems.

Where there is a significant risk associated with these considerations the designer may be able to ensure safety by specifying an appropriate inspection and maintenance schedule consistent with the fatigue or wear lives of the components.

33. It is normally possible to estimate by measurement the maximum bracing forces which may be imposed on a restraint by the passengers and dynamic loadings will also be calculable. However, there is normally an absence of data on actual restraint force variations in service (needed for the assessment of fatigue). In this case it will be necessary for the

designer to:

(a) carry out testing to establish appropriate design loads; or

(b) otherwise justify design loads; or

(c) issue written guidance on the safe monitoring / inspection of relevant restraint components.

34. Anchor devices for seat belts and harnesses and the structures to which they attach should be designed to cater for the static and dynamic loads which will be imposed.

Restraint Closure/ Locking / Release

35. If human confirmation that a restraint is properly closed and secured is to be relied upon for safety then this should be clearly stated in the operating manual. The provision of appropriate training for attendants should also be recommended. It should not be forgotten that there may be some advantages to manual (rather than solely automatic) checking of closure. For instance, the attendant is effectively carrying out a functional test of the restraint every time a passenger rides.

36. It is important to assess whether an automatic system for checking restraint closure can provide a satisfactory level of confirmation and reliability. For manual checking, the designer should consider the ergonomics of the system to ensure that safe closure and locking can be confirmed readily by the attendant / operator.

37. If it is possible for a ride to operate with the restraints in unoccupied passenger units still open, then it must be confirmed that this does not present any hazard (e.g. protruding parts/ejected components) and that the device will not suffer damage in this configuration (e.g. due to higher than expected loads on unrestrained components)

38. A release should require a definite action by an operator or attendant to open it or if automatic operation is used, be interlocked with the ride control system, so that it opens only when it is safe for passengers to alight (e.g. in the station).

Other Restraint Design Issues

39. Restraints should be designed to be easily fitted to the passenger, comfortable in use and not likely to cause injury in normal operation or emergencies. Where a hazard may arise from ejection or movement of the passengers, the restraint should be capable of adjustment to suit each passenger, or there should be further individual adjustment devices provided on the restraint. Where it is designed to fit more than one passenger it should be able to safely contain any combination of passengers who are within the permitted size range.

40. Power operated restraints should not act with excessive force on any sensitive or fragile part of the body - forces exceeding 0.15 kN at the point of restraint application are normally undesirable. The restraint should retract in response to an obstruction before there is sufficient force to cause injury.

41. Powered restraints should not be used where there is a risk to passengers from fire unless another suitable means of escape is provided. There should be a means of opening in emergency e.g. power failure.

42. Restraint catches and locking devices should be designed not to work loose (e.g. as a result of vibration or the forces imposed by the ride) where a significant risk would result.

43. Seat belts or harnesses should

(a) if adjustable, have self-locking adjustments

(b) prevent passengers approaching a place of danger where a risk assessment shows this to be necessary

44. Guidance on the technical basis of conventional vehicle seat belt specifications may be found in Annex I of the European Directive 2000131EC and, for children, in UN-ECE Regulation 44.03

45. There may sometimes be more than one independent restraint (e.g. lap bar plus over- shoulder restraint). In such circumstances there may be a safety advantage in designing independent release mechanisms (and control systems) for the different restraints.

46. For rides on which there is a risk of the passenger unit stalling (e.g. with the passenger units steeply banked or even upside down), the restraints should be designed to prevent them falling. Alternatively, they may be fully enclosed in a cage. In this case, any restraint should protect them from normally coming in contact with the walls of the cage if this could lead to injury.

47. Designers should specify appropriate operation, inspection and maintenance instructions.

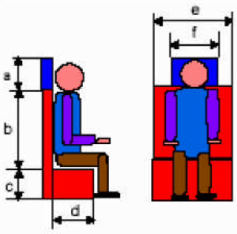
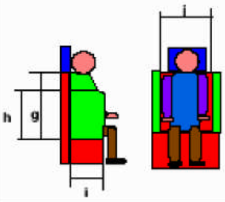
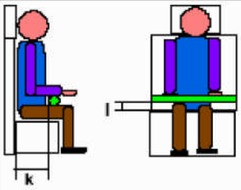
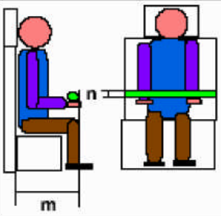
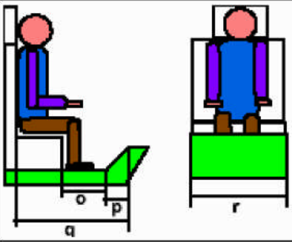
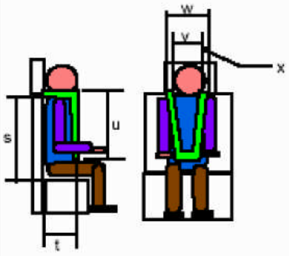
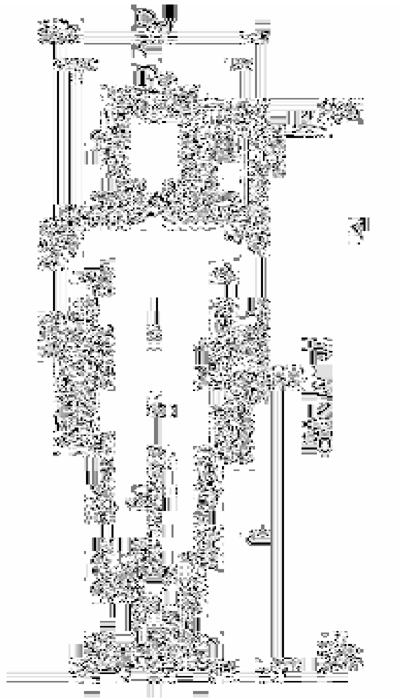
Table 10.1 Containment system components.			
Component			**Description**
Seating		a	head rest height
		b	seat back height
		c	seat pan height
		d	seat pan depth
		e	seat back width
		f	head rest width
		g	high side support height
		h	low side support height
		i	side support depth
		j	distance between side supports (per passenger)
Lap bar		k	distance from seat back to rear edge of lap bar
		l	distance from seat pan to lower edge of lap bar
Handrail		m	distance from seat back to front edge of handrail
		n	diameter of handrail
Footwell		o	length of horizontal floor from seat to front of car
		p	footrest length
		q	distance from back of seat to front edge of footrest
		r	footwell width (per passenger)
Over Shoulder		s	distance from seat pan to bottom edge of shoulder supports
		t	distance from seat back to back of trunk support
		u	trunk support overall length
		v	distance between inside edges of shoulder supports
		w	distance between outside edges of shoulder supports
		x	shoulder support width

Table 10.2 - Body dimensions and suggested ranges			
Measurement	Body dimension	Adjustable or not	Percentile range
a	Shoulder to crown	x	95th
b	Sitting shoulder height	x	95th
c	Popliteal height	x	5th
d	Buttock popliteal length	x	5th
e	Bi-deltoid	x	95th
f	Head width	x	95th
g	Sitting shoulder height (deltoid)	x	95th
h	g/2	x	95th
i	Buttock - popliteal	x	95th
j	Shoulder breadth (bi-deltoid)	x	95th
k	Abdominal depth	√	5th - 95th
l	Thigh clearance	√	5th - 95th
m	Forward reach	√ (x)	5th - 95th (50th)
n	Grip diameter	x	5th
o	Knee height	√	5th - 95th
p	Foot length, Heel ball length	x	95th
q	Hip height	x	95th
r	Foot breadth, hip breadth	x	95th
s	Sitting shoulder height	□(x)	5th - 95th
t	Chest depth	□	5th - 95th
u	Sitting shoulder height - thigh clearance	□(x)	5th
v	Head breadth	x	95th
w	Interacromion	x	50th
x	Shoulder length (to acromion)	x	95th

Table 10.3 Body Dimensions	
Measurement	**Body Dimensions**
a	Shoulder - crown
b	Sitting shoulder height
c	Popliteal height
d	Buttock - popliteal length
e	Shoulder breadth (bi-deltoid)
f	Head width
g	Sitting shoulder height (deltoid)
h	g/2
i	Buttock - popliteal length
j	Shoulder breadth (bi-deltoid)
k	Abdominal depth
l	Thigh clearance
m	Forward reach
n	Grip diameter
o	Knee height
p	Foot length, Heel ball length
q	Hip height
r	Foot breadth, hip breadth
s	Sitting shoulder height
t	Chest depth
u = b - l	Sitting shoulder height-Thigh clearance
v	Head width
w	Interacromion
x	Shoulder length (to acromion)
y	Thigh to toe length



