Standard Practice for Design of Amusement Rides and Devices[1]

This standard is issued under the fixed designation F 2291; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice establishes criteria for the design of amusement rides, devices and major modifications to amusement rides and devices manufactured after the effective date of publication except as noted in 1.2.

1.2 This practice shall not apply to:

1.2.1 Patron directed amusement rides or devices (for example, go karts, bumper cars, bumper boats),

1.2.2 Artificial climbing walls,

1.2.3 Air-supported structures,

1.2.4 dry slides,

1.2.5 coin operated rides,

1.2.6 Amusement rides or devices that involve the purposeful immersion of the patron's body partially or totally in the water and involves more than incidental patron water contact (for example, pools, water slides, lazy rivers, interactive aquatic play devices),

1.2.7 Amusement rides and devices whose design criteria are specifically addressed in another ASTM standard,

1.2.8 Portions of an amusement ride or device unaffected by a major modification,

1.2.9 Upgrades to electrical wiring, electrical motors and electrical components of amusement rides and devices provided the original design and safety criteria are maintained or enhanced, and

1.2.10 Pre-existing designs manufactured after the effective date of publication of this practice if the design is service proven or previously compliant and the manufacturer provides:

1.2.10.1 A historical summary of the amusement ride, device or major modification, and

1.2.10.2 A statement that the design is service proven or previously compliant as specified by Section 3.

1.2.11 Amusement rides and devices, and major modifications to amusement rides and devices may qualify as "previously compliant" for five years following the date of publication of this practice. Thereafter, amusement rides and devices, and major modifications to amusement rides and devices must qualify as "service proven" or meet the requirements of this practice.

1.3 This practice includes an annex (mandatory), which provides additional information (for example, rationale, background, interpretations, drawings, commentary, and so forth) to improve the user's understanding and application of the criteria presented in this practice. The annex information shall be interpreted as mandatory design criteria.

1.4 This practice includes an appendix (non-mandatory), which provides additional information (for example, rationale, background, interpretations, drawings, commentary, and so forth.) to improve the user's understanding and application of the criteria presented in this practice. The appendix information shall not be interpreted as mandatory design criteria.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

F 698 Specification for Physical Information to be Provided for Amusement Rides and Devices

F 747 Terminology Relating to Amusement Rides and Devices

F 770 Practice for Operation Procedures for Amusement Rides and Devices

F 846 Guide for Testing Performance of Amusement Rides and Devices

F 853 Practice for Maintenance Procedures for Amusement Rides and Devices

F 893 Guide for Inspection of Amusement Rides and Devices

F 1159 Practice for Design and Manufacture of Patron Directed, Artificial Climbing Walls, Dry Slide, Coin Operated and Purposeful Water Immersion Amusement Rides

[1] This practice is under the jurisdiction of ASTM Committee F24 on Amusement Rides and Devices and is the direct responsibility of Subcommittee F24.24 on Design and Manufacture.

Current edition approved April 1, 2004. Published April 2004. Originally approved in 2003. Last previous edition approved in 2003 as F 2291 – 03a.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

Copyright © ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States.

and Devices and Air-Supported Structures

F 2137 Practice for Measuring the Dynamic Characteristics of Amusement Rides and Devices

2.2 *ASTM Technical Publications:*[3]

MIL 17 The Composite Materials Handbook

MIL 882C System Safety Program Requirements

STP-1330 Composite Materials: Fatigue and Fracture, 7th Volume

2.3 *ACI (American Concrete Institute):*

ACI-301 Specifications for Structural Concrete

ACI-318 Building Code Requirements for Structural Concrete (ACI-318) and Commentary (318R)

2.4 *AFPA (American Forest & Paper Association), American Wood Council Publications:*[4]

NDS (National Design Standard) for ASD Design

2.5 *AISC (American Institute of Steel Construction):*[5]

AISC 316 Manual on Steel Construction, Allowable Stress Design (ASD)

AISC M015 Manual on Steel Construction, Load & Resistance Factor Design (LRFD)

2.6 *ANSI (American National Standards Institute):*[6]

ANSI B93.114M Pneumatic Fluid Power—Systems Standard for Industrial Machinery

ANSI B11.TR3 Risk Assessment and Risk Reduction—A Guide to Estimate, Evaluate, and Reduce Risks Associated with Machine Tools

ANSI B77.1 Passenger Ropeways—Aerial Tramways, Aerial Lifts, Surface Lifts, Tows and Conveyors—Safety Requirements

2.7 *ASCE (American Society of Civil Engineers):*[7]

ASCE 7 Minimum Design Loads for Buildings and Other Structures

ASCE 16 Standard for Load and Resistance Factor Design (LRFD) for Engineered Wood Construction

2.8 *ASMI (American Society of Metals International):*

ASM Atlas of Fatigue Curves

ASM Handbook Volume 19: Fatigue and Fracture

2.9 *ASME (American Society of Mechanical Engineers):*[8]

ASME B15.1 Safety Standards for Mechanical Power Transmission Apparatus

ASME A17.1 Safety Code for Elevators and Escalators

2.10 *AWS (American Welding Society):*[9]

ANSI/AWS D1.1/D1.1M Structural Welding Code—Steel

ANSI/AWS D14.4 Specification for Welded Joints in Machinery and Equipment

2.11 *British Standards Institute:*[10]

BS 5400-10 Steel, Concrete and Composite Bridges—Code of Practice for Fatigue

BS 7608 Code of Practice for Fatigue Design and Assessment of Steel Structures

2.12 *CDC (Center for Disease Control) Growth Charts:*[11]

CDC Basic Body Measurements

2.13 *CISC (Canadian Institute of Steel Construction):*

Hallow Structural Section Connection and Trusses—A Design Guide, J.A. Parker and J.E. Henderson

2.14 *DIN (German Institute For Standardization):*[12]

DIN 15018-1, Cranes; Steel Structures; Verification and Analyses Data

2.15 *EN (European Committee for Standardization):*

EN 280 Mobile Elevating Work Platforms—Design Calculations, Stability Criteria, Construction, Safety, Examinations, and Tests

EN 954-1 Safety of Machinery—Safety Related Parts of Control Systems—General Principles for Design

EN 1050 Safety of Machinery—Principles for Risk Assessment

EN 1993-1-9, Eurocode 3 Design of Steel Structures. Part 1.9. Fatigue Strength of Steel Structures

EN 1993-1-9, Eurocode 3 Design of Steel Structures. Part 6.9. Crane Supporting Structures—Fatigue Strength

EN 60947-1 Low-Voltage Switchgear and Controlgear

2.16 *IEC (Cable Assemblies Interface Equipment):*

IEC-60204-1 Safety of Machinery—Electrical Equipment of Machines—Part 1: General Requirements

IEC-61496-1 Safety of Machinery—Electrosensitive Protective Equipment—General Requirements and Tests

IEC-61508-1 Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems—General Requirements

IEC-61511 Functional Safety: Safety Instrumented Systems for the Process Industry Sector

IEC-62061 Safety of Machinery-Functional Safety-Electrical, Electronic, and Programmable Electronic Control Systems

2.17 *Federal Documents:*

USDA-72 (U.S. Dept. of Agriculture) The Wood Handbook—Wood As An Engineering Material, Forest Service, Forest Products Laboratory

2.18 *ISO (International Standards Organization):*[13]

ISO 4414 Pneumatic Fluid Power General Rules Relating to Systems

2.19 *NEMA (National Electrical Manufacturers Association):*[14]

NEMA 250 Enclosures for Electrical Equipment

[3] Available from ASTM International Headquarters, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959.

[4] Available from American Forest and Paper Association (AF&PA), 1111 19th St., NW, Suite 800, Washington, DC 20036.

[5] Available from American Institute of Steel Construction (AISC), One E. Wacker Dr., Suite 3100, Chicago, IL 60601-2001.

[6] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

[7] Available from The American Society of Civil Engineers (ASCE), 1801 Alexander Bell Dr., Reston, VA 20191.

[8] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Three Park Ave., New York, NY 10016-5990.

[9] Available from The American Welding Society (AWS), 550 NW LeJeune Rd., Miami, FL 33126.

[10] Available from British Standards Institute (BSI), 389 Chiswick High Rd., London W4 4AL, U.K.

[11] Available from Centers for Disease Control & Prevention (CDC), 1600 Clifton Rd., Atlanta, GA 30333, website: http://www.cdc.gov/ [Search: anthropometrics].

[12] Available from Beuth Verlag GmbH (DIN-- DIN Deutsches Institut fur Normung e.V.), Burggrafenstrasse 6, 10787, Berlin, Germany.

[13] Available from International Organization for Standardization (ISO), 1 rue de Varembé, Case postale 56, CH-1211, Geneva 20, Switzerland.

[14] Available from National Electrical Manufacturers Association (NEMA), 1300 N. 17th St., Suite 1847, Rosslyn, VA 22209.

2.20 *NFPA (National Fire Protection Agency):*[15]
NFPA-79 Electrical Standard for Industrial Machinery
NFPA-70 National Electric Code (NEC)
NFPA-101 Life Safety Code
2.21 *National Fluid Power Association, Inc.*[16]
NFPA/JIC T2.25.1M Pneumatic Fluid Power—Systems Standard for Industrial Machinery
2.22 *OIPEEC (International Organization for the Study of Endurance of Wire Rope)*[17]

2.23 *SAE (Society of Automotive Engineers):*[18]
SAE J-211 Instrumentation for Impact Test—Electronic Instrumentation
SAE J-833 Human Physical Dimensions
SAE HS 4000 Fastener Standards
2.24 *UL (Underwriter's Laboratory):*[19]
UL 508 Industrial Control Equipment
UL 508A Industrial Control Panels

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *acceleration, impact*—those accelerations with duration of less than 200 ms.

3.1.2 *acceleration, sustained*—those accelerations with duration greater than or equal to 200 ms.

3.1.3 *automatic mode*—the ability, after initialization, of the amusement ride or device to start, operate, move, etc. with limited or no operator intervention.

3.1.4 *closed*—when pertaining to restraint devices, the position in which the restraint is intended to remain during the operation of the ride or device in order to restrain the patron(s).

3.1.5 *designer/engineer*—the party(s) that establishes and describes the configuration of the amusement ride or device, establishes strength and fatigue life, designs and develops electrical/electronic control systems, and defines inspection criteria.

3.1.6 *electrical (E)/electronic (E)/programmable electronic systems (PES) (E/E/PES)*—when used in this context, electrical refers to logic functions performed by electromechanical techniques, (for example, electromechanical relay, motor driven timers, etc.), Electronic refers to logic functions performed by electronic techniques, (for example, solid state logic, solid state relay, etc.), and Programmable Electronic System refers to logic performed by programmable or configurable devices (for example, Programmable Logic Controller (PLC)). Field devices are not included in E/E/PES.

3.1.7 *electro-sensitive protective equipment (ESPE)*—an assembly of devices or components, or both, working together for protective tripping or presence-sensing purposes.

3.1.8 *emergency stop (E-Stop)*—a shut down sequence(s), other than a normal stop, that brings the amusement ride or device to a stop. An E-Stop may be more dynamic than a normal stop.

3.1.9 *fail-safe*—a characteristic of an amusement ride or device, or component thereof, that is designed such that the normal and expected failure mode results in a safe condition.

3.1.10 *fence*—a type of barrier consisting of, but not limited to, posts, boards, wire, stakes, or rails that is used to inhibit patrons from coming into undesirable contact with the moving portion or restricted portion of an amusement ride or device.

3.1.11 *filter corner frequency (Fc)*—with reference to a low-pass filter, Fc is the frequency (specified in Hz) where the frequency response curve of the filter has magnitude of –3 dB.

3.1.12 *force limiting*—when pertaining to restraint devices, a characteristic that, regardless of the amount of force available from the system actuators, limits the amount of force applied to the patron(s).

3.1.13 *gates*—a section of fencing that may be opened.

3.1.14 *guardrail*—system of building components located near the open sides of elevated walking surfaces for the purpose of minimizing the possibility of an accidental fall from the walking surface to the lower level.

3.1.15 *hand mode*—the ability of the amusement ride or device to start, operate, move, etc. only with operator intervention.

3.1.16 *handrail*—railing provided for grasping with the hand for support.

3.1.17 *latching*—when pertaining to restraint devices, held secure against opening except by intentional action of the patron, operator, or other means. This can include restraints (for example, drop bars) held in place by gravity, detents or other means.

3.1.18 *locking*—when pertaining to restraint devices, held securely against opening except by intentional action of the operator or other means not accessible by the patron.

3.1.19 *manual release*—when pertaining to restraint devices, a hand or foot operated mechanism that allows for opening the patron restraint.

3.1.20 *manufacturer*—the party producing the amusement ride or device, performing major modifications and can include the designer/engineer.

3.1.21 *patron containment*—the features in an amusement ride or device that accommodate the patron for the purpose of riding the ride or device. This may include but is not limited to the seats, side walls, walls, or bulkheads ahead of the patron(s), floors, objects within the vicinity of the patron(s), restraint systems, and cages.

3.1.22 *previously compliant*—an amusement ride or device, or major modification to an amusement ride or device, of which the design meets the ASTM Standard in place at the time of its design.

3.1.23 *primary circulation area*—areas leading directly to the entrance and exit of a ride that are normally traveled by patrons. These areas would not include emergency exit routes, maintenance areas, or other areas not normally on the route of the patron.

[15] Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02269-9101.

[16] Available from National Fluid Power Association, Inc., 3333 N. Mayfair Rd., Milwaukee, WI 53222–3219.

[17] Available from Grünenthaler Strasse 40d, 57072 Aachen, Germany.

[18] Available from Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001.

[19] Available from Underwriters Laboratories (UL), Corporate Progress, 333 Pfingsten Rd., Northbrook, IL 60062.

3.1.24 *restraint*—the system, device, or characteristic that is intended to inhibit or restrict the movement of the patron(s) while on the amusement ride or device.

3.1.25 *safety related control system*—the hardware and software that controls the safety functions and components of the amusement ride or device as defined by the Ride Analysis.

3.1.26 *service proven*—An amusement ride, device, or major modification to an amusement ride or device of which (*1*) unit(s) have been in service to the public for a minimum of five years, and (*2*) unit(s) that have been in service have done so without any significant design related failures or significant design related safety issues that have not been mitigated.

4. Significance and Use

4.1 The purpose of this practice is to provide designers, engineers, manufacturers, owners, and operators with criteria and references for use in designing amusement rides and devices or a major modification for amusement rides or devices.

5. General Design Criteria

5.1 *Ride Analysis*:

5.1.1 The manufacturer shall perform a ride analysis that shall include the following:

5.1.1.1 *Patron Restraint and Containment Analysis*—A patron restraint and containment analysis shall be performed in accordance with Section 6.