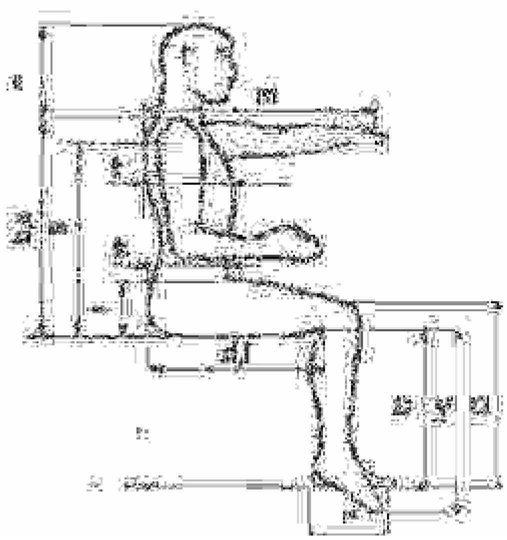


Table 10.4 - Body dimensions' associated with heights		Figures are 5th / 50th / 95th percentiles for British adults and children				
Measurement	Body dimension	Adult male	Height 1400	Height 1300	Height 1200	Height 1100
a	Shoulder to crown	265 / 315 / 365	242 / 262 / 282	237 / 256 / 275	235 / 252 / 269	225 / 240 / 255
b	Sitting shoulder height	540 / 595 / 650	435 / 460 / 495	400 / 430 / 460	375 / 400 / 425	350 / 375 / 400
c	Popliteal height	390 / 440 / 490	335 / 361 / 390	305 / 333 / 360	280 / 305 / 330	250 / 272 / 295
d	Buttock popliteal length	440 / 495 / 550	355 / 385 / 410	320 / 350 / 380	290 / 315 / 340	260 / 282 / 305
e	Bi-deltoid	420 / 465 / 510	290 / 335 / 380	280 / 325 / 370	250 / 288 / 325	240 / 273 / 305
f	Head width	145/155/165	132/146/160	130/145/160	123/123/123	123/123/123
g	Sitting shoulder height (deltoid)	540 / 595 / 650	435 / 460 / 495	400 / 430 / 460	375 / 400 / 425	350 / 375 / 400
h	g/2	270 / 298 / 325	212 / 230 / 248	200 / 215 / 230	187 / 200 / 213	175 / 187 / 200
i	Buttock - popliteal	440 / 495 / 550	355 / 385 / 410	320 / 350 / 380	290 / 315 / 340	260 / 282 / 305
j	Shoulder breadth (bi-deltoid)	420 / 465 / 510	290 / 335 / 380	280 / 325 / 370	250 / 288 / 325	240 / 273 / 305
k	Abdominal depth	220 / 270 / 320	145 / 185 / 220	135/175/215	135 / 160 / 185	135 / 155 / 175
l	Thigh clearance	135 / 160 / 185	95/117/140	90/113/135	75/ 95/120	72/ 93/114
m	Forward reach	835 / 890 / 945	545 / 580 / 620	500 / 540 / 580	475 / 508 / 540	435 / 470 / 505
n	Grip diameter	45/ 52 / 59	38/44/50	35/ 41 / 47	33/ 39 / 45	31 / 37 / 43
o	Knee height	495 / 545 / 595	415 / 445 / 475	380 / 410 / 440	345 / 370 / 395	305 / 330 / 355
p	Foot length, Heel ball length	240 / 265 / 290 170/190/210	194 / 218 / 242 151/168/184	185 / 210 / 235 145/160/175	165/187/210 140/155/170	155 / 173 / 190 130/148/165
q	Hip height	840 / 920 / 1000	690 / 740 / 790	630 / 680 / 730	565 / 613 / 660	500 / 540 / 580
r	Foot breadth, Hip breadth	85/ 95/105 310 / 360 / 410	77/86/95 210 / 255 / 300	75/ 85/ 95 200 / 245 / 290	65/ 75/ 85 185 / 217 / 250	62 / 70/ 78 180 / 207 / 235
s	Sitting shoulder height	540 / 595 / 650	435 / 460 / 495	400 / 430 / 460	375 / 400 / 425	350 / 375 / 400
t	Chest depth	215/250/285	125/165/200	115/155/195	110/140/170	110/135/160
u = b - l	Sitting shoulder ht. - thigh clearance	385 / 435 / 485	313 / 346 / 380	285 / 318 / 350	275 / 305 / 335	255 / 282 / 310
v	Head breadth	145/155/165	132/146/160	130/145/160	130/140/150	130/140/150
w	Interacromion	365 / 400 / 435	270 / 303 / 335	265 / 297 / 330	235 / 265 / 295	220 / 247 / 275
x	Shoulder length (to acromion)	145 / 170 / 195	127 / 150 / 174	120 / 145 / 170	115/140/165	110/133/155
y	Thigh to toe length	-/-/740	-/-/575	-/-/530	-/-/490	-/-/440

Grip diameter figures in row "n" and thigh to toe length in row "y" have been estimated only from data for adult males. Otherwise the Table values have been calculated from the age groups having average height nearest to the height to which the column relates. For methods used see 'Regression" and "Combination dimensions" on pages 60 and 61 in the Appendix of BSI PP7310.

Dimensions in mm, sources BSI PP7310 and "PeopleSize software, Open Ergonomics Ltd 1994-9". For example, the 5th percentile popliteal height associated with a height limit of 1200 mm would be 280 mm.

Relevant Standards and other Publications

European Directive 2003/3/EC	*Adapting to technical progress Council Directive 77/541/EEC relating to safety belts and restraint systems of motor vehicles.*
UN-ECE Regulation 44.03	*Uniform Provisions concerning the Approval of Restraining Devices for Child Occupants of Power-Driven Vehicles ("Child Restraint System")*
PeopleSize	*Software, Open Ergonomics Ltd 1994-9*
BSI PP7317, 1987	*ISBN0 580 15391 6*
Adult data	*The handbook of adult anthropometric and strength measurements - Department of Trade and Industry, Government Consumer Safety Research, 1998*
Child data	*The handbook of child measurements and capabilities - Department of Trade and Industry, Government Consumer Safety Research, 1995*

Chapter 11
Physical guards, barriers, fencing etc.

1. The design should specify the protection required from all dangerous parts of machinery, including transmission machinery. Further information is given in PD 5304, ISO 12100, EN 294, EN 349, EN 811, EN 953 and in the guidance to the Provision and Use of Work Equipment Regulations 1998 (abbreviated to PUWER).

2. Safeguarding of electrical equipment should comply with the Electricity at Work Regulations 1989, the Electrical Equipment (Safety) Regulations 1994 and relevant guidance. Workplaces should comply with the Workplace (Health, Safety and Welfare) Regulations 1992.

3. Where danger may occur from direct contact with live electrical parts the requirements of EN 60204 -1: 1998 paragraph 6.2 should be met.

4. Where a hazard exists, mechanical transmission machinery should be enclosed within guards or provided with other suitable means of preventing access while it is in motion.

5. A risk assessment should be made where the dimensions or arrangements of stairs, handrails, landings, ramps, or platforms cannot conform to relevant British or International Standards ref 5395. Slip-resistant surfaces should be considered, particularly for any parts which could become wet in use. [20]

6. Guidance on some aspects of barrier design, whether to protect against falls from height or against access to dangerous parts, is given in BS 6180. Although this relates to barriers in and about buildings, some of the advice may be useful for amusement devices.

7. Barriers, fencing or other measures needed to prevent access to dangerous parts should be specified where people may risk injury. Particular attention should be given to places where people could penetrate the safety envelope around moving parts of the device. Minimum barrier heights should be based on Table 11.1.

8. The design of stand alone fences round such rides as grass cutter Twist, Octopus, Big Wheel, should require the fence to be positioned so that, if it falls due to crowd pressure, persons will not fall into danger.

9. Every platform from which a person is liable to fall more than 600mm should be protected by a barrier (except at places where access is provided). The barrier should be at least 1000 mm high, securely fixed and provided with enough infilling to prevent people being trapped or falling underneath.

10. The design should provide for the safe evacuation of passengers including any stranded at remote positions. Barriers etc. on evacuation routes should comply with the preceding paragraphs and should be designed to meet the strength requirements in an appropriate category in Table 3.1.

[20] For further information see Chapter 1 – Risk Assessment and Appendix 1

Table 11.1								
Height above ground of the danger source, a	Height of the barrier, b							
	2400	2200	2000	1800	1600	1400	1200	1000
	Horizontal distance between barrier and danger source, c							
2400	-	100	100	100	100	100	100	100
2200	-	250	350	400	500	500	600	600
2000	-	-	350	500	600	700	900	1100
1800	-	-	-	600	900	900	1000	1100
1600	-	-	-	500	900	900	1000	1300
1400	-	-	-	100	800	900	1000	1300
1200	-	-	-	-	500	900	1000	1400
1000	-	-	-	-	300	900	1000	1400
800	-	-	-	-	-	600	900	1300
600	-	-	-	-	-	-	500	1200
400	-	-	-	-	-	-	300	1200
200	-	-	-	-	-	-	200	1100

Relevant Standards and Other Publications

ISO 12100	*Safety of machinery. Basic concepts, general principles for design.*
EN 294	*Safety of machinery. Safety distances to prevent danger zones being reached by the upper limbs.*
EN 349	*Safety of machinery. Minimum gaps to avoid crushing of parts of the human body.*
EN 811	*Safety of machinery. Safety distances to prevent danger zones being reached by the lower limbs.*
EN 953	*Safety of machinery. Guards. General requirements for the design and construction of fixed and movable guards.*
EN (IEC) 60204-1	*Safety of machinery. Electrical equipment of machines. General requirements.*

Chapter 12
Electrical systems

General

1. There are 2 principal Standards which contain recommendations of direct relevance to the electrical equipment in amusement devices and which form the basis of the guidance in this Chapter.

(a) The first standard is EN 60204-1. This harmonised European standard covers the safety-related aspects of electrical equipment of machines and is directly relevant to the electrical equipment used on amusement devices.

(b) The second standard is BS 7671 which sets out comprehensive standards for the design, selection, erection, inspection and testing of electrical installations. It is relevant to the power supply to, and power distribution systems on, amusement devices.

2. HSG175 deals with safe use of electrical equipment, at Fairgrounds and Amusement Parks, and contains some information relevant to designers.

Hazards and Risks Covered

3. This guidance is aimed at minimising the risk of injury from electric shock, burn, arcing and explosion, as well as protecting the equipment in the amusement device from the effects of overcurrent, overvoltage and similar disturbances. Typical causes of shock and burn injuries are shown in Table 12.1 below.

Table 12.1 Typical sources of shock injuries and burn on Attractions

Shock	Burn
Contact of persons with exposed conductive parts which have become live under fault conditions - "indirect contact"	Arcing of do supplies, e.g. at switches, terminals, etc Flashovers due to insulation failure Overheating leading to hot surfaces or fire (common causes are arcing and overloading)
Contact of persons with live parts - "direct contact" exemplified by:- • Live conductors exposed in damaged cables • Exposed live terminals • Live track (on ghost trains, dodgems etc.)	Contact with live conductors (electrical burns) Contact with surfaces that are hot under normal conditions (e.g. tungsten halide lamps or their surroundings)

Protection against Electric Shock and Burns

Prevention of Direct Contact

4. Prevention of injury by direct contact with live conductors energised at dangerous potentials [21] will generally be achieved by

[21] Live conductors above 25Vac or 60V ripple free dc

(a) covering the conductors with suitably-rated insulation which is protected against mechanical damage, or

(b) by placing the conductors in positions that will prevent them being touched, or

(c) by providing enclosures to prevent access to them.

5. It is foreseeable that access may be gained to any electrical enclosure on an amusement device by persons (e.g. operators / attendants) who do not have the required level of competence to ensure electrical safety. There are also extra risks, such as falls from height, or restricted access associated with the sometimes difficult access to panels on amusement devices which may also affect competent persons.

(a) In order to prevent injury by persons touching uninsulated live conductors inside the enclosures, equipment should be designed so that controls and devices which may need to be reset, such as circuit breakers and motor overloads, are readily accessible without exposing live parts which may be dangerous by, for example, putting these switches or controls in a separate enclosure with no live parts exposed or by using finger proof terminals and fully insulated conductors for all other items in the same enclosure.

6. Suitable measures to prevent direct contact with conductors energised at hazardous voltages may include a combination of

(a) components that have finger proof terminals (Ingress protection rating of IP2X as defined in BS EN 60529)

(b) conductors including busbars that are individually sleeved or insulated; or

(c) the placing of non-conducting barriers or shields (perspex, polycarbonate, etc.);

(d) interlocking the door of an electrical enclosure with an isolator so that the door can only be opened when the isolator is off and the isolator can only be turned on when the door is closed.

   i. All parts inside the enclosure that remain live after the isolator has been turned off shall be protected against direct contact to at least IP2X.

   ii. The interlock may need to be overridden to allow testing and fault finding work to be carried out, in which case the following provisions apply:

      a. defeating the interlock must only be carried out by electrically qualified personnel with the competencies required for undertaking live work; advice on this and the associated safety precautions must be contained in the instruction manual.

      b. it must be possible for the isolator easily and readily to be turned off while the interlock is defeated. It is preferable that, in addition, there should be an alternative means of isolation in the power circuit up stream of the enclosure in which the interlock is defeated.

   The above list is not exhaustive and reference may be made to Standards and other guidance material for further information.

7. If a screen or barrier is used to protect a group or number of items it should be designed in such a way that the switchgear and control gear that requires manual operation can be operated without the removal of the screen or barrier.

8. Designers should take steps to prevent foreseeable misuse of electrical equipment by, for example, providing robust locking facilities on enclosure doors and ensuring that equipment is of robust construction.

9. Where devices such as slip rings, live rails and pick-ups allow access to live exposed conductors they should be protected to a minimum standard of not less than IP2X except when rails,

conductive floors and ceilings are part of a Protective Extra Low Voltage (PELV) or Separated Extra Low Voltage (SELV) system.

Protective Extra Low Voltage (PELV) or Separated Extra Low Voltage (SELV)

10. PELV is defined in BS EN 60204-1 and both PELV and SELV are defined in BS 7671.

11. Sources for SELV must not have any connection between the output connections and any protective earthing circuit, even accidentally, and must have the maximum voltage restricted to 25 V a.c. or 60 V d.c. with a maximum ripple of 10% rms.

12. PELV sources are also restricted to a maximum voltage of 25 V a.c. or 60 V d.c. with a maximum ripple of 10% rms and they can only be used in dry locations and when large area contact of live parts with the human body is not expected, unless the maximum voltage is restricted to 6 V a.c. or 15 V d.c.

13. PELV sources have one side of the circuit connected to the protective bonding circuit therefore, in circumstances where it is foreseeable that faults may occur which can lead to the protective conductor becoming energised at voltages in excess of 25 V a.c. or 60 V d.c., SELV systems, are preferred.

14. The electrical risks, and recommended protective measures, associated with the operation of dodgems where voltages in excess of PELV and SELV are used are discussed in the specific annex.

Prevention of Injury by Indirect Contact

15. Precautions should be taken to prevent injury from exposed metalwork of the attraction becoming live under fault conditions at voltages and for lengths of time that may cause injury.

16. In a.c. systems this is commonly achieved by providing a system of earthed equipotential bonding and automatic disconnection of supply (EEBADS). This necessitates coordination between the type of electrical supply, the earthing system, the impedance of the different elements of the protective earthing and bonding system, and the characteristics of the devices such as fuses and circuit breakers used to detect excess of current and automatically to disconnect the supply.

17. Traditionally, many amusement devices with d.c. equipment have been supplied from generators which are not referenced to earth, i.e. where neither pole of the d.c. supply is deliberately connected to earth.

18. Key points for designers of attractions are

(a) There should be a terminal provided on the amusement device where the electrical supply is brought in to allow the circuit protective conductor from the source of supply to be connected to the bonding conductors which connect together all exposed conductive parts of the attraction.

(b) The minimum cross sectional area of the protective and bonding conductors should be selected according to the guidance in EN 60204

(c) Metallic structures of attractions and parts of attractions, including items such as pay boxes, chassis and frames, should be electrically connected (bonded) together.

(d) Bolted or similar mechanical connecting methods on the rides and / or structures may be used to provide continuity of the bonding conductor, provided that these mechanical connectors do not contain any insulating insert and are tight and free of corrosion.

(e) The conductivity of these parts of the ride and / or structure should be verified on initial manufacture and, if necessary, additional bonding conductors should be provided. Where the electrical risk justifies it, flexible conductors should be used to connect across discontinuities such as slotted joints, hinges and pins.

(f) Where slip rings are used to transmit power, an earth slip ring should be provided and used; bearings are not suitable for this purpose

(g) Where protective devices such as HRC fuses and circuit breakers are used to provide automatic disconnection on attractions that use the EEBADS technique, they should be installed and rated to ensure that

i. fixed equipment is disconnected from the supply under short circuit and earth fault conditions, in a disconnection time not exceeding 5 secs; and

ii. portable and handheld equipment is disconnected in a time not exceeding 0.4 sec.

(h) The excess current circuit protection should be installed in

i. all phase conductors of referenced a.c. systems;

ii. the live conductor of 2-pole referenced d.c. systems; and

iii. all live conductors of unreferenced a.c. and d.c. systems but not circuit protective conductors.

19. As an alternative to earthed equipotential bonding and automatic disconnection, amusement device designers may provide protection by

(a) the use of Class II equipment with double or reinforced insulation; or

(b) the use of electrical separation and PELV / SELV systems.

Residual Current Devices

20. For supplementary protection against electric shock on a.c. systems the designer should specify a residual current device (RCD), with a maximum sensitivity of 30 mA, no adjustable time delay, and disconnection time not exceeding 40 ms for a residual operating current of five times the sensitivity rating (i.e. for a 30 mA RCD this would be 150 mA) on earth-referenced systems supplied at a voltage exceeding 100 V a.c., which in turn supply:

(a) circuits which are likely to be used to supply portable equipment outdoors.

(b) socket outlets on an amusement device.

(c) theme lighting, although advice should be sought from the manufacturer of the RCD if dimmer and solid state control of the lighting is used since these may interfere with the operation of the RCD. RCD supplementary protection is only necessary where the luminaires are within reach of members of the public or by operators and attendants going about their normal duties.

21. The hazards and risks arising from loss of supply to lighting and motive power, as a result of disconnection by unwanted tripping of RCDs should be considered. (see later paragraphs referring to emergency lighting.)

22. More than one RCD may need to be specified to provide discrimination, and in particular to prevent power to the entire attraction being disconnected as a result of a single fault. Discrimination can normally be achieved by using RCDs with suitable time delays. Each RCD should be:

(a) as close as practicable to the supply of the circuit it protects

(b) easily accessible

(c) easily reset

Protecting systems against fault currents

23. Each system and its constituent parts should be designed to withstand without danger the effects of overcurrent and the maximum fault current which could occur as a result of short circuit or earth faults. Table 12.2 shows the differences between overload and short circuit faults.

Table 12.2 Typical differences between overload and short circuit fault currents

Example for a system with a 240 V ac supply, with cables rated at 30 amps, and a maximum load current of 20 amps

	Overload	Short circuit
Likely cause	Too many appliances on circuit or a stalled motor	Direct connection between live-live, live-neutral or live-earth
Magnitude of current depends mainly on	Number and rating of appliances connected or, in the case of the stalled motor, the circuit impedance.	For earth faults, the earth fault loop impedance For short circuit faults, the overall circuit impedance. In both cases, the lower the impedance, the higher the fault current.
Likely effect	Slow burnout of circuit – may cause fire	Rapid burnout of circuit – may be explosive
What to specify on circuit protective device	Nominal rating of device to be between 20 and 30 amps. Current causing effective operation of the device to be less than or equal to 43.5 amps (1.45 x 30)	Nominal rating of device to be between 20 and 30 amps. Current causing effective operation of the device to be less than or equal to 43.5 amps (1.45 x 30). Fault breaking capacity (i.e. the current the protective device can safely disconnect) to be greater than the prospective short circuit current.

24. There are two things the designer needs to consider in protecting against fault currents - system protection and coordination as described in paragraph 22, and the correct rating of the switchgear, equipment and cables protected.

25. System protection is achieved by specifying HRC fuses and / or circuit breakers to interrupt the supply if there is a fault or overload. The designer should make sure that both the nominal rating and fault breaking capacity of each protective device are specified and are sufficient for the intended use.

26. The current carrying capacity of switchgear, cables and equipment should be greater than the rating of the protective devices on the circuits supplying them. Protective switchgear should be rated such that it can withstand the maximum through fault for either 1 second or 3 seconds, depending upon the design specification of the installation or system. Note that changing the specification of a cable may not only change the fault current rating of the installation but, because the earth loop impedance is likely to be altered, also the value of the fault current itself.

Means of disconnecting (isolating) and functional switching of the supply

27. All attractions should be designed with means to disconnect (isolate) the supply to all live conductors. Suitable means of disconnection are listed in EN 60204-1. When used for achieving isolation, the disconnecting device should have a means permitting it to be locked in the off (isolated) position (e.g. by padlocks). Also, devices used for isolation must have a visible gap or a position indicator that conforms with IEC 60947-3.

28. Functional switching and disconnection for isolation should apply as a minimum to the following conductors :

Table 12.3 Disconnection of conductors for isolation	
three phase	all three phases
three phase and neutral	all three phases[22]
single phase referenced to earth	phase and neutral
single phase not referenced to earth	both phases
single phase centre tapped	both live conductors at the supply and at each individual consuming unit.
d.c. not referenced to earth	positive and negative
d.c. referenced to earth	positive

29. Where the means of switching the supply is by way of a plug and socket, the circuit protective conductor should make first and break last and the rating of plug and socket should not exceed 16 A.

30. For a.c. and d.c. systems not connected to earth, the means of cutting off the supply must break both poles, e.g. if a knife switch is used for disconnection, it must be a double knife. (Domestic switches are normally single pole only and are therefore unsuitable for this purpose).

31. Each motor circuit should be designed to contain a readily accessible isolator which may be used to cut off power to the motor and all associated equipment, including any automatic circuit breaker. (Not all switches, switch fuses, circuit breakers are capable of being used as isolators. Electromagnetically operated or semi-conductor contactors or motor starters are not isolators).

32. Isolators are needed at :-

(a) the point of supply

(b) other locations where equipment can be conveniently isolated

(c) each item of equipment where it cannot be isolated as a group

33. In considering the location of such isolators, the following should be considered :-

(a) The distance of the isolator away from the motor.

(b) The risk of persons not isolating due to the distance required to get to the isolator.

(c) The risk of persons not isolating due to difficult, or time consuming access to the isolator, such as when it is located at the bottom of a roller coaster or log flume escalator, when the relevant motor is at the top.