5.1.1.2 *Patron Clearance Envelope Analysis*—A patron clearance envelope analysis shall be performed in accordance with Section 6.

5.1.1.3 *Failure Analysis*—A failure analysis shall be performed on the safety related systems of the amusement ride or device. The failure analysis shall include either a Fault Tree Analysis, a Failure Mode and Effects Analysis (FMEA), or other accepted engineering practices.

5.1.2 The ride analysis shall specifically include an assessment of the suitability of the design of the amusement ride or device for the intended patrons, including anthropomorphic factors that relate age and physical size.

5.1.3 The ride analysis shall identify the most significant factors that may affect patron safety and shall include mitigation for each factor.

5.1.4 The ride analysis shall be documented listing the safety issues that were identified and the means used to mitigate each issue.

5.2 *Design and Calculations*:

5.2.1 The designer/engineer shall perform calculations showing compliance with the design criteria of this practice. Calculations and assessments of the following types are required.

5.2.1.1 Calculations verifying the adequacy of structural, mechanical, and electrical components.

5.2.1.2 Calculations of significant and predictable acceleration that is generated by the ride or device when operated as reflected in the manufacturer's provided operating and maintenance manuals or written instructions.

5.2.1.3 Performance and functional characteristics of control systems.

5.2.1.4 Calculations shall be performed using coordinate axis and load paths as defined by Practice F 2137 or the EN equivalent.

5.3 *Units*:

5.3.1 Units of measurement shall be clearly specified in all documentation.

5.3.2 The coordinate system shown in Fig. 1 shall be used as the standard reference for acceleration directions, including the application of the different means of restraint in accordance with the criteria of the restraint diagram shown in Fig. 2.

5.4 *Drawings and Records*:

5.4.1 The designer/engineer or manufacturer shall produce and retain as-built drawings, calculations, and control software that depict the amusement ride, device, or major modification details. These drawings and calculations shall be retained for a minimum of 20 years from the date of last manufacture. In the case of a major modification, only the records associated with that major modification, and not the entire ride or device, must be retained for a minimum of 20 years.

5.4.2 Documents deemed proprietary and confidential by the manufacturer shall include a statement of such on each document. Use of the manufacturer's documentation and records should be limited, where possible, to the installation, maintenance, inspection, and operation of the ride or device. All other dissemination should be limited.

5.4.3 Documentation supplied to the buyer, owner, or operator shall be complete and adequate for proper installation, maintenance, inspection, and operation of the amusement ride, device, or major modification.

5.4.4 Drawings and documents shall illustrate and define all important dimensions and tolerances. Dimensions, tolerances, and other important characteristics shall be clearly depicted in appropriate views and cross sections. The following shall be included:

5.4.4.1 General drawings or diagrams in plan, elevation, and section views showing the general arrangement of components, including patron clearance envelope as described in Section 6 of this practice.

5.4.4.2 Assembly and subassembly drawings providing additional views of areas not clearly discernible from the general

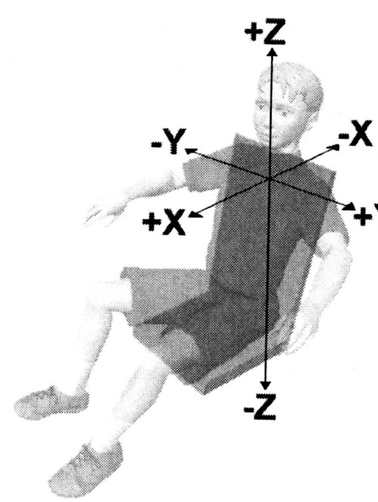
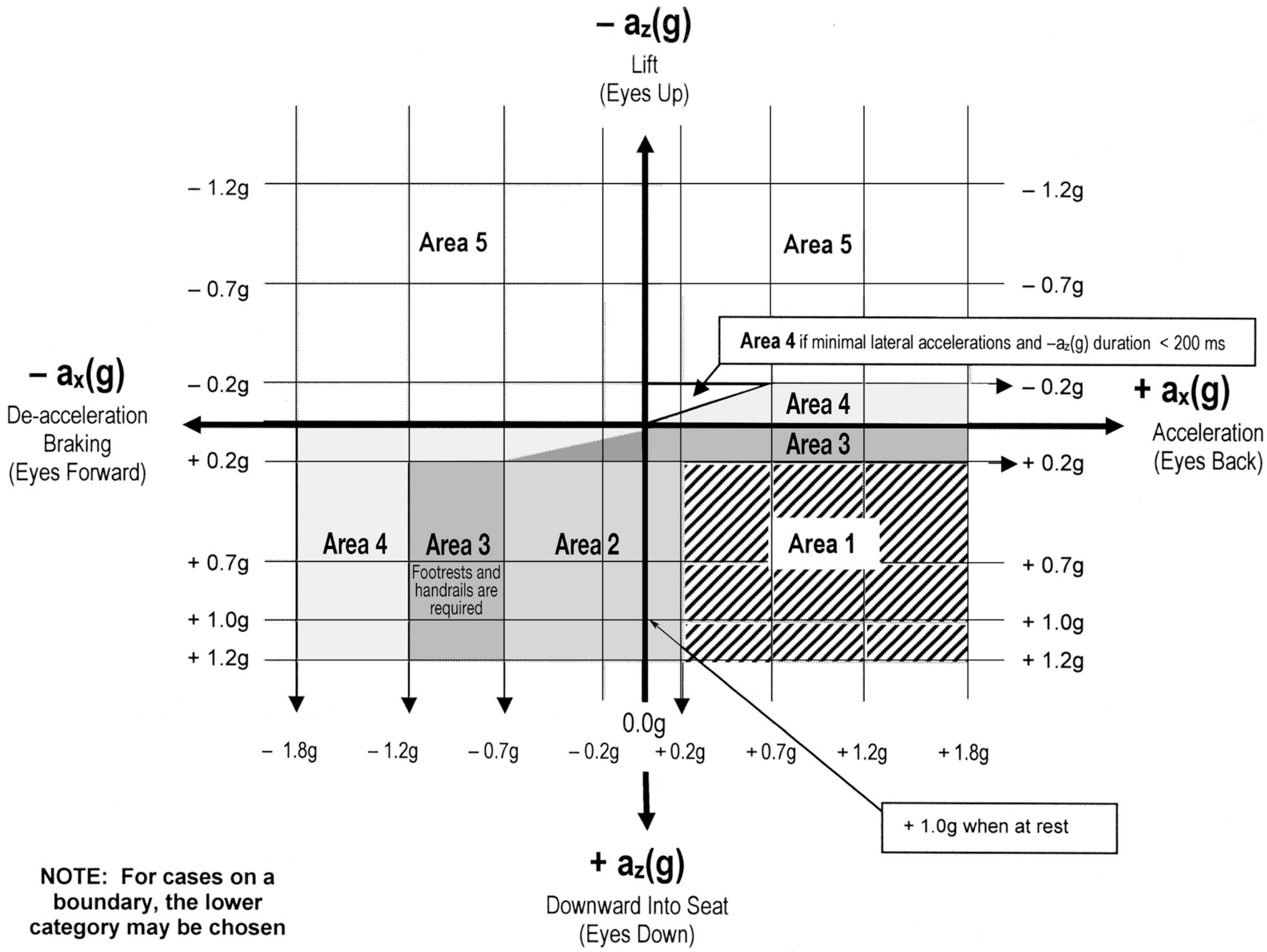


FIG. 1 Patron Containment Area Acceleration Coordinate Axes



Distinctive Areas 1 through 5

FIG. 2 Restraint Determination Diagram—Accelerations in Design Stage

drawings and providing clear identification and specification of all included components, their locations, and other information as applicable, for example, proper adjustment(s), fastener tightening specifications, descriptions of any other materials or lubricants used, and other important information.

5.4.4.3 Detailed drawings of all components specifically manufactured for use in the amusement ride, device, or major modification.

5.5 *Regulatory Body Review Documents*:

5.5.1 When the approval of the amusement ride, device, or major modification design is required by a regulatory authority, the following documents are typically made available for review:

5.5.1.1 General assembly drawings,

5.5.1.2 Facility interface drawings and related load calculations,

5.5.1.3 Operations, maintenance, and assembly instructions, and

5.5.1.4 Information otherwise called for in accordance with the guidelines in Specification F 698, Practice F 770, and Practice F 853.

5.5.2 Use of the manufacturer's documentation and records should be limited to the regulatory approval process and dissemination shall be limited to minimize disclosure of proprietary and confidential documents.

6. Patron Restraint, Clearance Envelope, and Containment Design Criteria

6.1 *Patron Containment*:

6.1.1 The amusement ride or device shall be designed to support and contain the patron(s) during operation. This support and containment shall be consistent with the intended action of the ride or device.

6.1.2 Parts of amusement rides and devices that patrons may reasonably be expected to contact shall be smooth; free from unprotected protruding studs, bolts, screws, sharp edges and corners, and rough or splintered surfaces; and considered for padding as appropriate.

6.1.3 *Ride or Device Vehicle Doors*:

6.1.3.1 When amusement ride or device patron vehicles are provided with doors, measures shall be taken to ensure that the doors do not open during operation, failure, or in case of emergency, unless otherwise determined by the ride analysis.

6.1.3.2 Powered doors shall be designed to minimize pinch points and entrapment areas. The doors' (opening and closing) movement shall be controlled, and the maximum exerted force, measured on the edge of the door at the furthermost point from the hinge or pivot, shall not exceed 30 lb (133 N).

6.2 *Security of Patron Containment System*:

6.2.1 Any system or systems used to support and contain the patron(s) shall be securely fixed to the structure of the ride or device and shall have adequate strength for the intended forces produced by the ride or device and the reasonably foreseeable actions of the patron(s).

6.3 *Patron Restraints*:

6.3.1 Patron restraints shall be provided as determined by the designer/engineer. This determination shall be based on the patron restraint and containment analysis performed in accordance with criteria defined in this practice and shall take into consideration the nature of the amusement ride or device and the intended adult or child patron physical characteristics, based on anthropomorphic data such as Dreyfuss Human Scale 4/5/6 (**1**[20]), 7/8/9 (**2**), or SAE J–833, and Center for Disease Control Growth Charts.

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

6.3.3 Where kiddie rides or devices do not provide fully enclosed compartment (that is, so as to reject a 4 in. diameter sphere at all openings), a latching restraint shall be provided unless the patron restraint and containment analysis indicates a locking restraint is needed or a restraint is not appropriate (for example, a kiddie canoe ride).

6.3.3.1 Where kiddie rides or devices provide either latching or locking restraints, the final latching or locking position of the restraint must by adjustable in relation to the patron(s).

6.3.4 The patron restraint and containment analysis may identify the need for a restraint system for reasons other than acceleration or seat inclination. The analysis shall also evaluate the need for locking or latching functions when restraints are required.

6.3.5 A manual restraint release shall be provided for authorized personnel use.

6.3.5.1 The manual release should be conveniently located and easily accessed by authorized personnel without crawling over or under or otherwise coming in direct contact with the patrons.

6.3.5.2 External or unmonitored internal nonmechanical stored energy, for example, battery, accumulator, hydraulic, or pneumatic, shall not be used for a manual release unless otherwise determined by the ride analysis.

6.3.5.3 Special tools shall not be required to operate the manual release, unless otherwise determined by the ride analysis.

6.3.6 The manufacturer shall take into consideration the evacuation of patrons from any reasonably foreseeable position or situation on the ride or device, including emergency stops and stops in unplanned locations. The patron restraint and containment analysis shall address whether individual or group restraints releases are appropriate.

6.3.7 The manufacturer shall specify the state, locked or unlocked, of the restraint system in the event of unintended stop, for example, emergency stop or loss of power. This specification shall be based on the results of the ride analysis performed in 5.1.

6.3.8 Restraints shall be designed such that the opportunity for pinching or unintentional trapping of fingers, hands, feet, and other parts of the patron's body is minimized.

6.3.9 The maximum exerted force produced by any powered patron restraint device while opening or closing shall not be more than 18 lb (0.08 kN), measured on the active surfaces contacting the patron. Force limiting systems, if used to achieve this, shall be configured so that the failure of any one element of that system will still result in force being limited to 18 lb (0.08 kN).

6.3.10 The manufacturer shall take into account the patron-induced loads, for example, bracing, etc., in addition to the loads and criteria specified in the Loads and Strengths section of this practice.

6.3.11 The physical information provided in accordance with Specification F 698 shall be consistent with the patron restraint system, if any.

6.4 *Restraint Configuration*:

6.4.1 The restraint diagram shown in Fig. 2 shall be used as part the patron restraint and containment analysis for determining if a restraint is required, and if required, what type. The restraint diagram identifies and graphically illustrates five distinctive areas of theoretical acceleration. Each of the five distinctive areas may require a different class of restraint as indicated in 6.5 of this practice. The restraint diagram applies for "sustained acceleration" levels only. It is not to be applied for "impact acceleration."

6.4.2 The application of the restraint diagram is intended as a design guide. The ride analysis or other factors or requirements of this practice may indicate the need to consider another class of restraint (either higher or lower). Any special situation needs to be taken into consideration in designing the restraint system. These may include:

6.4.2.1 Duration and magnitude of the acceleration,

6.4.2.2 Height of the patron-carrying device above grade or other objects,

6.4.2.3 Wind effects,

6.4.2.4 Unexpected stopping positions of the patron units, for example, upside down,

6.4.2.5 Lateral accelerations, for example, where sustained lateral accelerations are equal to or greater than 0.5 G, special consideration shall be given to the design of seats, backrest, headrest, padding, and restraints, and

6.4.2.6 The intended nature of the amusement ride or device.

6.5 *Restraint Criteria*—Referring to areas on the restraint determination diagram shown in Fig. 2, as a minimum, the following restraint classes shall be used (in all areas, a higher class restraint device or individual requirements of a higher class restraint device may be used):

[20] The boldface numbers in parentheses refer to the list of references at the end of this standard.

6.5.1 *Area-1*—A Class-1 restraint is required.

6.5.1.1 A Class-1 restraint device is defined as unrestrained or no restraint at all.

6.5.1.2 Based solely on Area-1 dynamic forces, no restraint is required; however, other criteria in this practice (that is, the ride analysis) may require a higher class restraint device.

6.5.2 *Area-2*—A Class-2 restraint is required unless patrons are provided sufficient support and the means to react to the forces, for example, handrails, footrest or other devices. A Class-2 restraint device shall have at least the following:

6.5.2.1 *Number of Patrons Per Restraint Device*—The restraint device may be for an individual patron or it may be a collective device for more than one patron.

6.5.2.2 *Final Latching Position Relative to the Patron*—The final latching position may be fixed or variable in relation to the patron.

6.5.2.3 *Type of Latching*—The patron or operator may latch the restraint.