Ingress Protection class of equipment and components

34. The degree of ingress protection of plugs, sockets, connectors, conduit, trunking, enclosures, fittings and other equipment shall not be less than IP2X when installed in closed rooms or where protected from the effects of the weather, although IP44 shall be specified where there is a possibility of the equipment and components being subjected to moisture or dust.

35. Equipment and components installed in all other areas should have ingress protection of not

[22] Neutral may also be disconnected but it should break after or at the same time as the phase conductor and be remade before or at the same time as the phase conductor

less than IP65

Protection against effects of lightning, static discharges and switching surges

36. On most attractions no additional provisions for lightning protection are required. However, in this respect designers should consult BS 6651 or ENV 61024-1 for guidance on how to carry out lightning risk assessments and on precautions that may need to be taken.

37. Some amusement devices suffer from static discharge, as passengers leave or enter the device, due to the composition of some types of running gear etc. Normal earthing procedures should eliminate this; however it may be necessary to fit extra earthing arrangements to devices such as non-powered roller coasters, that would not normally have any earth connection. Such arrangements may only need to be activated immediately prior to disembarkation or embarkation, subject to risk assessment.

38. Where electrical equipment may be subject to transient overvoltages due to switching surges, the designer should consider the need for overvoltage suppression devices to be fitted to the incoming terminals of the supply disconnector.

Generators, rectifiers and transformers

39. Designers of amusement devices need to take account of the nature of the electrical supply to the device and must provide information to the users of the device on the nature of the required electrical supply and earthing arrangements.

40. Permanent supplies from electricity companies will normally have an associated earth conductor connected to the star point of the company's distribution transformer, either directly or as part of a combined neutral / earth conductor. Provision should be made on an amusement device likely to use external supplies to connect the incoming earth to the device's main earth terminal.

41. On a.c. generators supplying amusement devices, the star point (or neutral) should be connected to the frame of the generator and the circuit protective conductors and bonding conductors connected to the frame. Where practicable, the frame should be connected to earth using suitable earth electrodes or mats.

42. Small single phase generators rated at less than 5 kVA and supplying single amusement devices such as bouncy castles via short lengths of cable (less than 10 metres) may be used as unreferenced isolated supplies, provided that the cables are suitably protected against mechanical damage and that the exposed metalwork of the amusement device is bonded to the frame of the generator.

43. D.C. generators are normally operated as unreferenced supplies, but the protective and bonding conductors for the connected attractions should where possible be connected through to the frame of the generator.

44. Equipment used to provide d.c. supplies should be configured so as to limit the ripple on the supply to the levels specified for PELV and SELV systems, but see Annex 1 for the requirements relating to dodgems.

45. Adequate measures should be provided at the generator output distribution point in order to protect all outgoing cables against overload and short circuit. Any such protection should take account of the actual size of conductors used to supply equipment, and be in accordance with BS7671.

46. Any circuit breaker or fuse device should not have a current rating higher than the rated maximum current carrying capacity of any cable connected to that circuit breaker or fuse.

47. It should be ensured that the earth loop impedance, of any distribution system or ride feeder system, is co-ordinated with the associated generator output circuit breaker or fuse, so that the maximum disconnection times required by BS 7671 are not exceeded.

48. Secure mountings should be specified for the generator including, if necessary, anti-vibration mountings on the generator or immediately adjacent.

49. Adequate ventilation should be specified for enclosures to contain rectifiers or transformers.

50. It is necessary to ensure that there is clearly visible information marked on generators (this may include information necessary to the user e.g. voltage, connection information, minimum cable sizes, correct fuses, maximum load, frequency and earthing requirements).

Motors

51. Motors should be provided with readily accessible means of starting and stopping, including in emergency. Motors driving rides should be fitted with systems to prevent them restarting automatically, either when power is restored after an interruption to the supply or when resetting circuit breakers or overload protection devices.

Lighting and audio systems

52. All parts of an amusement device around which persons may circulate, including access and egress, should be provided with sufficient illumination to ensure safety, bearing in mind the intended times and locations at which the device may be used.

53. In locations where amusement device controls are to be operated, and in electrical switch-rooms, there must be adequate and sufficient lighting available at all times.

54. Light fittings and speakers should be designed :-

(a) to be securely attached to the structure, battens or support wire intended to carry them, i.e. the support structures and the equipment should be sufficiently strong in all foreseeable environmental conditions (including wind);

(b) not to rely on electric cable conductors to carry their weight, inclusive of any attachments, unless the cable is specifically designed for this purpose;

(c) not to be exposed to moisture unless designed for such exposure;

(d) to be placed out of reach unless precautions are taken to protect against shock and burn (e.g. in the event of broken fittings leaving filaments exposed);

(e) to be protected against damage in attractions where projectiles are used

Emergency lighting

55. All parts of an amusement device around which persons may circulate, including access and egress, should be provided with sufficient emergency escape lighting, bearing in mind the intended times and locations at which the device may be used.

56. In the case of devices deliberately designed to be operated in dark conditions, emergency escape lighting should be provided which should comply with BS 5266-1 and EN 1838.

57. If at any time there is a failure of the lighting in a structure containing amusement devices, the parts of the structure affected, including any exit signs, should immediately be illuminated by emergency escape lighting.

58. Emergency escape lighting may be supplied from the same source as the normal lighting, but should also be capable of being powered by an independent supply. The independent supply should be brought into operation immediately and automatically in the event of failure of the normal supply.

59. Where batteries are specified as the means of powering emergency escape lighting, the designer should provide instructions for checking and ensuring that adequate charge will be available at all necessary times.

60. Any area entered or used by operators or attendants shall be provided with standby and / or escape illumination as above.

Additional requirements for water rides

61. Water rides that use electrical systems such as electrically driven water pumps have the potential for increased risk of electrical injury and, as a consequence, special precautions must be taken. BS 7671 and its supporting Guidance Note 7 Special Locations provide comprehensive guidance on the measures that should be taken in locations where the presence of water increases the risk of electrical injury. Designers of water rides and similar amusement devices should refer to these publications.

Provision of Information about Supply Requirements

62. The following data should be marked on a plate at the point of connection of supply to an amusement device and repeated in the Operations Manual

(a) Minimum / Maximum power requirements

(b) Voltage

(c) If AC, the number of phases, the frequency in Hz, and whether or not a neutral connection is required.

(d) Maximum allowable Ze (earth loop impedance at that point).

Relevant Standards and Other Publications

BS EN 1838	*Lighting applications. Emergency lighting.*
BS EN 60204-1	*Safety of machinery. Electrical equipment of machines.*
BS EN 60529	*Specification for degrees of protection provided by enclosures (IP code).*
ENV 61024-1	*Protection of structures against lightning. General principles.*
BS 5266-1	***Emergency lighting. Code of practice for the emergency lighting of premises***
BS 6651	*Code of practice for protection of structures against lightning.*
BS 7671	*Requirements for electrical installations. IEE Wiring Regulations. Sixteenth edition.*
HSG 175	*Fairgrounds and amusements parks: Guidance on safe practice.*

Chapter 13
Information to be provided by Designers

General

1. So far as the safety of a particular design of amusement device is concerned, the Health and Safety at Work etc Act 1974 (as amended particularly by the Consumer Protection Act 1987), and associated Regulations, apply in Great Britain. Under section 6(1A) of the Act :-

(a) " It shall be the duty of any person who designs, manufactures, imports or supplies any article of fairground equipment'[23]

(b) ... ;[24]

(c) ...

(d) to take such steps as are necessary to secure that persons supplied by that person with the article are provided with adequate information about the use for which the article is designed or has been tested and about any conditions necessary to ensure that it will be safe and without risks to health at all times when it is being used for or in connection with the entertainment of members of the public; and

(e) to take such steps as are necessary to secure, so far as is reasonably practicable, that persons so supplied are provided with all such revisions of information provided to them by virtue of the preceding paragraph as are necessary by reason of its becoming known that anything gives rise to a serious risk to health or safety."

2. The industry associations that endorse this guidance, with the support of the Health and Safety Executive, are concerned that the law shall be followed and, to help to demonstrate that it is, they have put in place some amusement device safety principles which must be followed by their members if they are to operate in Great Britain. One of the fundamental safety principles is that :

(a) The significant risks associated with safety-related work potentially affecting an amusement device are formally checked and thereby require the agreement of an independent party that the primary duty holders (designers, in this case) have adequately controlled any associated risks.

3. Safety-related aspects of designers' duties are independently checked in a process known as "Design Review". A second fundamental principle relates to those persons carrying out the checks :-

(a) Such individuals, and the firm or business for whom they work (known as an "inspection body"), are required to meet specified competence requirements, including minimum qualifications, experience and training appropriate to the particular types of work for which they claim competence. The details have to be registered annually with an agreed registration body which carries out a range of appropriate checks on their validity.

4. Then, a third fundamental principle relates to the independence of the inspection body and their personnel from those whose work they are checking :-

(a) The inspection body shall be independent of other parties involved.

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[23] *"article of fairground equipment"* means any fairground equipment or any article designed for use as a component in any such equipment.
Note also that section 6(1) includes similar duties regarding safety during installation, maintenance etc.

[24] Subsections 6 (1A) (a) & (b) have been omitted here for reasons of clarity.

(b) The inspection body, and its staff responsible for carrying out the inspection (in this case the "Design Review") shall not be the designer, manufacturer, supplier, installer, purchaser, owner, user or maintainer of the items which they inspect, nor the authorized representative of any of these parties.

(c) The inspection body and its staff shall not engage in any activities that may conflict with their independence of judgement and integrity in relation to their inspection activities. In particular they shall not become directly involved in the design, manufacture, supply, installation, use or maintenance of the items inspected.

5. The industry believes that its commitment to these 3 principles - of double-checking, registration of competence of those carrying out checks, and independence from conflicting influences on their checking work - helps to ensure greater public safety.

6. Where a design combines a number of different disciplines and / or persons, any person commissioning design work, or any person who imports, should appoint a design project safety co-ordinator (which may be himself if he has appropriate competence) and inform the relevant parties in writing. That person should check the way in which the elements combine and should ensure that every safety-related aspect has been covered.

7. In order for the necessary checks to be carried out and for controllers of amusement devices and their staff to be able to maintain and operate their equipment in a way which ensures safety, appropriate documentation must be made available. This needs to be in English and the language of the controller. The main elements of this should be as follows below:

Information to be used in Design Review

8. Designers need to make technical information available to enable Design Review to be carried out. More details about this process may be found in a sister publication[25] but it should be noted that the inspection bodies carrying out this work are required to ensure confidentiality of commercially-sensitive information which does not need to be divulged for safety reasons.

9. The information that needs to be passed on to the amusement device controller should be included but needs to be supplemented by the following more specialised technical information :-

(a) design risk assessment documentation (see Chapter 1);

(b) assessments, or checks that have been carried out, relating to functional safety, installation, testing, commissioning

(c) details of any modifications to the original design together with details of checks that have been made regarding such modifications;

(d) information on the correct configuration of equipment and computer systems;

(e) description and relevant up-to-date drawings of the components used, how they should be correctly assembled and the correct setting of adjustable features;

(f) instructions for installation and commissioning;

(g) instructions provided for the user which specify the actions necessary to maintain safety during operation and maintenance, including details of when operational and proof checks should be done;

[25] *Safety of amusement devices: Inspection;* to be published by ADSC on behalf of the industry associations endorsing the British guidance documents (i.e. ACES, AIS, ALES, BACTA, BALPPA, SGGB, SIRP, NAFLIC) in partnership with the HSE.

(h) in-service NDT schedules based on calculated fatigue lives (NDT schedule);

(i) information on possible fault conditions and their significance for safety.

Information to be used by the controller in the Operations Manual

Information on design and manufacture

10. The manual needs to contain certain specific information on design, including:

(a) a summary of salient safety features;

(b) a summary of design and required manufacturing standards (materials, quality control, etc);

(c) the design specification, including, where possible:

i. the grade and dimensions of any bolts, screws and rivets whose failure could cause danger;

ii. specifications and manufacturers' names for proprietary assemblies such as motors, gear boxes, pumps, hydraulic cylinders, etc.

Relevant drawings or diagrams

11. The manual needs to contain relevant drawings or diagrams, including:

(a) outline drawings, showing the main dimensions of the device when assembled and the recommended safe clearance distances when in motion;

(b) a plan showing the weight distribution and recommended packing points, together with the maximum permitted load at each point and any foundations required;

(c) the interrelationship of regularly assembled parts, with each part identified by a unique number where appropriate;

(d) diagrams of all control systems (hydraulic, pneumatic, electrical) according to ISO standards together with program listings, etc, for all programmable and non programmable electronic systems (PLCs, drive parameters, etc).

Replacement parts

12. The manual needs to contain a full list of replacement parts and their reference numbers.

Information on transport, installation, erection, dismantling

13. The manual needs to contain information on transport, installation, erection and dismantling, including:

(a) diagrams to show the correct assembly of the component parts;

(b) a key to the identification of non-interchangeable parts;

(c) information on the correct use of any special equipment required for assembly;

(d) procedures for setting up and dismantling the device correctly including, where relevant, details of:

i. any safe systems of work required;

ii. advice on ground or foundation preparation;

iii. order of assembly / disassembly of component parts;

iv. any temporary measures needed to support a partially completed device;

v. torque settings essential to the safety of screws or bolts;

vi. any procedures needed to prevent or relieve stress concentration during assembly / disassembly;

vii. jacking and packing points and procedures, including selection of materials, load spreading and ballasting where relevant;

viii. levelling and out-of-level tolerances;

ix. physical guards, barriers, fencing, etc;

x. mechanical and electrical power requirements;

xi. correct methods for connecting electrical equipment to the power supply;

xii. grounding for lightning protection;

(e) the following data regarding electrical requirements, which should be identical to that marked on the plate at the point of connection of supply to an amusement device :

i. Minimum / maximum power requirement

ii. Voltage

iii. If AC, the number of phases, the frequency in Hz, and whether or not a neutral connection is required

iv. Maximum allowable Ze (earth loop impedance at that point).

(f) any checks or testing needed to make sure the device has been assembled correctly and is functioning in the intended manner.

Information on safe use

14. The manual needs to contain information on:

(a) safe use, including:

i. a description of the normal functioning of the device (including the function and motion of the major components);

ii. the normal safe operating procedure (including the functions and responsibilities of the operator and attendants);

iii. details of operating speeds. The maximum or limiting speed should not be based solely on the forces that the device can withstand but should also take account of the need to prevent injury to users;

(b) loading which should specify:

i. the maximum working loads;

ii. maximum passenger numbers;

iii. permissible out of balance loading;

iv. order of passenger loading;

(c) limitations to use, e.g.

i. passenger dimension (size, weight), medical condition,

ii. adverse environmental conditions (particularly wind speed);

(d) details of any passenger containment system and guidance on its use;

(e) information on relative positioning of passengers in the same car;

(f) detailed explanation of the controls and their function;

(g) safe passenger access;

(h) limitations required to prevent overload of the structure in waiting areas;

(i) faults and fault finding, including indications of malfunction and the action to be taken;

(j) emergency procedures.

(k) evacuation procedures.

Instructions and guidance on any maintenance and inspection

15. The information needs to cover:

(a) components which require regular lubrication including information on suitable lubricants and the frequency required;

(b) components which require regular replacement and the period between replacement;

(c) components which require inspection for wear and fatigue, correct setting etc, together with details of the correct settings and allowable tolerances;

(d) electrical equipment together with any checks to be done by the user and details of safe isolation procedures;

(e) maintenance and testing of controls and interlocks.

Information relating to Examination and testing of the device once in use

16. Safety-critical components need to be identified and estimates given of their likely life. It is important that the documentation is adequate (e.g. by the inclusion of drawings or photographs) to identify the safety-critical regions of these components to those who will subsequently have to inspect them.

(a) Inspection or examination intervals need to be specified as well as the type of techniques to be used, e.g. visual or NDT, and criteria for acceptance / rejection.

(b) Where appropriate reference material relating to the original condition can be included, e.g. the results of original NDT or measures of the performance of safety-critical components or systems. Guidance should also be given on the parts which should be covered by the daily and other periodic checks.

17. A NDT schedule should be prepared by the designer, which should take account of calculated fatigue lives, revised in the light of information received from inspection, testing, operation, etc. For further information see Chapter 4.

18. It is important to record as much information as possible about the original as-built condition of the device for two principal reasons.

(a) Firstly, such information can be critical to the accuracy of initial design assumptions and it is vital that this information is fed back to the designer and design reviewer so that the accuracy of these assumptions can be checked.

i. Any necessary alterations to, for example, fatigue life assessments and consequent NDT schedules can then be implemented (eg. as a result of unexpected secondary accelerations caused by variations in accuracy of a ride track or play in rotating elements, etc).

(b) Secondly, it provides a benchmark of the condition of the device, which is vital for future inspections in terms of determining the amount of wear, degradation of components, etc (e.g. the amount of play in slewing rings, bearings, bushes, etc, under prescribed, repeatable test conditions, the settings of adjustable parameters, etc).

i. It is important that this information is considered in relation to the design parameters and assumptions, its significance to those parameters and assumptions is carefully assessed and the designer alters any information they need to provide accordingly. Any such alteration to this information also needs to be subject to Design Review.

Appendix 1
Common amusement device hazards

1. The following Table A.1 lists some of the more common hazards associated with fairground and amusement park machinery and structures.

2. The right hand column indicates Chapter numbers in this publication which contain text relating to the particular hazard.

3. Chapter 1 explains the process by which risk assessment associated with a particular hazard should be carried out.

4. The Table is not claimed to include every amusement device hazard that may exist, nor does this publication address all of those listed. The designer should identify any additional significant hazards for risk assessment in accordance with Chapter 1.

Table A.1 Some hazards associated with amusement devices

Hazards		**Refer to Chapter**
Falls of persons (also slips and trips)		
	On flat (e.g. poor surfaces, inadequate lighting)	11
	From one level to another	11
Persons (including employees and bystanders) struck by falling or ejected objects		
	Passengers' belongings	
	Mechanical / structural or other parts coming unfastened or failing in service (including backdrops, scenery, light fittings, speakers)	4,6
	Tools	
	Ejected passengers / employees	2,10
Persons (including employees and bystanders) struck by other objects		
	Airgun pellets	
	Arrows / darts	
	Other projectiles	
Hazards arising from raised anxiety states affecting vulnerable persons		
	Persons with heart problems	
	Pregnant women	
	Mentally impaired passengers	
Hazards arising from forces of motion on passengers		
	Nausea	2
	Physical damage resulting from intensity, direction and duration of accelerations and jerks (i.e. change of accelerations)	2,10
Hazards associated with passenger containment		
	Ejection of passenger	2,10
	Effect of forces exerted by elements of containment	2,10
	Movement of passenger unit while loading / unloading	8,9
Hazards from impact/ collision		

Table A.1 Some hazards associated with amusement devices		
Hazards		Refer to Chapter
	Collision of passenger unit with pedestrians (land trains etc.)	
	Collision of passenger unit with structures	
	Collision with another vehicle (e.g. Dodgems, multiple unit roller coasters)	9
Hazards from motion relative to, contact with, or proximity to, machinery		
	Squeezing / crushing	10
	Cutting / severing	10
	Shear traps	10
	Entangling (including ride passengers' hair and clothing)	
	Struck while moving / reaching into or out of	11
	Asphyxiation / poisoning / nausea etc. from contact with or inhalation of dust, fluids, gases, mists, fumes, vapours	
	Burning by high temperature surfaces	11
	Electric shock	12
	Hearing or other damage from high noise levels	
Positional instability of amusement device including wind effects		
	Overturning (including the possibility of inadequate foundations or packing)	6
	Sliding off packing	6
	Lifting off	6
Structural / mechanical breakage		
	Static failure following from :-	
	Loadings not properly accounted for; including overloading, excessive out-of-balance loading, wind and snow loading (earthquake not relevant in UK)	3,6
	Calculation error	
	Fatigue failure following from :-	
	Inadequate dynamic analysis or stress analysis	2, 3, 4
	Structural / mechanical vibrations unaccounted for	2
	Secondary dynamic effects unaccounted for	2
	Inspection regime not consistent with calculated fatigue life	4
	Failure or seizure as a result of wear, corrosion or rot	
	Escape of liquids / gases under pressure (hydraulic / pneumatic systems) as a result of poor design or in-service deterioration	7
Hazards associated with electricity		
	Electric shock or burn by direct contact with live parts	12
	Electric shock or burn by contact with parts which have become live under fault conditions	12
	Arcing	12
	Static discharge	12