6.5.2.4 *Type of Unlatching*—The patron or operator may unlatch the restraint.

6.5.2.5 *Type of External Correct or Incorrect Indication*—No indication is required.

6.5.2.6 *Means of Activation*—The restraint may be manually or automatically (for example, motorized) opened and closed.

6.5.2.7 *Redundancy of Latching Device*—A redundant design is not required.

6.5.3 *Area-3*—A Class-3 restraint is required. A Class-3 restraint device shall have at least the following:

6.5.3.1 *Number of Patrons per Restraint Device*—The restraint device may be for an individual patron or it may be a collective device for more than one patron.

6.5.3.2 *Final Latching Position Relative to the Patron*—The final latching position must be variable in relation to the patron, for example, a bar or a rail with multiple latching positions.

6.5.3.3 *Type of Latching*—The restraint device may be manually or automatically latched. The manufacturer shall provide instructions that the operator shall verify the restraint device is latched.

6.5.3.4 *Type of Unlatching*—The patron may manually unlatch the restraint or the operator may manually or automatically unlatch the restraint.

6.5.3.5 *Type of External Correct or Incorrect Indication*—No external indication is required. The design shall allow the operator to perform a visual or manual check of the restraint each ride cycle.

6.5.3.6 *Means of Activation*—The restraint may be manually or automatically (for example, motorized) opened and closed.

6.5.3.7 *Redundancy of Latching Device*—A redundant design is not required.

6.5.4 *Area-4*—A Class-4 restraint is required. A Class-4 restraint device shall have at least the following:

6.5.4.1 *Number of Patrons per Restraint Device*—A restraint device shall be provided for each Individual patron.

6.5.4.2 *Final Latching Position Relative to the Patron*—The final latching position of the restraint must be variable in relation to the patrons, for example, a bar or a rail with multiple latching positions.

6.5.4.3 *Type of Locking*—The restraint device shall be automatically locked.

6.5.4.4 *Type of Unlocking*—Only the operator shall manually or automatically unlock the restraint.

6.5.4.5 *Type of External Correct or Incorrect Indication*—No external indication is required. The design shall allow the operator to perform a visual or manual check of the restraint each ride cycle.

6.5.4.6 *Means of Activation*—The restraint may be manually or automatically (for example, motorized) opened or closed.

6.5.4.7 *Redundancy of Locking Device*—Redundant design shall be provided for the locking device function.

6.5.5 *Area-5*—A Class-5 restraint is required. A Class-5 restraint shall have at least the following:

6.5.5.1 *Number of Patrons per Restraint Device*—A restraint device shall be provided for each individual patron.

6.5.5.2 *Final Latching Position Relative to the Patron*—The final latching position of the restraint must be variable in relation to the patrons, for example, a bar or a rail with multiple latching positions.

6.5.5.3 *Type of Locking*—The restraint device shall be automatically locked.

6.5.5.4 *Type of Unlocking*—Only the operator shall manually or automatically unlock the restraint.

6.5.5.5 *Type of External Correct or Incorrect Indication*—An external indication is required. Detecting the failure of any monitored device shall either bring the ride to a cycle stop or inhibit cycle start.

6.5.5.6 *Means of Activation*—The restraint may be manually or automatically (for example, motorized) opened or closed.

6.5.5.7 *Redundancy of Locking Device*—Redundant locking device function is required.

6.5.5.8 *Restraint Configuration*—Two restraints, for example, shoulder and lap bar or one fail-safe restraint device is required.

6.5.6 *Secondary Restraints for Class 5*—A Class-5 restraint configuration may be achieved by the use of two independent restraints or one fail-safe restraint. When two independent restraints are used, the secondary restraint device shall have the following minimum characteristics:

6.5.6.1 *Number of Patrons per Restraint Device*—The restraint device may be for an individual patron or it may be a collective device for more than one patron.

6.5.6.2 *Final Latching Position Relative to the Patron*—The final latching position may be fixed or variable in relation to the patron.

6.5.6.3 *Type of Locking*—Only the operator may manually or automatically lock the restraint.

6.5.6.4 *Type of Unlocking*—Only the operator shall manually or automatically unlock the restraint.

6.5.6.5 *Type of External Correct or Incorrect Indication*—No external indication is required other than a visual check of the restraint itself.

6.5.6.6 *Means of Activation*—The restraint may be opened or closed manually or automatically (for example, motorized).

6.5.6.7 *Redundancy of Locking Device*—The actuation means of the locking device shall be redundant.

6.6 *Patron Clearance Envelope Analysis*:

6.6.1 Amusement rides and devices shall be designed to provide a patron clearance envelope adequate to minimize the opportunity for contact between the patron and other objects where said contact is likely to cause injury.

6.6.2 The designer/engineer shall determine the shape and size of the required clearance envelope based on the appropriate patron model and the design of the patron containment system, if any. The minimum patron model shall be based on Dreyfuss Human Scale 4/5/6 **(1)**, 7/8/9 **(2)**, SAE J–833, or CDC 95th percentile, with an additional (extended) arm and leg reach of 3 in. (effectively a 99.9th percentile) male, adult or child, as appropriate. (See Section 2, Referenced Documents.) The following shall be considered:

6.6.2.1 The intended patron size and height and any designer/engineer specified restriction for minimum or maximum patron height.

6.6.2.2 The shape(s) and configuration of the patron containment system, including:

(1) Seats, armrest, seat back and sides, foot well, or other,

(2) Associated restraint system(s), if provided, for example, lap bar, seat belt, shoulder restraint, cage, or other, and

(3) The ability, as limited by the patron containment, of the patron to extend any part of his or her body, for example, arms and legs, outward beyond the perimeters of the vehicle.

6.6.2.3 The physical nature of surrounding objects or surfaces that might otherwise be contacted, for example, sharp, hard, rough or abrasive, ability to snag or trap and hold, or other attributes that may produce undesirable contact for the patrons of the ride or device.

6.6.2.4 The relative speeds and directions that contact might take place.

6.6.2.5 The reasonably foreseeable changes that are likely to occur in the location or nature of the surroundings, for example, other adjacent moving vehicles or objects and their physical nature and speeds.

6.6.2.6 The possibility of variations in the position or orientation of the patron carrying device, (for example, angular movement, side movement, unrestrained or undampened motion, or free swinging).

6.6.3 The patron clearance envelope analysis shall be in accordance with 6.6.2. These formats and the following definitions may be used as a guideline for determining minimum patron clearance envelope for amusement rides and devices.

6.6.3.1 The reach distance shall be the maximum reach, limited only by the vehicle and seat geometry and restraint system. The possibility of a patron extending arms or legs through vehicle openings or beyond the reasonably foreseeable reach shall be considered. The ride analysis performed in accordance with 5.1 may modify these requirements.

6.6.3.2 Where the design of an amusement ride or device allows contact within the clearance envelope between patrons and surrounding surfaces or objects, the manufacturer shall take reasonably appropriate measures to ensure that those surfaces or objects are configured to avoid hostile features such as splinters, sharp or sharply angled features or edges, protruding items, pinch points, or entrapment areas. This requirement is especially important in a ride or device load/unload area where patron control and assistance devices are provided.

6.6.3.3 When the design of an amusement ride and device allows patron-to-patron contact (for example, while seated in separate vehicles), the designer/engineer shall take reasonably appropriate steps to insure that the potential contact is appropriate for the amusement ride or device's intended use and the intended patron experience.

6.6.4 The designer/engineer or manufacturer shall determine a means by which direct measurement may be taken to confirm that the intended patron clearance envelope is attained in the completed amusement ride or device assembled in its operating location.

6.6.4.1 The determined means shall include points from which measurements may be taken. The locations of these points shall be illustrated with appropriate drawings in the manufacturer provided instructions or they may be physical markers on the amusement ride or device.

6.6.4.2 The determined means and clearance distances shall be shown in a convenient form and illustrated both graphically and numerically. Illustrations similar to Figs. 3 and 4 are one acceptable method.

6.6.5 Any moveable system or device designed to encroach on the clearance envelope, that is, loading/unloading platforms, decks, or other devices, shall be designed in a fail-safe manner in order to prevent undesirable contact.

6.7 *Signage*—The manufacturer shall determine and may make recommendations for appropriate advisory signs or warning signs based on the attributes of the amusement ride or device. These recommendations should be clear and concise but are not intended to be the final wording of the signs that may be generated and displayed at the ride or device.

7. Acceleration Limits

7.1 *Acceleration Limits*:

7.1.1 Amusement rides and devices shall be designed such that the ride dynamics, when measured as provided herein, are within the limits specified in this practice. Test data intended for evaluation against the limits specified in this practice shall be acquired and prepared as follows:

7.1.1.1 The data shall be acquired in accordance with the provisions of the Standard Amusement Ride Characterization (SARC) test, as specified in Section 12 of Practice F 2137

7.1.1.2 The acquired SARC test data shall be post-processed, with a 4-pole, single pass, Butterworth low pass filter using a corner frequency (Fc) of 5 Hz.

7.1.2 Amusement rides and devices or major modifications that are designed to operate outside the acceleration limits herein shall include justification in the ride analysis. The justification shall include a review by a biodynamic expert.

7.1.3 Acceleration can vary greatly depending on the type and design of the amusement ride or device, and the effect of

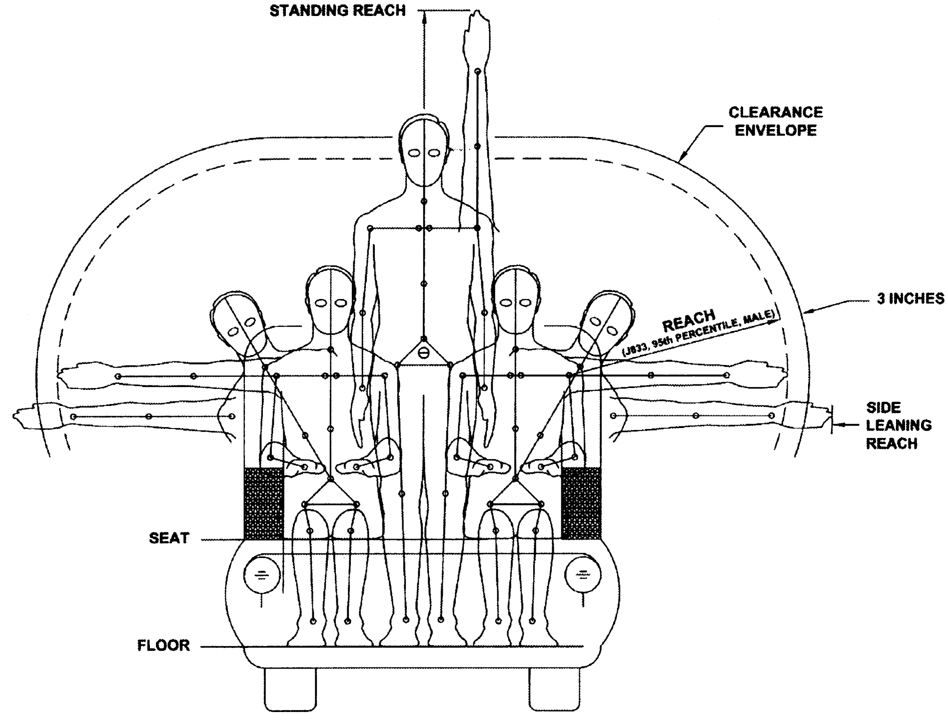


FIG. 3 Sample Patron Clearance Envelope—Front View

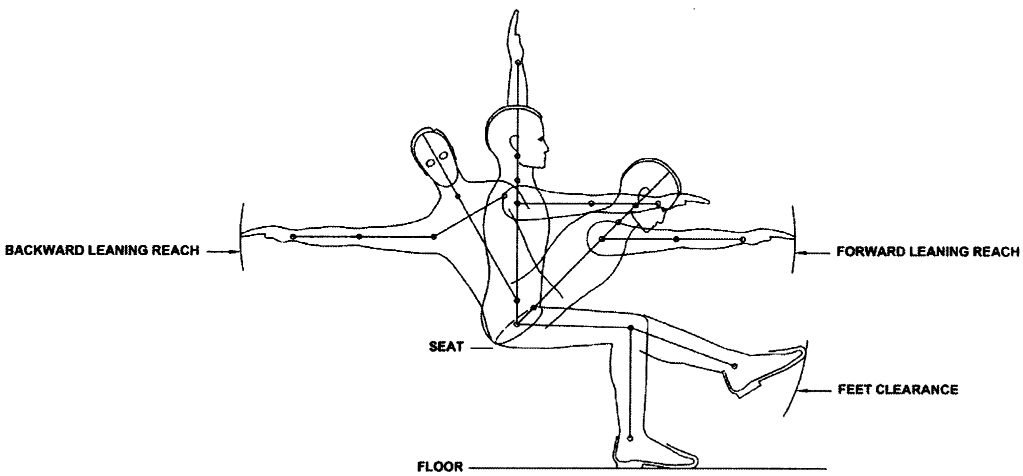


FIG. 4 Sample Patron Clearance Envelope—Side View

these accelerations is dependent on many factors that may be considered in the design (see Appendix X2). Accelerations shall be coordinated with the intended physical orientation of the patron during the operating cycle. Rides and devices with patron containment systems shall be designed such that the patron is suitably contained and positioned to accept these accelerations. The patron restraint and containment analysis shall consider cases related to patron position within the restraint as determined by the designer/engineer. Fig. 1 illustrates the coordinate system utilized.

7.1.4 Sustained acceleration limits are shown in this section (see Figs. 5-9). The following definitions apply:

7.1.4.1 Acceleration units are "G" (32.2 ft/s/s or 9.81 m/s/s).

7.1.4.2 Impacts of less than 200 ms duration are not addressed by this practice.

7.1.4.3 Acceleration limits herein are for patrons 48 in. in height and above. The designer/engineer shall determine whether more restrictive limits are appropriate for an amusement ride or device that accommodates patrons under 48 in. in height. In making this determination, the designer/engineer shall consider biodynamic effects on the patrons. If an amusement ride, device, or major modification that accommodates patrons under 48 in. in height is designed to operate outside the acceleration limits herein, the ride analysis must include a review by a biodynamic expert.

7.1.4.4 Because of insufficient data, the suitability of the acceleration limits herein for disabled patrons must be addressed on an individual basis.

7.1.4.5 The limits specified for all axes are for total net acceleration, inclusive of earth's gravity. A motionless body

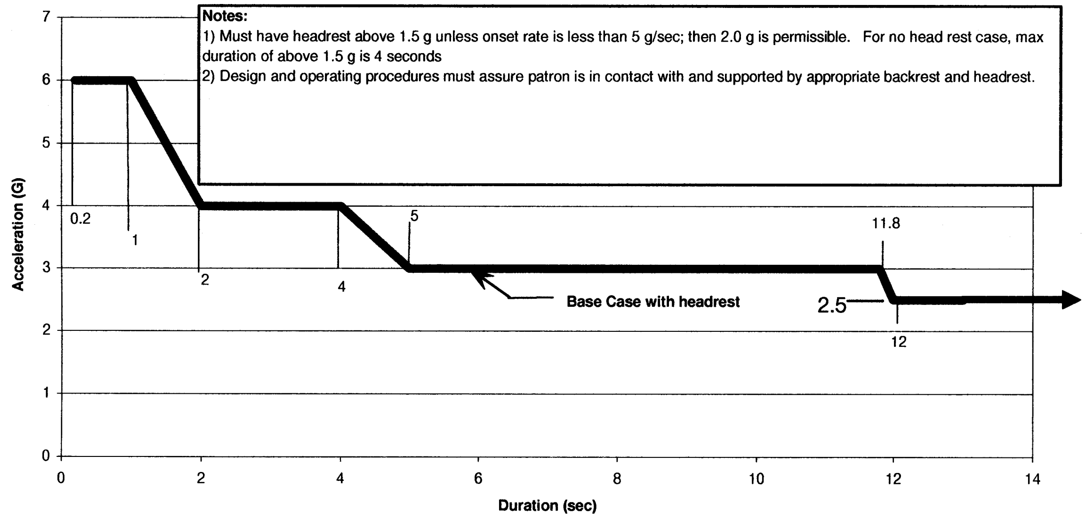


FIG. 5 Time Duration Limits for +Gx (Eyes Back)

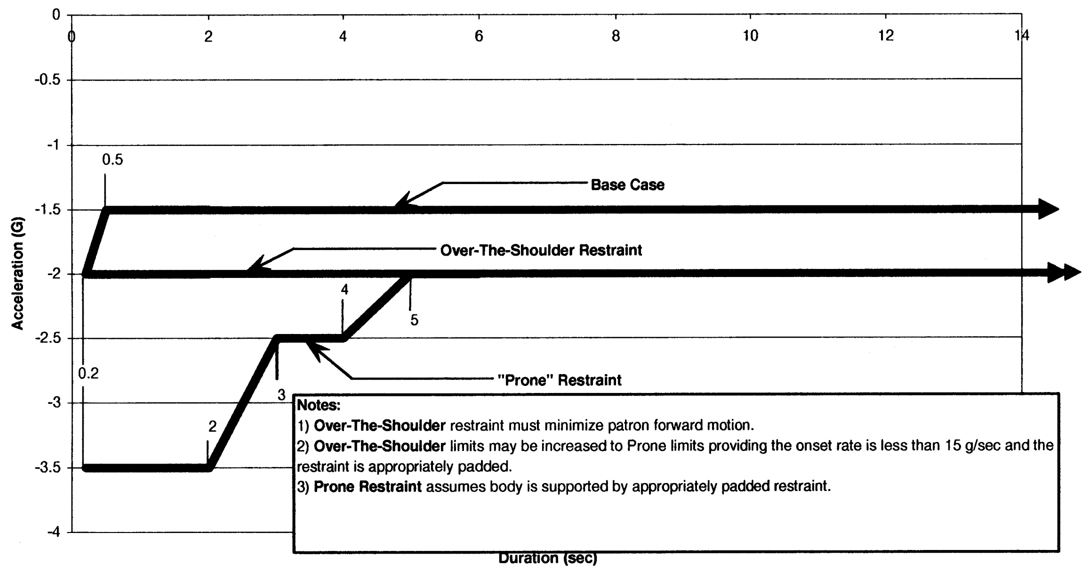


FIG. 6 Time Duration Limits for –Gx (Eyes Front)

would therefore have a magnitude of 1 G measured in the axis perpendicular to the earth's surface, and a zero G magnitude in the axes parallel to the earth's surface.

7.1.4.6 Steady state values in the charts are not limited in time unless otherwise specified. Sustained exposure in excess of 90 s has not been addressed by this practice.

7.1.4.7 These limits are provided for the following basic restraints types:

(1) Base Case (Class-4 or -5 Restraint)—For the purpose of acceleration limits the Class-4 restraint used as the base case herein also provides support to the lower body in all directions and maintains patron contact with the seat at all times.

(2) Over-the-Shoulder (Class-5 Restraint)

(3) Prone Restraint—A prone restraint is one in which the patron is oriented face down at a point or points during the ride cycle. A prone restraint is a restraint designed to allow the patron to accept higher acceleration in the –Gx (eyes front) as compared to the base case and over-the-shoulder restraints.

NOTE 1—The patron restraint and containment analysis shall be used to determine the type of restraint. The type and performance of the restraint system selected may require a reduction in the acceleration limit.

7.1.5 Simultaneous combinations of single axis accelerations shall be limited as follows:

7.1.5.1 The instantaneous combined acceleration magnitude of any two axes shall be limited by a curve that is defined in each quadrant by an ellipse. The ellipse is centered at (0,0) and is characterized by major and minor radii equal to the allowable 200 ms G limits × 1.1. Graphical representations of this requirement are presented in Figs. 10-17. Note that for a given ride, only three of the curves will apply.

7.1.6 Reversals in X and Y accelerations are shown in Fig. 18. The following criteria shall apply:

7.1.6.1 The peak-to-peak transition time between consecutive sustained events in X and Y accelerations shall be greater than 200 ms, as measured by the time between the peaks of the consecutive events. When the elapsed time between consecutive sustained events is less than 200 ms, the limit for the peak values shall be reduced by 50 %.

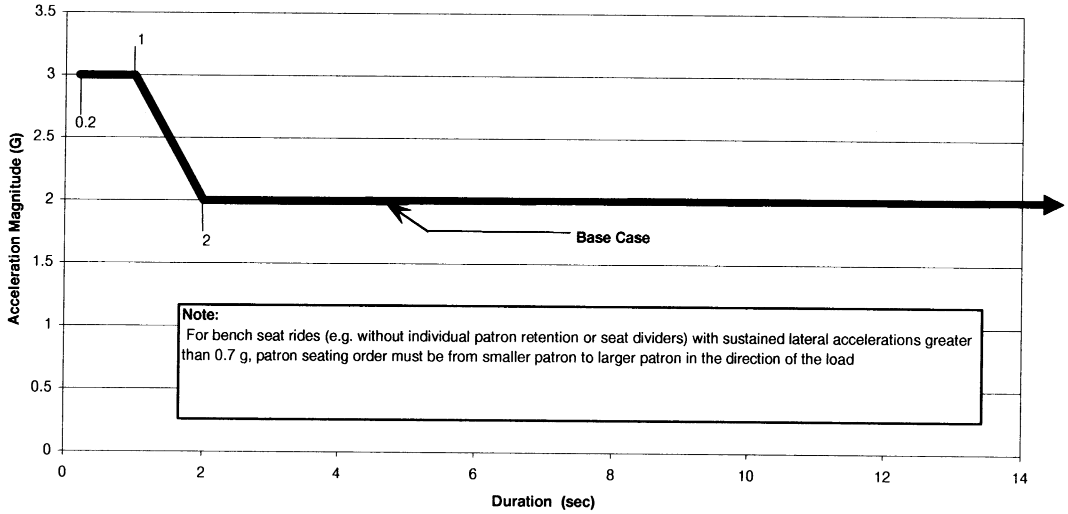


FIG. 7 Time Duration Limits for ±Gy (Eyes Left or Eyes Right)

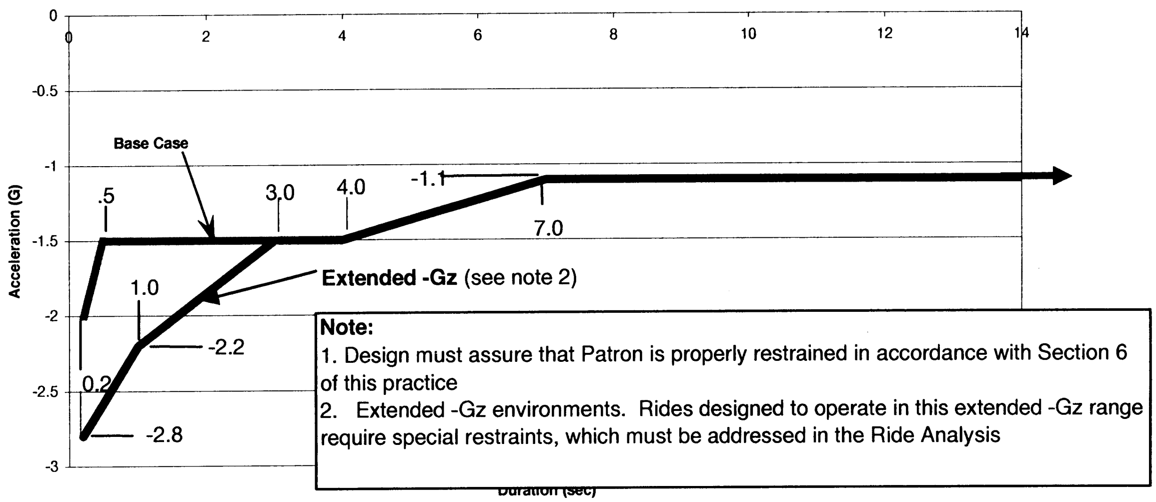


FIG. 8 Time Duration Limits for –Gz (Eyes Up)

7.1.6.2 The following examples illustrate such reversal:

7.1.7 *Transitions in Z*:

7.1.7.1 Transition directly from negative (eyes up) limits to positive (eyes down) limits is restricted. If Patrons are exposed to a negative Gz environment for more than 3 s, then the limits are reduced as shown in the +Gz limit chart for 6 s after the transition to positive Gz. After the 6 s period, the limits may be increased to the normal chart levels.

7.1.7.2 Other transitions in Z accelerations are shown in Fig. 19. The following criteria shall apply: When transitioning from sustained weightless (0 G) and more negative levels to 2 G and more positive levels, the effective onset of positive G shall be less than 15 G/s. Fig. 19 illustrates such transitions.

7.1.8 Measurement and analysis of acceleration on amusement rides and devices shall be performed in accordance with Practice F 2137. The design acceleration levels of the final operational assembly of a newly developed amusement ride, device, or major modification shall be verified at commissioning. The manufacturer may verify acceleration limits herein by using either manual (for example, graphic, hand calculations, etc.) or automatic (for example, computational, computer, etc.) procedures.

8. Loads and Strengths

8.1 *Overview*:

8.1.1 This section defines the loads and strengths criteria that shall be applied in the process of design for amusement rides and devices and in the process of design for major modifications made to amusement rides and devices. This criteria is specifically intended for use in determining the loads and strengths of materials, and in performing the calculations and analyses used in the process of design.

8.2 *General*:

8.2.1 Amusement rides and devices shall be designed so that load conditions expected during operation shall not cause failures during the operational hours used in the design per 8.3 and 8.4.

8.2.1.1 In general, amusement rides and devices shall be designed so the expected loading conditions will not cause

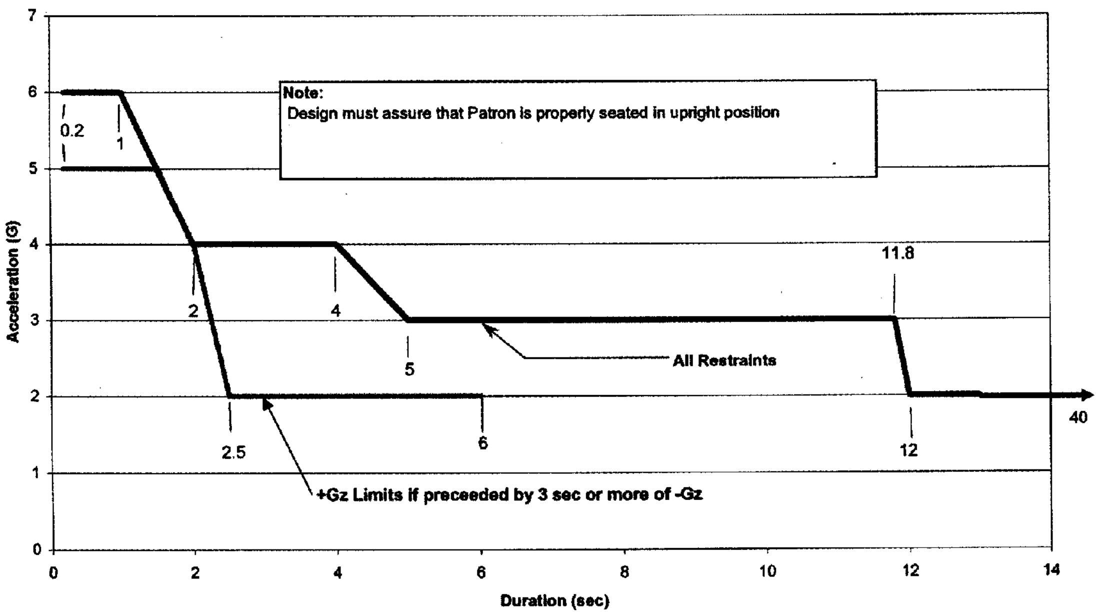


FIG. 9 Time Duration Limits for +Gz (Eyes Down)

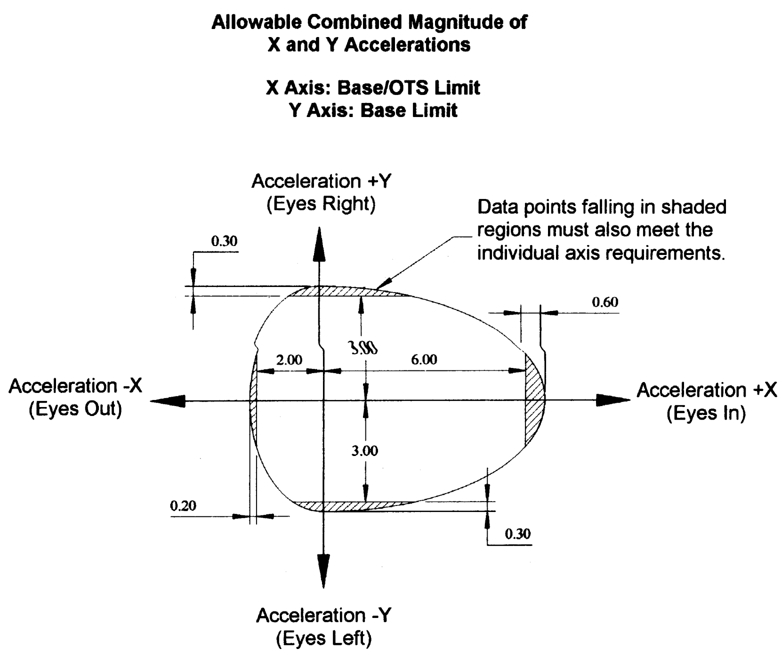


FIG. 10 Allowable Combined Magnitude of X and Y Accelerations

stresses to exceed the yield strength of the materials (that is, no significant plastic deformation should occur when structures and components are subjected to expected loads). One exception to this generality is that when designed for seismic loads, seismic design allows for the possibility of plastic deformation and relies on connection ductility to absorb energy.