Table A.1 Some hazards associated with amusement devices		
Hazards		**Refer to Chapter**
	Explosion	12
	Lightning strike	12
	Fire risk	12
Hazards associated with controls / control systems		
	Over/under speed	9
	Inadequate braking	8,9
	Excessive braking	8,9
	Inadequate operational, safety, or emergency stops	9
	Insufficient safety integrity	9
	Software errors	9
	Over-reliance on operator / attendant judgement or skill	
	Unauthorised tampering (e.g. resetting by staff, access by members of public)	8
Hazards due to poor use of ergonomic principles (operators / attendants)		
	Resulting from :-	
	Inadequate design, location or identification of manual controls	8
	Inadequate design or location of visual displays	8
	Insufficient visibility of significant parts of the device from operator / attendant position	8
	Inadequate local lighting	12
	Excessive physical effort	
	Effect of exposure to noise (e.g. music)	
	Noise interference with speech communication, acoustic signals etc.	
Additional hazards associated with water (ponds, pools, log flumes, water parks, rapids rides)		
	Drowning of member of public	
	Biological or microbiological (e.g. viral or bacterial) - water quality	
	Hazards associated with underwater maintenance and inspection	
	Hazards associated with use of electricity	12
Additional hazards associated with crowds		
	Crushing due to crowd pressure	
Emergency situations		
	Fire	11
	Evacuation of members of public from enclosures (including issues such as lighting, pinch points, etc.)	11,12
	Evacuation of passengers from remote locations (e.g. following ride breakdown)	11

Appendix 2
Electrical safety of dodgem rides

Introduction

1. This appendix provides design guidance on the electrical safety of dodgem rides supplied in the UK. The electrical safety features of this type of ride are unusual because of the characteristic large areas of exposed live conductors on the floor and the net which are normally, respectively, the negative and positive poles of the d.c. supply to the dodgem cars. The main complication is that the power and current requirements of the cars, and the need to keep current-carrying cable sizes to manageable dimensions, are such that it is not feasible to restrict the supply voltage to a maximum of 60 Vd.c. The supply therefore cannot satisfy the SELV or PELV requirements that apply to other types of ride that feature exposed live conductors.

2. It is accepted that dodgem rides may be supplied at voltages exceeding the recommended limits for other fairground devices with exposed live conductors. However, in the light of this, care must be taken to ensure that users and operators of the rides and other members of the public are not exposed to unacceptable levels of risk of electrical injury. This guidance explains how this can be achieved for rides supplied from 2 types of power source; firstly, a transformer / rectifier unit and, secondly, a d.c. generator.

Basic Principles

3. A generalised configuration of a dodgem ride is shown in Figure A2.1, which is an elevation drawing showing the floor, net and support structure. In most modern ride designs the support structure is metallic, typically steel poles or lattice towers, and is electrically connected to the floor of the ride, as illustrated in the diagram. Older rides may have support structures made of wood or other insulating material.

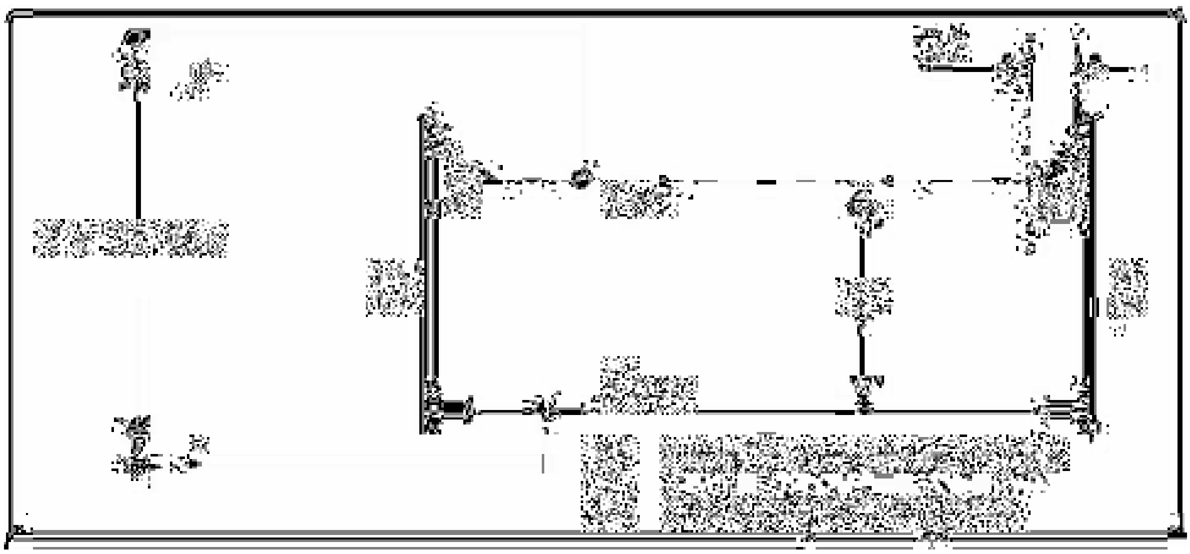

Figure A2.1 Basic Configuration of Ride (in elevation)

4. The overriding design requirement for the d.c. supply to the ride is that its mean value must not exceed 110 V and that its peak value taking account of ripple must not exceed 120 V. This voltage is generally recognised to be sufficiently low to prevent serious or irreversible electrical injury (shock and burn injuries arising from current flowing through the body) in dry conditions for the large majority of people. This is reinforced by the history of accidents on dodgems – in essence, there is no evidence that

the presence of large areas of exposed conductive parts energised at this voltage has led to injury from electric shock or bums.

5. In addition to restricting the voltage in the way described, the risk of injury from simultaneous contact between the floor and the net can be further reduced by ensuring that distance D1 in Figure A2.1 is as high as possible; typically, it will be in the order of 2 metres. Furthermore, direct contact between the 2 poles of the d.c. supply should be prevented by constructing the ride in a way that makes it difficult for persons to climb the vertical metallic members and reach over to the net.

6. On some designs of car it may be possible to contact opposite poles of the supply whilst in the car, for example by reaching under the dashboard and touching the positive connection to the motor above the front wheel whilst also touching metalwork which is at negative potential. This should be prevented by either insulation of the connection or by physical barriers.

7. Measures must also be taken to ensure that the power collectors on the top of the insulated poles on the cars cannot bridge the gap between the net and the metallic structure. If this happens, considerable arcing can occur, creating molten spatter that can cause thermal burn injuries to people using the ride. This can be prevented by ensuring that distance D2 is greater than the length of the collectors or by providing an insulating barrier between the net and the supports.

8. The design of the car should be such that it should not be possible for the pole to become displaced, so that a short circuit at the base of the pole is not possible. Such incidents have been known to happen, causing burn injuries to the riders.

Rides supplied from transformer/rectifier units

9. The general configuration of this supply arrangement is depicted in Figure A2.2, which illustrates a Class I transformer / rectifier unit fed at low voltage. The Figure excludes the start, stop and other controls for the ride. Most units of this type will be supplied at 400 V a.c. 50 Hz 3 - phase from a TN source, as shown. For clarity, later diagrams will show single phase supplies, but the safety principles apply to both three phase and single phase supply arrangements.

10. The supply into the transformer rectifier assembly must be configured as either a TN-S source, as depicted, or a TT source for the reason described later in this section.

11. It will be noted that Figure A2.2 incorporates a 'dotted' earth symbol. This has been included to show that in many applications there will be a fortuitous connection of the metallic structure to earth because the structure may be standing on the ground. For this reason, the d.c. supply to the ride should be configured as an isolated supply, meaning that there should be no deliberate connection of either pole at the point of supply on the secondary side of the transformer to a reference point, including earth; this includes the metal casing of the assembly. This will prevent return current flowing back to the transformer secondary windings through fortuitous earth paths.

12. In normal operation the configuration shown in Figure A2.2 will be safe. However, additional features are required to take account of foreseeable faults that may occur and which may lead to danger.

13.	Multiple connections may be used to both the net and to the track to ensure equipotential. However, the cross-sectional area of each of the individual conductors should be equal to the main supply cable.

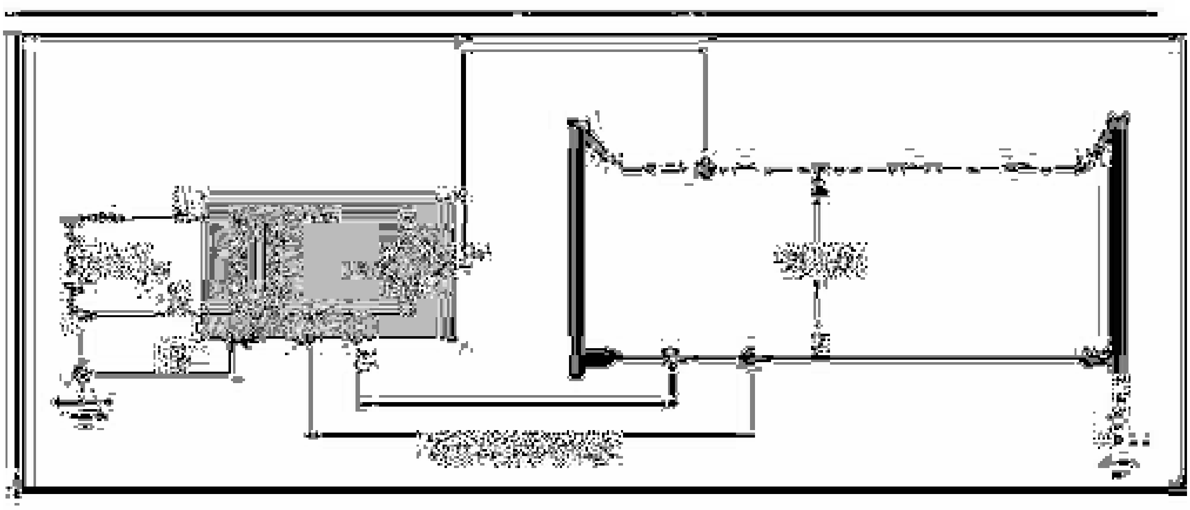

Figure A2.2 General arrangement of transformer/rectifier unit supplying a ride

14.	Overcurrent protective devices should be inserted in both poles of the supply on the secondary side of the transformer to cater for conditions where excess of current will flow. This may include, for example, faults in the car motors and a short circuit fault between the net and the floor or support structures.

(a) The prospective short circuit current from the transformer will often be lower than the current carrying capacity of the cables connected to the ride, but means still need to be taken to protect against excess current flowing for extended periods of time.

(b) The rating and tripping characteristics of the overcurrent devices should be selected to take account of the maximum prospective short circuit current and factors such as stalled motor currents that will flow into the motor loads at start up and during stalled conditions.

15.	In those cases where the transformer assembly is not constructed to meet the safety isolating transformer requirements set out in EN 60742 there is the possibility of inter-winding faults that may create a conducting path between the primary and secondary windings of the transformer.