8.2.1.2 A possible exception to 8.2.1 may be made in the case of components and portions of structures that are intended to provide secondary load paths during a failure condition (not to be interpreted as an emergency-stop event). Components such as safety cables or links and certain limited portions of the primary structure that they are attached to, may be designed to yield (and thus absorb a significant amount of energy) when subjected to load conditions expected to occur during a plausible, although unlikely primary structure failure scenario. In such cases, the expected failure mode loading shall not cause rupture to occur (that is, the stresses shall not exceed the ultimate strength). Designs that rely on such criteria shall utilize materials that possess high elongation for components where stresses may be expected to exceed the yield strength under failure mode loading conditions.

8.3 *35 000 Operational Hour Criteria*:

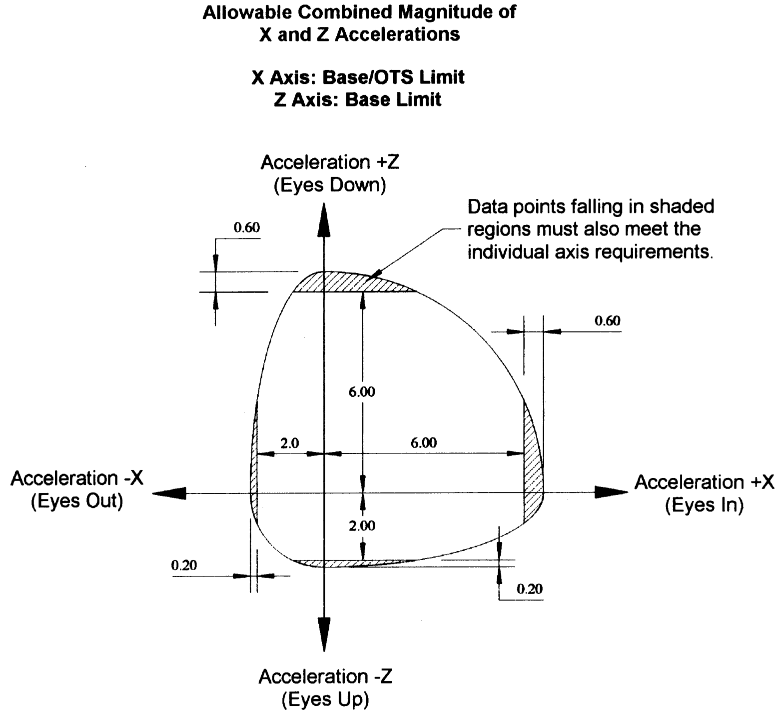


FIG. 11 Allowable Combined Magnitude of X and Z Accelerations

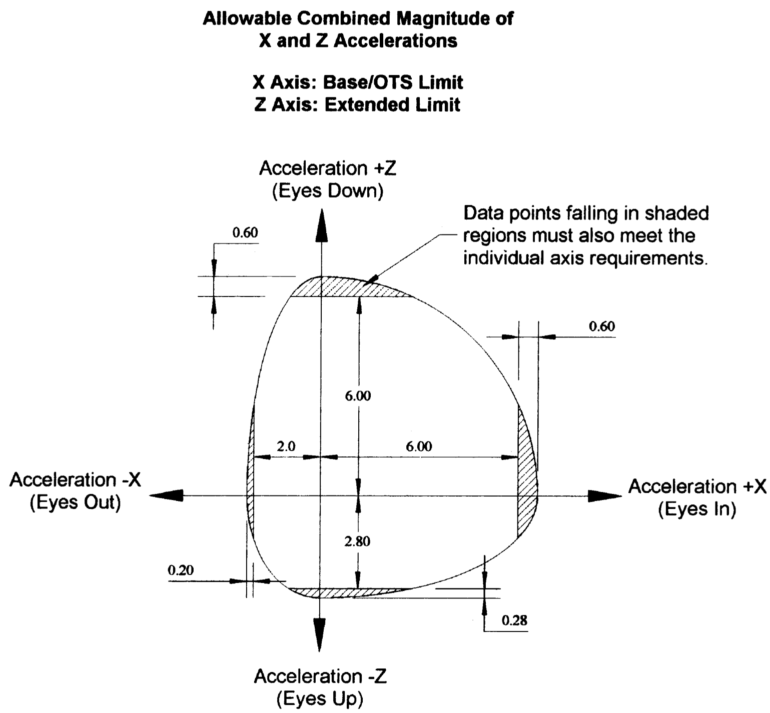


FIG. 12 Allowable Combined Magnitude of X and Z Accelerations

8.3.1 All primary structures of an amusement ride or device (for example, track, columns, hubs, and arms) shall be designed using calculations and analyses that are based on the minimum 35 000 operational hour criteria. The designer/engineer shall verify that the calculations and analyses meet or exceed this minimum operational hour requirement. This requirement is intended to ensure that all primary structures within an amusement ride or device are designed for at least a minimum fatigue life.

8.3.2 An “operational hour” is defined as an hour of time during the normal operation of the amusement ride or device. Normal operation includes startup (that is, beginning of the operational day), operation, and shutdown (that is, end of the operational day). Those periods of time that the amusement

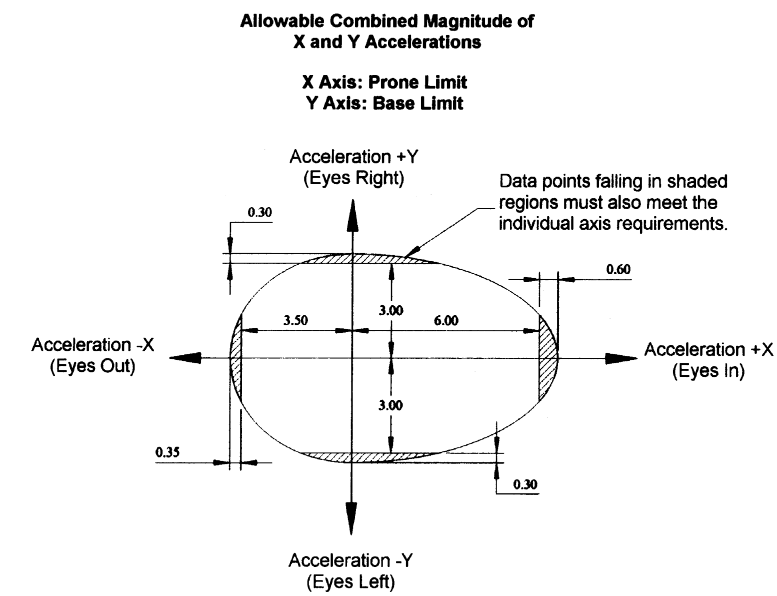


FIG. 13 Allowable Combined Magnitude of X and Y Accelerations

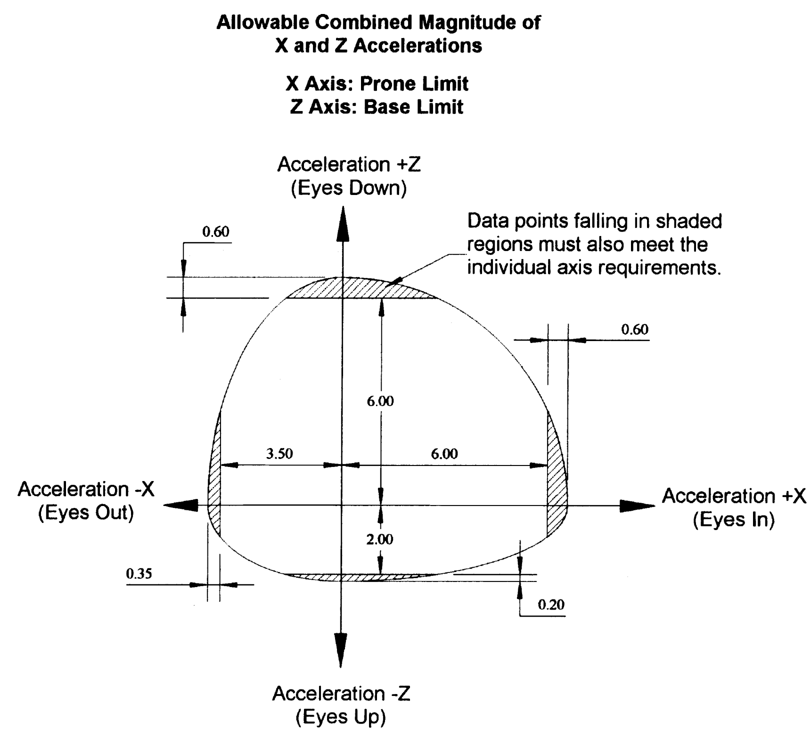


FIG. 14 Allowable Combined Magnitude of X and Z Accelerations

ride or device is not being operated (that is, nonoperating hours, seasonal park closures, or transit times for portable rides and devices) shall not be included in the operational hour calculations.

8.3.2.1 Calculations for the 35 000 operational hour criteria can include a general reduction to account for the load and unload time of the amusement ride or device. The value selected for the reduction shall be based on the specific amusement ride or device and the designer/engineer-defined load and unload times. This reduction shall be limited to a maximum of 50 % of the 35 000 operational hour criteria for the amusement ride or device. The amount of operational hours calculated after applying the general reduction for load and unload times will be the value used for the design calculations and analyses.

Calculation to Determine the General Reduction for Load and Unload Time:

$$\left(\frac{\text{(Total load/unload time for one ride cycle)}}{\text{(Total load/unload time for one ride cycle)} + \text{(Time for one ride cycle)}}\right)$$

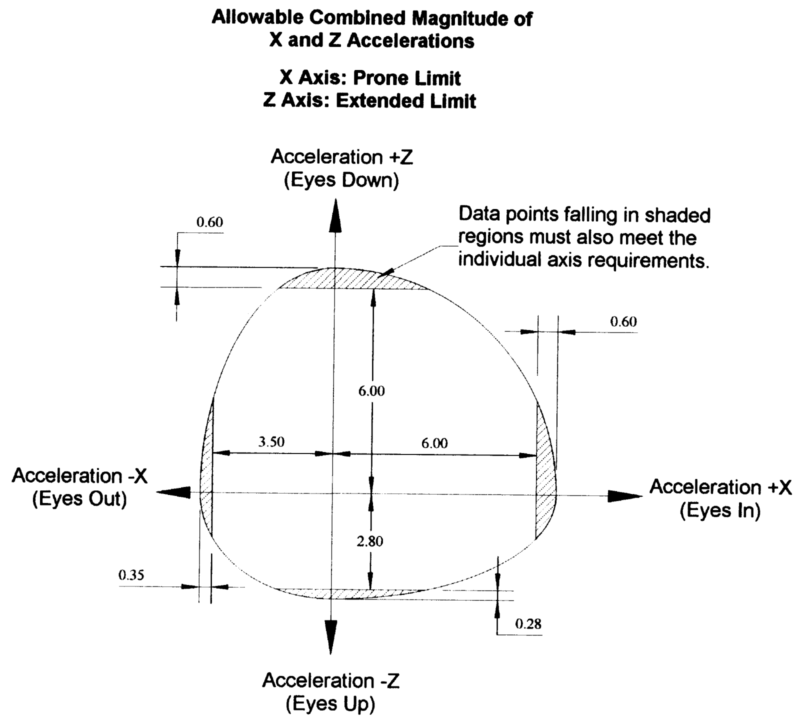


FIG. 15 Allowable Combined Magnitude of X and Z Accelerations

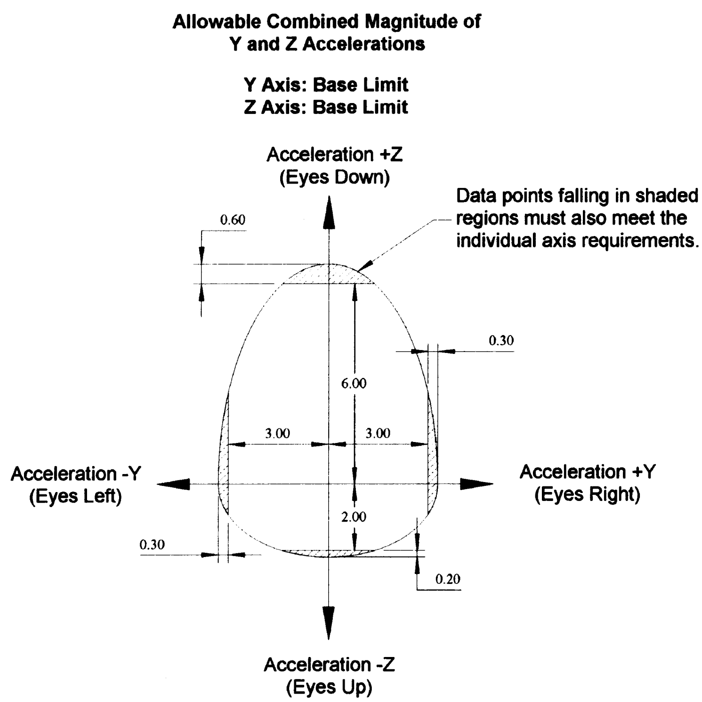


FIG. 16 Allowable Combined Magnitude of Y and Z Accelerations

= General reduction for load/unload time

Calculation to Determine the Operational Hours to be Used in the Applicable Design Calculations and Analyses for the Amusement Ride or Device:

$$[(35\,000 \text{ Operational hours Criteria}) \times (1.00 - \text{general reduction for load/unload time})]$$

= Operational hours

8.3.3 The designer/engineer shall determine the ride cycle time, and the load and unload time to be used in the calculations to determine the operational hours. These values