(a) This would lead to dangerous a.c. voltages being present on the exposed conductive and accessible parts of the ride. To reduce the risk of danger from this type of fault, the exposed metalwork of the floor and support structure should be bonded to the exposed metalwork of the transformer / rectifier unit which, in turn, should be earthed by the protective conductor of the external supply.

(b) Note that this reinforces the need to ensure that no connection is made between the secondary side of the transformer and the casing of the unit – if such a connection were to be made, a proportion of the return current would flow through the bonding conductor and any earth paths that may exist.

(c) The cross sectional area of the bonding conductor should be at least half the cross sectional area of the d.c. cables supplying the ride.

16.	In those circumstances where the transformer does satisfy the requirements of a safety isolating transformer, the bonding connection should still be made.

17.	The configuration described in the foregoing paragraphs is depicted in Figure A2.3.

Figure A2.3 Recommended basic configuration[26]

18. In many circumstances there will be theme lighting and other equipment attached to the ride's support structure, as depicted in Figure A2.4.

(a) Preferably, the supplies to this equipment should be SELV but, where they exceed extra low voltage (as exemplified in Figure A2.4 for equipment supplied at 230 V a.c.), alternative precautions against both direct and indirect shock must be taken.

19. It is preferable for the equipment to be of Class II construction.

(a) Where the equipment is Class I with exposed conductive parts, there should be a supplementary bonding conductor connected between those parts and any metallic parts on the structure of the ride.

(b) The bonding conductor should be the same size as the protective conductor on the supply to the equipment.

(c) Lighting and other electrical equipment supplied with a.c. power, other than lighting provided to illuminate the ride for safety reasons (e.g. emergency exit lighting), should be protected by an RCD, or combination of RCDs, rated to trip at a residual operating current of 30 mA.

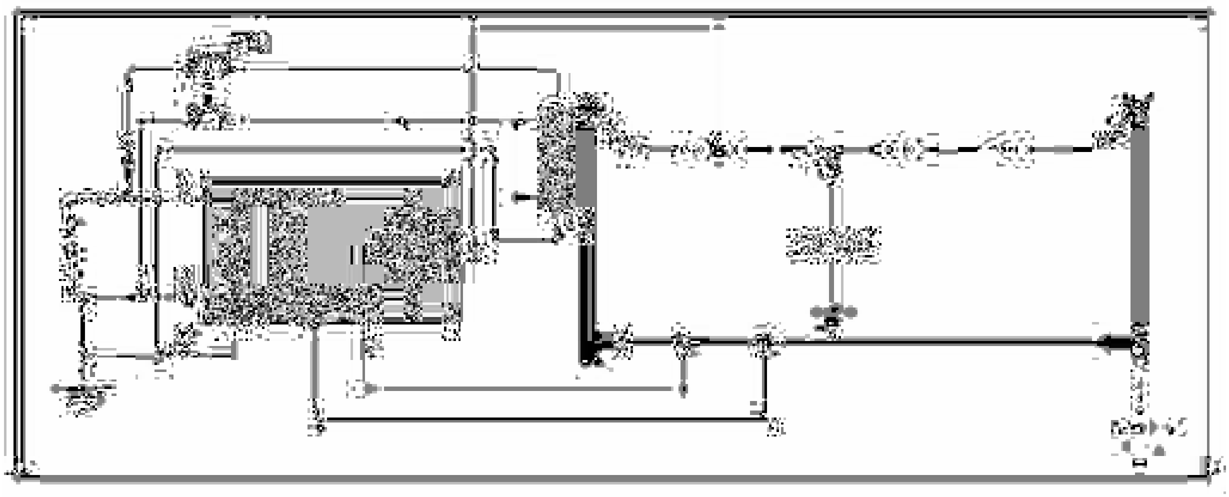

Figure A2.4

Recommended configuration with Class 1 apparatus installed on structure

20. This configuration of earthing and bonding means that the a.c. supply to the transformer must not be of the TN-C-S variety (also known as protective multiple earthing, PME, with a combined neutral earth, CNE). This is because an open circuit neutral fault on the supply could lead to the ride's exposed conductive and accessible parts becoming live at the supply's phase voltage, which would be a dangerous condition. For this reason, the supply must be either TN-S, as depicted, or TT.

21. Where a TN-C-S supply is provided by, for example, a power distribution company, the supplier's earth must not be used as the main earth connection to the ride, in which case a local earth electrode should be used as the main earth. In these circumstances, the supply to the transformer / rectifier assembly should have earth leakage protection installed in addition to the usual excess current protection.

[26] For clarity, this and later diagrams illustrate a single phase supply to the transformer assembly; in most cases the supply will be 3-phase.

Rides supplied from generators

22. The general configuration of this supply arrangement is depicted in Figure A2.5, which illustrates the dodgem ride being supplied directly at 110 V dc from a d.c. generator set. The figure does not illustrate any of the control devices needed to operate the ride.

23. The d.c. source should be operated as an isolated supply, with no deliberate connection between the windings and the frame of the generator. This prevents the flow of return current through earth paths. The only other main precaution is the provision of overcurrent protection in both poles of the supply – this is normally in the form of fuses or thermal overloads.

24. Although not essential, it is advisable to connect a bonding conductor between the live floor plates of the ride and the frame of the generator. The bonding conductor should have a cross sectional area at least half the cross sectional area of the d.c. cables supplying the ride. The main purpose of this is to maintain the floor and support structure at the same potential as the generator's frame.

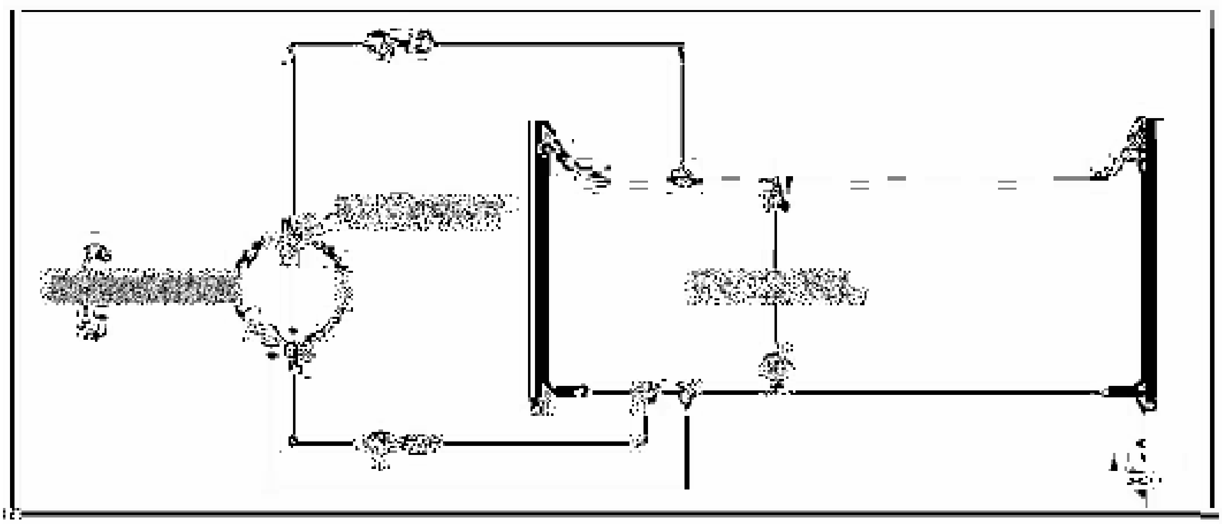

Figure A2.5 General arrangement of ride supplied directly by d.c.. from generator

25. Where the design of the ride incorporates theme lighting and other electrical equipment, precautions must be taken against direct and indirect shock injuries. Preferably, the supplies to this equipment should be SELV but, where they have to exceed extra low voltage for sound engineering reasons, alternative precautions against both direct and indirect shock must be taken. The bonding conductor connecting the exposed metalwork of the a.c. equipment to the structure of the ride should be the same size as the a.c. system's protective conductor

26. Class II equipment is preferred, but Figure A2.6 illustrates the situation where an item of Class I equipment such as theme lighting is supported on the metallic structure of the ride. This equipment is supplied at 230 Vac from a separate a.c. generator. In this case, the a.c. supplies are referenced to earth and to the a.c. generator frame, so the a.c. generator supply must be treated as a TN source.

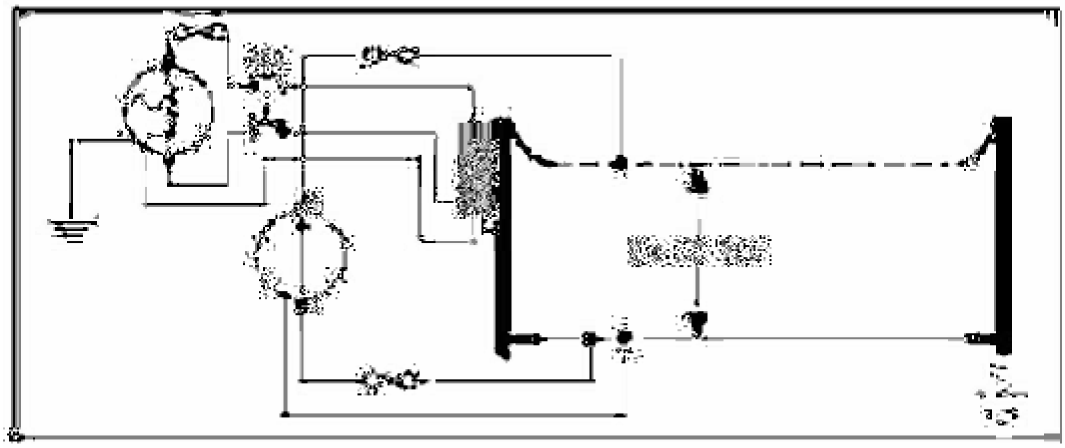

Figure A2.6 Dodgem supplied from d.c. generator with theme and other equipment supplied from a.c. generator (other than SELV and PELV supplies)

27. In some cases the a.c. and d.c. generators are mounted in the same generating set in a so-called piggy-back configuration. In these circumstances the frames of the d.c. and a.c. sets are electrically bonded together. An insulation failure between the windings of the d.c. generator and its frame can lead to d.c. fault current flowing through the bonding conductor and the a.c. system's protective conductor, as depicted in Figure A2.7. For this reason, in such piggy-back configurations, the bonding conductor and the protective conductors must be sized to carry the maximum prospective fault current of the a.c. or d.c. system, whichever is the larger