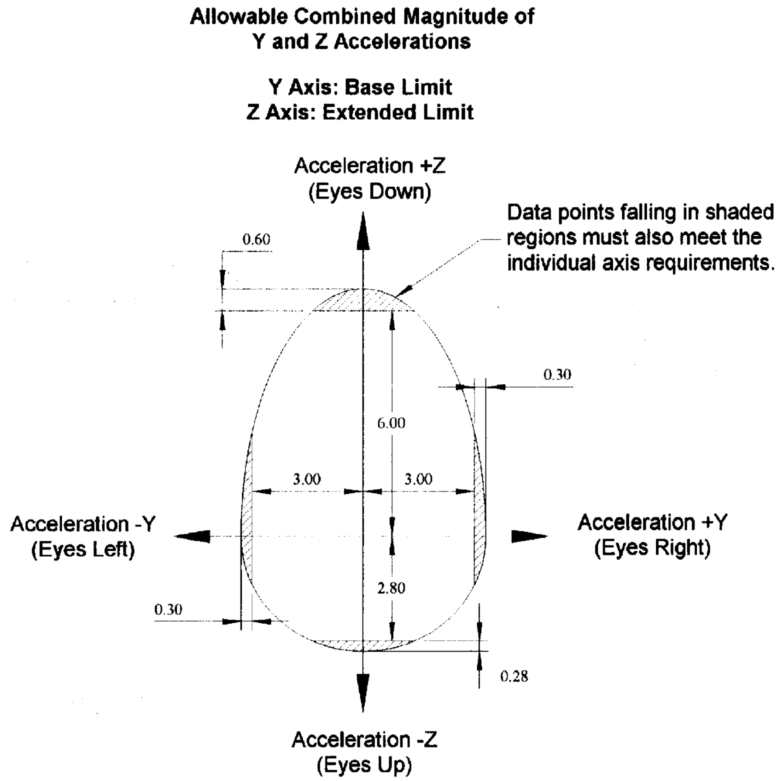


FIG. 17 Allowable Combined Magnitude of Y and Z Accelerations

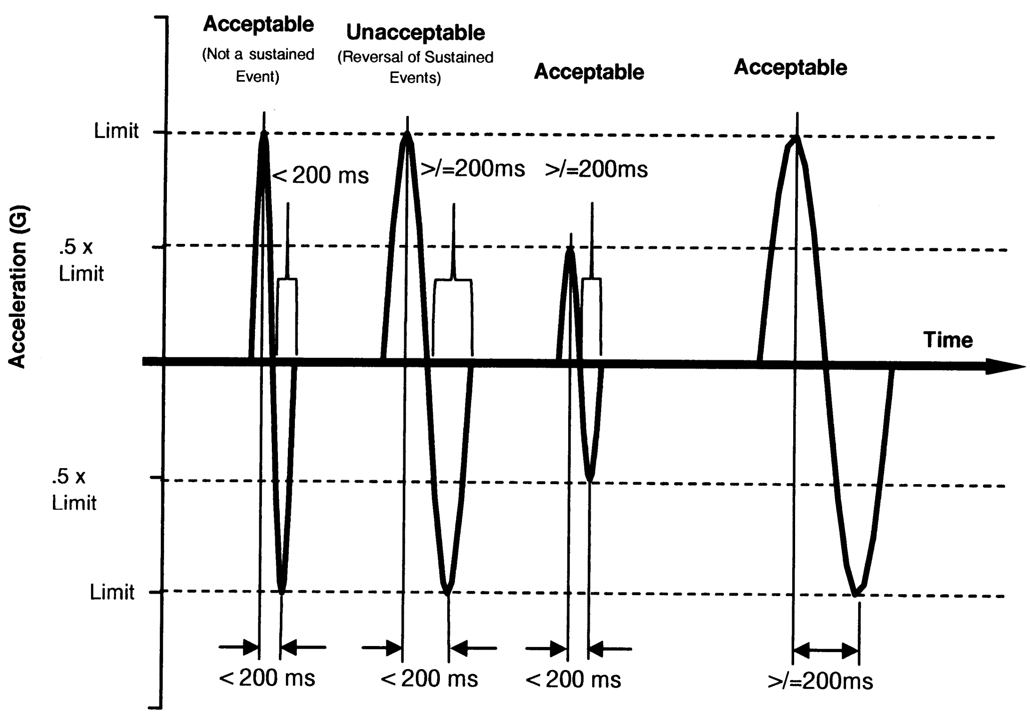


FIG. 18 Reversals in X and Y (5 Hz Filtered Data)

are for design calculation and analysis purposes only and shall not be interpreted as operational requirements for the amusement ride or device.

8.4 *Exceptions to the 35 000 Operational Hour Criteria*:

8.4.1 Specific components of an amusement ride or device structure can be excluded from the 35 000 operational hour criteria only when such components are replaced or inspected and reevaluated per the designer/engineer's instructions. This

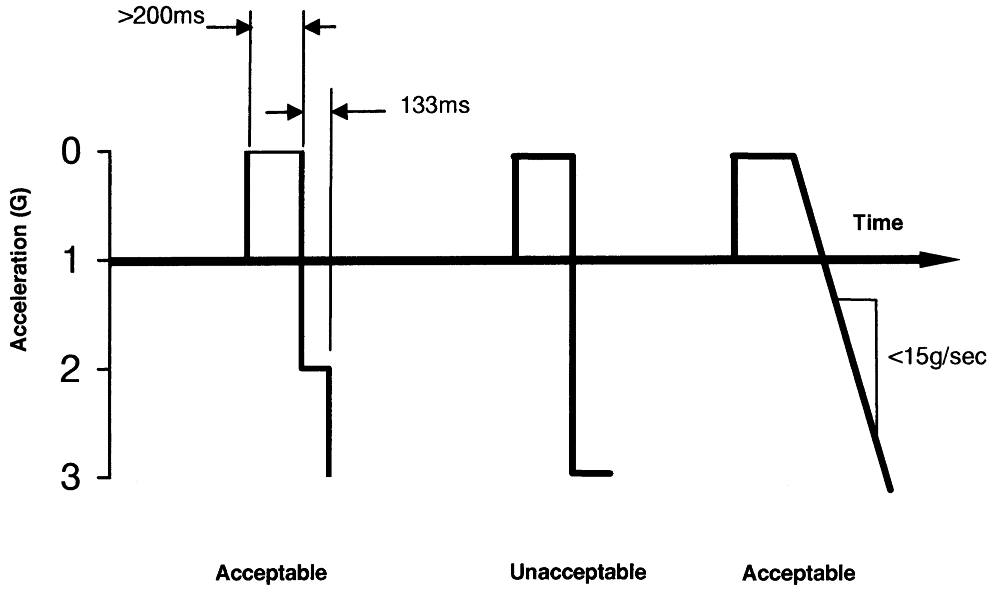


FIG. 19 Transitions from Sustained –Gz (Eyes Up) to +Gz (Eyes Down) (5 Hz Filtered Data)

exclusion applies only to "components" that are replaceable by disassembly and reassembly, (that is, attached with fasteners, for example, bushings, bearings, removable pins, axles, bogies, inter-car connections, hydraulic pumps, and electric motors), and does not include components that are permanently attached (that is, welded) to the "primary structure." This requirement does not exclude the use of primary components connected to the primary structure with fasteners or a primary structure that is connected with fasteners.

8.4.2 The designer/engineer shall identify and list all components of the primary structure excluded from the 35 000 operational hour criteria, including the criteria for replacement or inspection and reevaluation, in the operating and maintenance instructions for the amusement ride or device. See section on Manufacturer's Responsibility in Practice F 770 and section on Manufacturer's Responsibility in Practice F 853.

8.4.3 Specific components of an amusement ride or device structure designed to take advantage of this specific exception to the 35 000 operational hour criteria are not exempt from other criteria listed within this practice.

8.5 *Operation Beyond the 35 000 Operational Hour Criteria*:

8.5.1 The minimum 35 000 operational hour criteria is not intended to be, nor should it be interpreted to be, an absolute limit of the operational hours for an amusement ride or device. Owners and operators of amusement rides and devices commonly extend the operational hours of these systems significantly by performing proper reevaluations, inspections, repairs, refurbishment, and ongoing maintenance by appropriately qualified personnel. (See the section on Owner/Operator Responsibility in Practice F 853, and the section on Owner/Operator Responsibility in Guide F 893.)

8.6 *Patron Weights*:

8.6.1 The weight assigned to an adult patron, for design purposes, shall be 170 lb or 0.75 kN.

8.6.2 The weight assigned to a child patron, for design purposes, shall be 90 lb or 0.40 kN.

8.6.3 As a fatigue case, amusement rides and devices designed for adult and child patrons shall be designed to operate during typical ride or device operating cycles with a full patron payload of 170 lb or 0.75 kN located at all available seat positions.

8.6.4 As a fatigue case, amusement rides and devices designed for adult and child patrons shall be designed to operate during typical ride or device cycles with partial payloads (that is, worst case unbalanced load as specified for fatigue by the designer/engineer) of adult patrons.

8.6.5 As a fatigue case, amusement rides and devices designed for child patrons shall be designed to operate during typical ride or device operating cycles with a full patron payload of 90 lb or 0.40 kN located at all available seat positions.

8.6.6 As a fatigue case, amusement rides and devices designed for child patrons shall be designed to operate during typical ride or device cycles with partial payloads (that is, worst case unbalanced load as specified by the designer/engineer) of child patrons.

8.6.7 Any specific limitations to operating with partial or maximum payloads assumed by the designer/engineer in the load calculations (that is, certain kinds of eccentric loading not allowed during operation), shall be clearly specified in the operating restrictions within the operating and maintenance instructions. (See section on Owner/Operator Responsibility in Practice F 853 and section on Owner/Operator Responsibility in Guide F 893.)

8.6.8 As a nonfatigue, dynamic case, amusement rides and devices shall be designed for occasional full or partial payloads of large adult patrons weighing 300 lb per seat or an appropriate lesser amount if patrons are limited by the size of the seat or restraint or both. This means that if an adult patron weighing 300 lb cannot fit into an amusement ride or device due to limitations with the size of the seat or restraint or both, then the amusement ride or device does not have to be designed to accommodate for occasional full or partial payloads of large adult patrons weighing 300 lb per seat. In this case, the amusement ride or device shall be designed to accommodate occasional full or partial payload of the heaviest adult patrons that the amusement ride or device can physically accommodate.

8.6.8.1 Section 8.6.8 is for calculation purposes only and shall not be interpreted as a requirement for the operation of the amusement ride or device. In addition, 8.6.8 shall apply to elastic deflection and permanent deformation load calculations only.

8.7 *Loads*:

8.7.1 All designer/engineer-defined applicable loads that the amusement ride or device may be subjected to shall be considered.

8.7.2 Load calculations shall be performed for all amusement rides and devices.

8.7.3 The appropriate empirical tests shall be performed as soon as practical on the amusement ride or device (for example, weigh ride vehicles, measure acceleration and deceleration) to verify that the design assumptions used and weights and loads calculated are in accordance with the empirically measured values.

8.8 *Permanent Loads*:

8.8.1 Permanent loads (that is, dead loads) for an amusement ride or device include all loads that do not fluctuate with respect to time during operation of the amusement ride or device.

8.9 *Variable Loads*:

8.9.1 Variable loads (that is, live load) for an amusement ride or device include all loads that fluctuate with respect to time. Variable loads are divided into four subsets: operational loads, nonoperational loads, environmental loads, and operation in wind.

8.10 *Operational (Dynamic) Loads*:

8.10.1 Operational loads include varying loads normally encountered during operation of the amusement ride or device.

8.10.2 Both high (number of) cycle and low (number of) cycle dynamic loads shall be considered.

8.11 *Nonoperational Loads*:

8.11.1 All loads associated with transportation or handling or both (that is, setting up, tearing down) and ongoing maintenance of portable and permanent amusement rides or devices shall be considered in the analysis.

8.12 *Environmental Loads*:

8.12.1 Portable amusement rides and devices shall be designed to resist all Designer/Engineer defined environmental loads.

8.12.2 Fixed or permanent amusement rides and devices shall be designed to resist all applicable environmental loads for the intended location in accordance with the environmental loads in the applicable building codes for the intended location.

8.12.3 The designer/engineer shall clearly indicate the environmental loads the amusement ride or device was designed for, in the operating and maintenance instructions. See section on Manufacturer's Responsibility in Practice F 770 and section on Manufacturer's Responsibility in Practice F 853. In addition to the environmental load information, any restrictions, limitations, or special procedures associated with amusement rides or devices exposed to these environmental loads shall be included.

8.13 *Operation in Wind*:

8.13.1 As a minimum, amusement rides and devices exposed to wind shall be designed to operate in winds up to 34 mph (15 m/s).

8.13.2 The designer/engineer or manufacturer shall include any restrictions, limitations, or special procedures for the safe operation of an amusement ride or device exposed to wind, in the operating and maintenance instructions. See section on Manufacturer's Responsibility in Practice F 770, and section on Manufacturer's Responsibility in Practice F 853.

8.14 *Nonoperational In Wind*:

8.14.1 The designer/engineer or manufacturer shall include any restrictions, limitations, or special procedures for nonoperating or out-of-service amusement rides and devices, and their associated components exposed to wind, in the operating and maintenance instructions. See section on Manufacturer's Responsibility in Practice F 770 and section on Manufacturer's Responsibility in Practice F 853.

8.15 *Design*:

8.15.1 A structural analysis shall be performed for each amusement ride or device to verify that there is adequate structural capability in the design.

8.15.2 The type of calculation or analysis selected shall be a widely recognized and generally accepted engineering practice.

8.15.3 The structural analyses performed shall consider and incorporate all significant loads and identify all significant stresses and strains that are foreseen to be experienced by the amusement ride or device. See 8.7 for applicable loads.

8.15.4 Structures shall be analyzed to verify that significant plastic deformation or collapse or both does not occur under any reasonably foreseeable designer/engineer defined loading condition expected to occur a limited number of times throughout the operational hours used in the design per 8.3 and 8.4. Examples include environmental loads, patrons attempting to apply excessive (that is, abusive) loads to restraints, extremely heavy patron weights, and loads generated by E-stop events.

8.15.5 A deflection analysis shall be performed if deformations in structural members or structural systems due to expected loading conditions could impair the serviceability of the structure. See 8.20 on Serviceability.

8.15.6 The structural analysis for the amusement ride or device shall consider "strength" and "fatigue" criteria in the evaluation of stresses resulting from the application of loads. The number of times that a specific load or combination of loads is expected to occur throughout the designated number of operational hours for the amusement ride or device shall determine whether the resulting stress levels will be compared to strength or strength and fatigue material allowables. The method of analysis and load factors applied to specific loads shall be selected and based upon the number of times loads are expected to occur during the specified number of operational hours (that is, strength versus fatigue evaluation).

8.15.7 The yield and ultimate strengths and fatigue properties of the materials utilized for all components that could affect safety upon failure of the component shall be evaluated. Empirical testing, or empirical testing in combination with analysis, may be used as a means of evaluating the strength and fatigue properties of the materials for these components. If empirical testing is used for evaluation, the designer/engineer shall clearly specify and describe the testing procedure and refer to Guide F 846.

8.16 *Impact Factor for Strength and Fatigue Analysis*:

8.16.1 An impact factor of not less than 1.2 shall be applied to all moving (dynamic) loads. If the manufacture or operation of the structure leads to a higher value, the higher value shall be used in the calculations.

8.16.2 An impact factor more than 1.0 and less than 1.2 can be applied to all moving (dynamic) loads only when the actual impact forces are empirically measured and do not exceed the product of the impact factor and the calculated load.