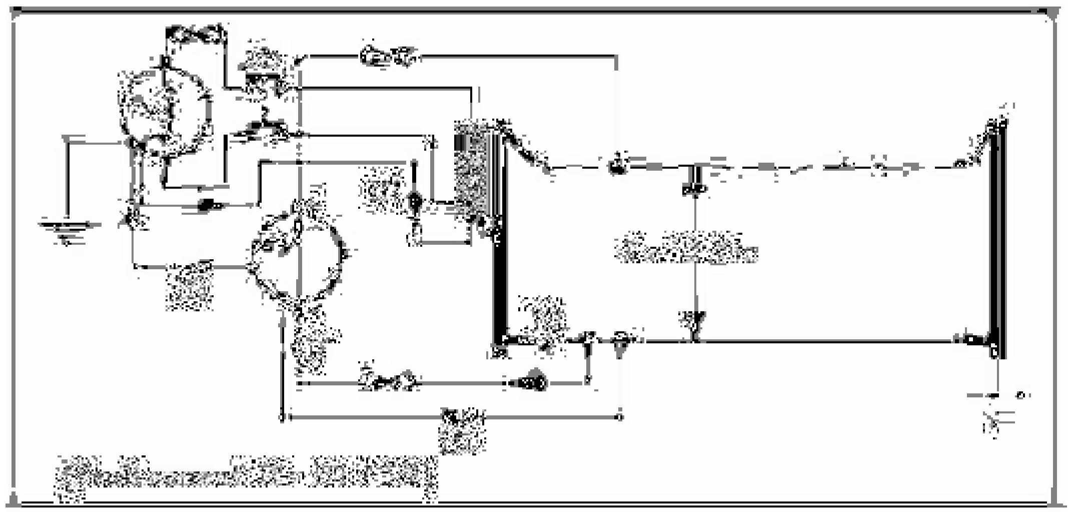

Figure A2.7 Dodgem supplied from d.c. generator with theme and other equipment supplied from 'piggy-back' a.c. generator, illustrating fault current flowing in the event of winding-to-frame fault on the d.c. set

Coin ejection mechanisms

28. Many dodgem rides have automatic token mechanisms in the cars. These incorporate a mechanical latching arrangement that maintains the token on a switch for the duration of the ride. The token is then ejected at the end of the ride, commonly by a momentary reversal of the polarity of the d.c. supply.

(a) From an electrical safety perspective, this facility does not present any additional hazards so long as the earthing and bonding arrangements are not affected by the temporary polarity reversal. Where this type of coin ejection technique is used, no other equipment should share the same d.c. supply as the dodgem track.

Appendix 3
Variations from EN 13814

1. The following text provides some explanation of supplementary safety provisions in Great Britain in addition to those contained in the European Standard EN 13814 - "Fairground and amusement park machinery and structures - safety".

2. The original proposals for revisions to the text of EN 13814, submitted by BSI in 2000, numbered approximately 128, of which about 57 were either adopted wholesale or dealt with in other ways in the final Standard dated December 2004. Unfortunately, there remain some serious issues. For instance, we believe there are cases of "requirements" which :-

(a) include matters which are not permitted in or consistent with other EN Standards;

(b) could be insufficiently safe, unsafe or dangerous; or

(c) break British or European law.

3. While we are pleased that the Standard has been published and that much of it is satisfactory, we have identified the following main points of objection which will necessitate additional or different safety measures to be followed for amusement devices that are to be used in Great Britain[27]

4. The Standard includes many references to types of inspection, approval, etc. which are inconsistent with current practice in Great Britain.

5. A consequence of the current state of the text is that compliance with the Standard would not necessarily be sufficient to satisfy British expectations. It is our view that designers etc. would need to fulfil additional conditions or variations imposed by ADIPS (the Amusement Device Inspection Procedures Scheme), the Health and Safety Executive's publication HSG 175, and this ADSC publication. Indeed, the amusement industry associations in Great Britain expect these to be followed. We consider that paragraphs numbered 3.2 - 3.7, 5.1.1, 5.1.4.2, 6.4.2.4.3.2, 6.4.2.4.3.3, 6.5, 6.6, 7 and Annex H may in some aspects conflict with or be insufficient to satisfy British expectations in this respect.

6. It has been British practice for over 20 years to expect that fatigue life assessments of components are to be carried out by designers. Unfortunately, EN 13814 does not require the designer to pass on any information regarding fatigue lives exceeding 35000 hours, nor to cross check that inspection / maintenance instructions are consistent with any of the calculated lives. We believe that this would be inconsistent with Section 6 of the Health and Safety at Work, etc., Act 1974. Indeed in relation to assessment of risks affecting workers (in contrast to the public), on which the European Union has common requirements, we believe that it would also break the law in the other member states.

7. For this and related reasons we consider that paragraphs numbered 5.6.1, 5.6.3 (including Table 6), 6.4.3.1.4 and Annex A may in some aspects conflict with British requirements, and duty holders would need to carry out fatigue life calculations for all safety-related components and, for each of those which are seen to have a life which is shorter than the maximum anticipated lifetime of the device, prepare maintenance and inspection schedules which are consistent with the results, including details of method and frequency that each procedure is to be carried out. Please note that there is a requirement in Great Britain for a written inspection / NDT schedule, often produced in tabular form for clarity, to be in place in the Operations Manual. Paragraphs 1 - 9 of Chapter 4 above are relevant.

8. Great Britain has recently introduced specific electromechanical safety advice for dodgems which covers some issues not addressed in EN 13814. We therefore consider that paragraph

[27] Note that if, as a duty holder, you follow the steps outlined here in addition to EN 13814 you will normally be doing enough to comply with British law. If you do otherwise you will need to demonstrate and justify equally effective compliance.

numbered 6.2.4.1.6 may in some aspects conflict with or fail to satisfy British expectations. Duty holders should refer to Appendix 2 above for more information.

9. EN 13814 now contains several references which tell the designer to apply partial safety factors for ultimate limit states even when carrying out fatigue life assessment. This is inconsistent with other Standards (e.g. EN 1993-1-9) and may result in underestimates of fatigue lives, onerous inspection regimes or, if re-design is carried out, unnecessarily heavy structures. We therefore consider that paragraphs numbered B.1.1, B.2.1 and B.3 may in some aspects conflict with British expectations. In accordance with British and European Standards covering fatigue (see, for instance, those listed in Chapter 4 above), input loads need not be factored when calculating fatigue lives and preparing associated inspection schedules.

10. Great Britain has recently updated and extended safety advice for amusement device electrical and control system design safety. We therefore consider that Annex D may in some aspects conflict with or fail to satisfy British expectations. Duty holders should refer to Chapters 9 and 12 above for more information.

11. British requirements for the assessment of design safety of passenger containment are more extensive than those in EN 13814. (For instance, there have been recent prosecutions of duty holders for not making proper use of anthropometric data in assessing safety). We therefore consider that 6.1.6 and Annex E (which is, in any case, only "informative") may in some aspects conflict with or fail to satisfy British requirements. Duty holders should refer to Chapters 9, 10 and 11 above for more information. These contain, amongst other things, anthropometric data associated with common passenger height limits. Such data, arranged by height, is not available in European or ISO Standards and is commonly miscalculated by designers.

12. It is also the British view that passenger reach distances, as required in the standard, do not take sufficient note of available anthropometric data and should be increased accordingly. The existing values will not prevent passenger's extremities from coming into contact with external objects (passenger clearance envelope)

13. Unlike earlier draft versions of EN 13814, there is no longer any reference to the need for design risk assessment to be carried out (formerly in a paragraph then numbered 6.1.3, immediately following 6.1.2, now deleted; see also Annex 1). Failure to do this assessment conflicts with British regulations. Indeed in relation to assessment of risks affecting workers (in contrast to the public), on which the European Union has common requirements, we believe that it would also fail to meet the law in the other member states. Design duty holders would need to ensure that a design risk assessment is carried out. This should form part of the package supplied to the ADIPS - registered inspection body responsible for its Design Review.

14. Paragraph 6.3.8.2.1.6 specifies safety factors for ropes and chains which are much smaller than those recommended by the Machinery Directive (98/37/EC). Although the Directive and related Regulations and ACOPs will not apply in many cases it may in some. Duty holders would need to consider whether to apply the larger safety factors.

15. In addition to these broad difficulties, we are aware of a number of specific details in EN 13814 (e.g. formulae) which we believe to be incorrect and which could lead to lack of safety. We identify the following :-

16. Wind loading (5.3.3.4.1) - British designers, inspection bodies, etc. are already expected to assess structural shape factors in accordance with BS 6399-2 and EN 1991-1-4. Figure 1 in EN 13814 is not consistent with either of these or with any other European or ISO Standard, so far as we can ascertain. Shape factors which accord with BS 6399-2 or EN 1991-1-4 should be used.

17. The third paragraph of 5.4.3.5 contains unsafe recommendations about when anti-rollback

devices may be dispensed with. Duty holders will need to assess whether the rollback of a roller coaster car or train through the station can be accomplished with minimal risk to passengers and others in the station area before omitting safety devices against running back.

18. The second paragraph of 5.7.3 does not deal with all the safety issues of which we are aware relating to open hooks. That is to say that, in the absence of other justification, the risk assessment should assume that in-service primary failure of a member having an open hook termination will lead to unhooking. The consequences of striking or spearing passers-by etc. should be considered.

19. Paragraph 6.1.4.5 does not deal adequately with all the known hazards associated with fences and railings having horizontal members. The following objectives should be satisfied where an associated unacceptable risk might result :-not permitting climbing (up, under or through); and not permitting trapped heads

20. Paragraph 6.1.6.1.7 no longer (compared with earlier drafts of the Standard) warns the designer about the risk of entrapment of body parts between the outside of the passenger containment and any object. Nor is there any mention of this in the subsection 6.1.6.1. It is our view that this will lead to a greater number of unsafe interpretations of the Standard and some non-compliance with Regulation 11 of the Provision and Use of Work Equipment Regulations 1998. Unguarded clearance distances in the Standard may be unacceptable for use in Great Britain where dangerous shear traps, etc., have not been removed. Duty holders should take account of Chapter 11 above or take other equally effective precautions to ensure compliance with British law.

21. Paragraphs A.4.2 and A.4.3 contain incorrect formulae numbered A.24 and A.31 which could result in unsafe results. Calculations involving these formulae will not be acceptable. Since the calculation of "equivalent constant amplitude stress range" is not a necessary step in the determination of fatigue life, we do not propose the use of any alternative formulae.

22. Annex G, which in any case is only an informative annex, has some remaining unresolved problems which could be unsafe. Duty holders should therefore be aware that compliance with this annex will not automatically imply that safety requirements have been satisfied.

23. For help in complying with British requirements, inspection bodies registered to carry out Design Review may be contacted.

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