8.16.3 If impact forces (for example, due to vehicles operating over track rail joints), empirically measured during trial runs on the completed structures in the amusement ride or device, are significantly higher than calculated values, then the calculations shall be revised to reflect the measured empirical forces.

8.16.4 If the revised calculations show any deficiencies in the structure, then modifications shall be made to correct the deficiencies, and the empirical tests shall be repeated.

8.16.5 The impact and vibration loads associated with operation of the amusement ride or device when the maximum allowable wear limits for applicable components are reached (as defined by the designer/engineer) shall be considered.

8.17 *Anti-rollback Devices*:

8.17.1 An impact factor of not less than 2.0 shall be applied to anti-rollback devices. If the manufacture or operation of the anti-rollback structures leads to a higher value, the higher value shall be used in the calculations.

8.17.2 The fatigue properties for anti-rollback devices shall be verified when operation can cause fatigue damage to the anti-rollback device or its related structures. Otherwise only the strength properties of the anti-rollback device need be verified.

8.18 *Vibration Factor for Structural Ride (or Device) Track Components for Strength and Fatigue Analysis*:

8.18.1 A vibration factor of 1.2 shall be applied to dynamic loads resisted by the amusement ride or device track (that is, track rails, ties, and tie connections). If the manufacture or operation of the structure leads to a higher value, the higher value shall be used in the calculations. This vibration factor is in addition to applicable impact factors.

8.18.2 Vibration factors need not be applied to supports or suspensions of the structural components, (that is, track backbone, columns) or factored into calculations of:

8.18.2.1 Ground pressures,

8.18.2.2 Settling, and

8.18.2.3 Stability and resistance to sliding.

8.19 *Resonance Protection*:

8.19.1 Certain structures may require special additional provisions for the reduction or attenuation of undesirable vibrations (for example, resonance). Examples of special provisions may include the addition of structural members or adding damping devices to the system.

8.20 *Serviceability*:

8.20.1 The design of the overall structure and the individual members, connections, and connectors shall be checked for serviceability (that is, deflection, vibration, deterioration, as defined in AISC). Provisions applicable to design for serviceability are given in AISC M015, Chapter L.

8.20.2 Machinery support structures and bases shall be designed with adequate rigidity and stiffness to maintain the required alignment of movable components.

8.21 *Design for Strength*:

8.21.1 One of two accepted methods for assuring adequate strength for amusement rides or devices shall be selected and used: Load and Resistance Factor Design (LRFD) or Allowable Stress Design (ASD).

8.21.2 Only the load factors and allowables from the method selected shall be used in calculations. Load factors or allowable from one method shall not be used in combination with load factors or allowables from he other method.

8.22 *Load Combinations For Strength Using ASD*:

8.22.1 The following nominal loads are to be considered:

D: Permanent load due to the weight of the structural elements and the permanent features on the structure,

L: Variable load due to occupancy and moveable equipment,

L_R: Roof live load,

W: Wind load,

S: Snow load,

E: Earthquake load determined in accordance with the applicable local code or ANSI/ASCE 7,

NOTE 2—This practice does not require portable amusement rides and devices to be designed for seismic loads. However, when a portable amusement ride or device is designed for seismic loads, a description of these loads will be stated in the strength calculations, and included in the operating and maintenance instructions. See section on Manufacturer's Responsibility in Practice F 770 and section on Manufacturer's Responsibility in Practice F 853.

F: Load due to fluids with well-defined pressures or maximum heights or both,

H: Load due to the weight and lateral pressure of soil and water in soil,

R: Load due to initial rainwater or ice exclusive of the ponding contribution, and

T: Load due to self-straining forces arising from differential settlements of foundations and from restrained dimensional changes due to temperature, moisture, shrinkage, creep, and similar effects.

8.22.2 The required strength of the structure and its elements shall be determined from the appropriate critical combination of loads. The most critical effect may occur when one or more loads are not acting. The following load combinations shall be investigated:

$$D$$

$$D + L + F + H + T + (L_R \text{ or } S \text{ or } R)$$

$$D + (W \text{ or } E)$$

$$D + L + (L_R \text{ or } S \text{ or } R) + (W \text{ or } E)$$

8.23 *Material Allowables for Strength Using ASD*:

8.23.1 The material allowables used in the ASD analyses shall be selected from an appropriate ASD reference.

8.24 *Load Combinations for Strength Using LRFD*:

8.24.1 The following nominal loads shall be considered:

D: Permanent load due to the weight of the structural elements and the permanent features on the structure,

L: Variable load due to occupancy and moveable equipment,

L_R*:* Roof live load,

W: Wind load,

S: Snow load,

E: Earthquake load determined in accordance with the applicable local code or ASCE 7.

NOTE 3—This practice does not require portable amusement rides and devices to be designed for seismic loads. However, when a portable amusement ride or device is designed for seismic loads, a description of these loads will be stated in the strength calculations, and included in the operating and maintenance instructions. See section on Manufacturer's Responsibility in Practice F 770 and section on Manufacturer's Responsibility in Practice F 853.

F: Load due to fluids with well-defined pressures or maximum heights,

H: Load due to the weight and lateral pressure of soil and water in soil,

R: Load due to initial rainwater or ice exclusive of the ponding contribution, and

T: Load due to self-straining forces arising from differential settlements of foundations and from restrained dimensional changes due to temperature, moisture, shrinkage, creep, and similar effects.

8.24.2 The required strength of the structure and its elements shall be determined from the appropriate critical combination of factored loads. The most critical effect may occur when one or more loads are not acting. The following load combinations and the corresponding load factors shall be investigated:

$$1.4D$$

$$1.2(D + F + T) + 1.33^*(L) + 1.6(H) + 0.5(L_R \text{ or } S \text{ or } R)$$

$$1.2D + 1.6(L_R \text{ or } S \text{ or } R) + (0.5L \text{ or } 0.8W)$$

$$1.2D + 1.3W + 0.5L + 0.5(L_R \text{ or } S \text{ or } R)$$

$$1.2D + 1.0E + 0.5L + 0.2S$$

$$0.9D \pm (1.0E \text{ or } 1.3W)$$

NOTE 4—In the load combination equation: $1.2(D + F + T) + 1.33 \cdot (L) + 1.6(H) + 0.5(L_R$ or S or $R)$, this practice has reduced the original live load factor for L from 1.6 to 1.33. This was done because a minimum impact factor of 1.2 is applied to all live loads. This 1.33 factor multiplied to the impact factor of 1.2 results in an effective live load factor value of 1.6. See section on Combining Factored Loads Using Strength Design in ASCE 7.

8.25 *Load Factors for Strength in LRFD*:

8.25.1 Load factors are used in the LRFD method to account for uncertainties inherent in the development process, including design, engineering, manufacturing, and operations. Some of the uncertainties that need to be accounted for with load factors using LRFD include:

(1) Design assumptions,

(2) Determination of loads,

(3) Calculations and analyses (that is, accuracy of models and calculation of stresses),

(4) Evaluation of strength/material properties—fatigue, yield, ultimate,

(5) Variability in raw materials (that is, plates, beams, tubes, etc.),

(6) Manufacturing inconsistencies (that is, welding and machining variables, distortion, etc.),

(7) Variation in performance—displacement, velocity, acceleration, and onset rates, and

(8) Variations in performance due to differences between the actual software program and those assumed in the analysis.

8.25.1.1 The load factors included in the LRFD load combination equations (see 8.24.2) should be considered the minimum values that shall be applied in the design for amusement rides and devices using LRFD. The designer/engineer should use good judgment and consider using higher load factor values if the level of uncertainty with loading, analysis, manufacturing, or operation is higher than normal.

8.26 *Resistance Factors and Nominal Material Strengths for LRFD*:

8.26.1 The resistance factors and nominal strengths for the materials shall be selected from an appropriate LRFD reference.

8.27 *Design for Fatigue*:

8.27.1 The calculated working stress shall be used when designing amusement rides or devices for fatigue. Because material properties and material behavior may influence the fatigue analysis, the technique selected for fatigue analysis shall be material dependent.

8.27.2 The total number of load cycles expected to be experienced by the amusement ride or device throughout the operational hours shall be determined and applied in the fatigue analysis.

8.27.3 Designing for high cycle fatigue loading requires that the designer/engineer either know (through empirical measurement) or estimate the total number of load cycles the structure will experience during the operational hours. The total number of load cycles selected then becomes a fundamental ingredient of the structural fatigue analysis.

8.27.4 The approach utilized to evaluate a structure for fatigue shall be consistent with the method and allowables utilized to evaluate the same structure for strength criteria.

8.27.5 The means used to calculate and establish fatigue life shall be by a widely recognized and generally accepted engineering practice.

8.27.6 Components of amusement rides or devices that are not subject to cyclic loading can be excluded from fatigue analysis requirements (for example, maintenance storage track, fasteners for transportation, equipment and structures used to set up and tear down amusement rides and devices (that is, lifting struts, rigging, etc.)).

8.28 *Load Factors for Fatigue*:

8.28.1 Load factors for fatigue greater than 1.0 shall be applied if determined necessary by the designer/engineer. The possibility of impact or amplification of other dynamic loads are reasons why factors greater than 1.0 may be required (see

Annex A1). In the case where test measured dynamic loads are used, the use of a factor greater than 1.0 is not warranted or required.

8.29 *Load Combinations for Fatigue*:

8.29.1 Fatigue evaluations shall include loads combined in multiple combinations to produce the largest fluctuations in stresses and strains at all locations within the structure or component being analyzed.

8.30 *Fatigue Material Allowable Properties*:

8.30.1 When determining allowable stress or strain levels for materials for fixed or permanent amusement rides or devices, the designer/engineer shall use published fatigue property data (for example, a material specific S-N curve) for the material being used. In addition, the published fatigue property data for the material shall be representative of the specific structural detail as implemented in the design (that is, plates, weldment, bolted joints, etc.).

8.30.1.1 Published fatigue property data presented as design properties, such as that found in AWS, can be used directly. These properties generally have some factor of safety associated with their use. Published fatigue property data based on empirical data, including those based on mean data, shall be adjusted before use to provide an appropriate factor of safety and allow for material inconsistencies. In the case of mean fatigue property data, the fatigue data shall be reduced by no less than two standard deviations to allow for material inconsistencies.

NOTE 5—See A1.18.1.4 for Shigley's alternate reliability based approach to achieve a specified factor of safety.

8.30.1.2 Fatigue property data for a material that is derived from empirical data can be used when published fatigue property data is not available for the material. The proper techniques needed to establish a material's fatigue property data are described in appropriate published technical references and shall be used when employing this method. See A1.18.2.3 for more information.

8.30.2 Designer/engineers of portable amusement rides and devices shall use the applicable sections of Practice F 1159 to select fatigue data and material allowables for the materials used in the design of portable rides and devices.

NOTE 6—The requirements for using published fatigue property data and the fatigue property values for portable rides and devices is currently being reviewed by the Strength & Loads Subtask Group and will be inserted here at a later date.

8.31 *Stability*:

8.31.1 Portable amusement rides and devices shall be designed such that when erected and operated per the designer/engineer provided written instructions, the portable amusement ride or device is adequately stable and resistant to overturning. The designer/engineer shall take into consideration all worst-case loading (for example, unbalanced loading, wind loading).

8.31.2 Within the manufacturer-provided written Inspection Instructions, the manufacturer shall specify how the stability of the portable amusement ride or device can be visually checked for acceptable settlement and level. This specific inspection instruction shall be specified to be performed after erection is completed and prior to the daily start of operation of the portable amusement ride or device at the installed location. This written inspection instruction shall describe how these measurements are to be assessed including the maximum amount of settlement and the maximum out-of-level tolerance allowable for portable amusement ride or device operation.

8.32 *Metal Structures*:

8.32.1 *Suitability of Materials*—Only metals and metal alloys for which industry recognized data is available, indicating the physical capabilities including endurance limit or fatigue S/N curve, shall be used for structural elements in amusement rides and devices.

8.33 *Timber Structures*:

8.33.1 Timber Structures shall be designed in accordance with the USDA–72 (The Wood Handbook) or NDS (National Design Standard) for ASD Design or ASCE 16, or accepted equivalent standard for structural use of timber.

8.33.2 Allowable loads and stresses, as indicated in the above referenced data, shall be reduced as deemed adequate by the designer/engineer as required to allow for special combinations of conditions, which may include stress concentrations, shock, dynamics, load cycles, degree of risk, and environment.

8.33.3 As a general rule, features that result in a weakening of timber members subjected to impacts, alternating or pulsating stresses shall be avoided. Bored holes in such members, particularly those in which bolts are regularly removed and installed in dismantling operations, shall be relieved from local stresses by the use of suitable load spreading plates or other recognized methods.

8.33.4 When timber elements are used in amusement rides and devices, the designer/engineer shall design the details of construction to prevent or reduce damage due to decay. The designer/engineer shall provide inspection instructions. See Guide F 893 for ongoing inspection requirements for any timber elements. These instructions shall include:

8.33.4.1 Inspection for damaged or missing paint and the presence of moisture; any situations where water might enter and become trapped, supporting the development of rot or insect damage, or failure from expansion due to ice formation, and recommended methods of examinations required to determine the presence and extent of rot in timber members,

8.33.4.2 Inspection for the presence of corrosion on bolts or other fasteners, or both, sufficient to produce fretting in the timber and resultant loss of joint effectiveness, and

8.33.4.3 Inspection for otherwise damaged or missing timbers that might affect the load carrying capacity of the structure.

8.34 *Concrete Structures*:

8.34.1 The selection of concrete grade shall be in accordance with ACI–301 and ACI–318 or accepted equivalent standard for structural use of concrete.

8.35 *Plastic and Plastic Composite Structures*:

8.35.1 The assessment of allowable loads and stresses in plastic, plastic composite, and bonded structures shall be performed in a manner suitable for that specific material and structure.

8.35.2 The designer/engineer shall properly select and design joint and connection details.

9. Hydraulics Systems and Components

9.1 The applicable provisions of ANSI (NFPA/JIC) T2.24.1 or the equivalent shall be used as the standard for the design and manufacture of fixed and portable amusement rides and devices except as expanded or modified in the following sections or subsections. This section shall apply to all amusement rides and devices manufactured after January 1, 1999.

9.2 Deviation from Section 6.7.1 of ANSI T2.24.1 shall be permitted only when components are designed for higher temperature operation and adequate shielding is provided to prevent hot fluid from reaching any passenger or observer on or near the ride or device.

9.3 Changes or additions, or both, to ANSI T2.24.1 shall be incorporated for use in the design and manufacture of amusement rides and devices as defined by subsections herein.

9.3.1 The following changes (**bold**) to Section 7.2.3.1 of ANSI T2.24.1 are incorporated as follows:

7.2.3.1 Adjustments of control **should** not require access between, over or in close proximity to moving equipment or parts.

9.3.2 The following deletion (**bold**) to Section 7.4.1 of ANSI T2.24.1 is incorporated as follows:

7.4.1 Emergency stop and/or return controls
Delete in its entirety, item e: **e) Shall provide a blocking device in servovalve(s) supply line(s).**

9.3.3 The following changes (**bold**) to Section 7.7.1 of ANSI T2.24.1 are incorporated as follows:

7.7.1 **Emergency safety device or means**
When the possibility exists that undesirable motion will result due to an emergency or uncontrolled stop condition, a **device or means** shall be provided in the proportional **or servo** control **circuit** to prevent such motion.

9.3.4 The following changes (**bold**) to Section 12.2.4 of ANSI T2.24.1 are incorporated as follows:

12.2.4 Filters **should** be sized to provide a minimum of 800 hours of operation under normal system conditions.

9.3.5 The following changes (**bold**) or deletions (**bold**) to Section 18.3.4 of ANSI T2.24.1 are incorporated as follows:

18.3.4 Diagnostic pressure test points, **when used**, should be, accessibly installed in hydraulic circuits to verify system pressure, and also where pressure can be adjusted from the main system pressure.

9.3.6 The following deletions (**bold**) to Section 18.5 of ANSI T2.24.1 are incorporated as follows:

18.5 Oil sampling
Sample test points shall be made available close to hydraulic pumps and at other key locations for the purpose of checking fluid for contamination. Sample test points must provide safe, reliable access to fluid **while under full system pressure**.

9.4 *Position Limits*—Effective means are provided to prevent a linear actuator, where piston and rod are the same diameter, from traveling beyond to physical limits of the actuator.

9.5 *System Failures*—In the event of a system failure or malfunction of the hydraulic system, the velocity or acceleration, or both, shall be controlled with respect to forces acting on the passengers.

10. Pneumatic Systems and Components

NOTE 7—This section only applies to pneumatic systems and components of amusement rides and devices.

10.1 The design and manufacture of amusement rides and devices and major modifications to amusement rides and devices shall comply with the applicable provisions of ANSI B93.114M (was NFPA/JIC T2.25.1M) or equivalent standard, except as modified in the following sections.

NOTE 8—Equivalent Standard, ISO 4414.

10.2 Deviations, as defined by ANSI B93.114M (was NFPA/JIC T2.25.1M) are allowed if not prohibited or restricted herein. Any such deviations shall be reviewed and approved by the manufacturer or designer/engineer.

10.3 The following additions and changes (in **bold** print) shall be deemed a part of ANSI B93.114M (was NFPA/JIC T2.25.1M) for use in this practice. Only those provisions or sections with additions or changes are shown herein. Refer to ANSI B93.114M (was NFPA/JIC T2.25.1M) (see above comment on date) for other sections.

10.3.1 *ANSI T2.25.1M, Section 5.9.1.1*—Pneumatic circuits shall be designed for a maximum supply pressure of 8 bar (116 psig), unless otherwise specified. **Deviations are allowed only when components are designed for higher operating pressures**.

10.3.2 *ANSI T2.25.1M, Section 5.10.1, Manufacturer's Information*—The following information **should** be permanently indicated on each pneumatic component manufacturer's identification; a) the component manufacturer's part or model designation, where space permits; b) where applicable, other data required by this standard (see 7.7, 8.4, 9.1, 10.1,11.4, and 12.5).

10.3.3 *ANSI T2.25.1M B93.114M, Section 6.3.6, Locking of Adjustable Component Settings*—**To prevent unauthorized access, a** means for locking (for example, by means of a key) the enclosure(s) or compartment(s) in which flow control and/or pressure control components are mounted, or for locking their individual settings, shall be provided **unless other provisions preclude such access**.

10.3.4 *ANSI T2.25.1M, Section 6.4.2.1*—Emergency stop and/or return control, where identified by the Failure Analysis of **amusement ride and device** equipment, shall incorporate an emergency stop or return control, whichever provides more safety (see 15.7.1). **The provided emergency stop or return control shall be in accordance with the Control System, Section 11 of the latest edition of ASTM 1159**.

10.3.5 *ANSI T2.25.1M, Section 6.4.2.2f*—Shall not create additional hazard (for example, by releasing any locating pin, index drive engagement, latch, clamping or similar device).

10.3.6 *ANSI T2.25.1M, Section 12.2b*—Adequate internal space to accommodate 152 mm (6 in) leads of 14 AWG wire from each electrical supply connection and ground wire.

11. Safety Related Electrical/Electronic/Programmable Electronic Control Systems

11.1 *Scope*—This section establishes the design requirements for Safety Related Control Systems for amusement rides and devices incorporating Electrical/Electronic/Programmable

Electronic Systems (E/E/PES), associated sensors, and final actuator elements and interfaces. Examples of E/E/PES technologies are:

11.1.1 Electromechanical relays,

11.1.2 Solid state logic,

11.1.3 PES (Programmable Electronic Systems),

11.1.4 Motor-driven timers,

11.1.5 Solid state relays and timers,

11.1.6 Hard-wired logic, and

11.1.7 Combinations of the above.

NOTE 9—This section does not address requirements of the non-safety-related control system portion of the design.

NOTE 10—This section does not define the need for a Safety Related Electrical/Electronic/Programmable Electronic Control System.

11.2 *Reference Standards*:

11.2.1 NFPA 79, NFPA-NEC 70, EN 1050, EN 954-1, IEC 61508-1, and ANSI B11.TR3.

11.3 *Safety Related Control Systems*

11.3.1 *General Requirements*:

11.3.1.1 A safety related control system is a system that participates in achieving or maintaining, or both, a safe state for the attraction or device, whether on it's own or in conjunction with other components/systems. This includes:

11.3.1.2 Any system that implements safety features, and

11.3.1.3 Any system that has the capability to block or otherwise alter the performance of systems that implement safety features.

11.3.1.4 Safety-related control systems features shall, at a minimum. comply with those functions presumed by the ride's safety analysis.

11.3.1.5 The design and construction of a safety-related control system shall follow a documented process which demonstrates that due diligence has been applied to the evaluation and mitigation of identified safety issues.

11.3.2 *Electrosensitive Protective Equipment (ESPE)*—ESPE used for safety-related purposes shall comply with the relevant parts of IEC 61496–1, NFPA–79, or equivalent standard.

11.4 *Stop Functions*:

11.4.1 The choice of category of stop shall be determined in accordance with the requirements of the application, functional requirements of the amusement ride or device, and the ride safety analysis. The three stop categories are defined as (see Section 9.5.2 of NFPA–79NFPA–79):

11.4.1.1 *Category 0*—Stopping by immediate removal of all control power to the amusement ride or device (that is, an unpowered (uncontrollable) stop).

(*1*) *Unpowered Stop*—The stopping of ride motion by removing control power to the amusement ride or device, all brakes, or other mechanical stopping devices being activated (see IEC 60204–1).

11.4.1.2 *Category 1*—Stopping with power to the amusement ride or device to achieve a controlled stop and then removal of control power when the controlled stop is achieved.

(*1*) *Controlled Stop*—Bring the amusement ride or device to a controlled stop and then remove the control power.

11.4.1.3 *Category 2*—A controlled stop with power left available to the ride actuators.

NOTE 11—Bring the amusement ride or device to a controlled stop (power may remain).

11.4.1.4 *Additional Stop Functions Requirements*

(*1*) Where required, provisions to connect protective devices and interlocks shall be provided.

(*2*) Where applicable, the stop function shall signal the logic of the control system that such a condition exists.

(*3*) The reset of the stop function shall not initiate any hazardous conditions.

(*4*) Category 0 and Category 1 stops shall be operational regardless of operating mode and a Category 0 stop will take priority.

(*5*) Category 0 shall remove power to actuators that can cause a hazardous condition(s) as quickly as possible without creating other hazards (for example, by the provision of mechanical means of stopping requiring no external power, by reverse current braking for a Category 1 stop).

(*6*) Stop functions shall operate by de-energizing the relevant circuit and shall override related start functions. See Annex A11.4.

11.4.2 *Category 0 Stop Functions*—The Category 0 stop functions shall have the same requirements of a Category 1 or 2 functions (see Annex A11.4) and shall also have the following requirements:

11.4.2.1 Each amusement ride or device shall be equipped with a Category 0 stop.

11.4.2.2 When necessary, the safety related control system may provide Category 0 stopping of the amusement ride or device.

11.4.2.3 Category 0 stop functions have priority over all other functions.

11.4.2.4 When a Category 0 stop function is initiated, the amusement ride or device will reach standstill in the shortest time commensurate with avoiding hazardous conditions.

11.4.3 *Emergency Stop Functions*:

11.4.3.1 *Emergency Stop Category 1*—Where a Category 1 stop is used for the emergency stop function, final removal of power to the machine actuators shall be ensured and shall be by means of electromechanical components.

11.4.3.2 *Emergency Stop Category 0*—Where a Category 0 stop is used for the emergency stop function, it shall have only hardwired electromechanical components. In addition, its operation shall not depend upon electronic logic (hardware or software) or the transmission of commands over a communication network or link.

11.4.3.3 *Category 0/1 Recovery Requirements*—After a Category 0/1 stop function has been initiated, a restart of the amusement ride or device may not take place without a deliberate manual action. The resetting of the Category 0/1 stop function shall not start the ride.

11.5 *Safety Related Parameters*—When the ride manufacturer defines specific safety related parameters, the safety related control system shall not allow the amusement ride or device to exceed the specific manufacturer's safety performance specifications.

11.6 *Operational Modes*—Each amusement ride or device shall be permitted to have one or more operating modes (for example, automatic, hand) that are determined by the type of ride and its operation.

11.6.1 When a safety related control systems has more than one mode of operation, the selected mode of operation must be visibly indicated. Any change of mode shall require deliberate operator action.

11.6.2 Where hazardous conditions can arise from mode selection, such operation shall be protected by suitable means (for example, key operated switch, access code).

11.6.3 Mode selection by itself shall not initiate operation. A separate action by the operator shall be required.

11.6.4 Safeguards shall remain effective for all operating modes.

11.6.4.1 Where it is necessary to temporarily override one or more safeguards, a mode selection device or means capable of being secured in the desired mode shall be provided to prevent automatic operation. In addition, one or more of the following measures shall be provided:

(1) Initiation of motion by a hold-to-run or other control device.

(2) A portable control station (for example, pendant) with an emergency stop device. Where a portable station is used, motion shall only be initiated from that station.

(3) Limiting motion speed or power.

(4) Limiting the range of motion.

12. Electrical Requirements

12.1 *Scope*:

12.1.1 This section provides guidelines for the electrical components and their installation and procedures used in amusement rides or devices. This general section includes all electrical components from the point of electrical power connection through the amusement ride or device. The National Electrical Code (NEC), NFPA 70, NFPA 79, NEMA 250, and UL508A are the basis for design and manufacture of electrical systems and components in this guideline for North America. This section provides supplemental requirements to these codes that improve the level of electrical design for amusement rides and devices. Other equivalent standards or alternate methods may be used when allowed by the authority having jurisdiction. This includes, but is not limited to, the use of standards from jurisdictions outside the United States of America. This may include but is not limited to standards from the CSA, EN, DIN, ISO, and IEC.

12.1.2 This scope does not cover the following:

12.1.2.1 Electrical systems or components prior to the connection point of the electrical lead wires to the source of power for the amusement ride or device, or

12.1.2.2 Other building, structure, or facility that is not defined as an amusement ride or device.

12.1.3 *Section Arrangement*—Section 12 of this practice is divided into subsections that follow the general layout of NFPA 70, National Electric Code (NEC). See Table 1. Subsections 12.1 through 12.4 apply generally to all amusement rides and devices. Subsections 12.5 through 12.7 are for special types of equipment, occupancy, or conditions, which may modify the subsections 12.1 through 12.4.

12.1.4 *Compliance*:

TABLE 1

ASTM F 1159 Section Number	Description ASTM F 1159 Section Number	NFPA 70-2000 Chapter
12.1	Scope	
12.2	General Requirements for Electrical Installations	2
12.3	Wiring Methods and Materials	3
12.4	Equipment for General Use	4
12.5	Special Equipment	6
12.6	Audio/Communications Systems	7
12.7	Portable Ride Assembly/Disassembly Conditions	8

12.1.4.1 *Existing Equipment*—All existing equipment that undergoes a major rewire, other than for routine maintenance/repair, must be in compliance with Section 12 of this practice. Major rewire is defined as replacement of one-third (⅓) or more of the electrical wiring or components, or both, that changes the operation/function of the equipment.

12.1.4.2 New equipment manufactured or produced by the original manufacturer, but designed prior to January 1, 1990 and acquired after (TBD), shall follow Section 12 of this guideline. New equipment produced by a manufacturer not responsible for original ride or device design shall meet the requirements of Section 12 of this guideline.

12.1.4.3 Acquisition of used equipment does not require compliance with Section 12 of this practice, unless as defined by 12.1.4.2.

12.1.5 *Documentation Requirements for All Rides and Devices*:

12.1.5.1 *Signage Requirements*—There shall be a plaque, permanently mounted on main electrical panel, that contains, as a minimum, the following information:

Main Supply Voltage—Power
Main Supply Voltage—Lighting
Total Power Load Amperage
Total Motor Load Amperage
Total Lighting Load Amperage
Number of Electrical Power Phases
Number of Lighting Power Phases
Electrical Power Frequency
Year Version of NEC Used for Design
Year Version of ASTM 1159 Used in Design
Date of Electrical System Manufacture

12.1.5.2 *Schematics and Diagrams*—All amusement rides and devices shall have a complete set of electrical schematics and diagrams available.

12.2 *General Requirements for Electrical Installations*

12.2.1 *Wiring and Protection*:

12.2.1.1 *Branch Circuits Required*—At least one 20-ampere line-neutral branch circuit shall be provided on each ride, as a service or utility outlet.

12.2.2 *Disconnects*:

12.2.2.1 Multiple disconnecting means shall be labeled, as appropriate, at the disconnecting location.

12.2.2.2 Rides or devices with other voltage sources (that is, central battery systems, etc.) shall have a disconnecting means with an approved means of lockout/tag-out. This disconnect shall be located: (*1*) Immediately adjacent to the primary main disconnect; or, (*2*) Labeled at the primary main disconnect(s) as to the location of this disconnect.

12.2.3 *Grounding*:

12.2.3.1 Refer to National Electrical Code, NFPA 70, Section 525–Carnival, Circuses, Fairs and Similar Events.

12.2.3.2 All enclosures, switchboards, and panel boards shall have an approved grounding bar installed.

12.3 *Wiring Methods and Materials*:

12.3.1 *Physical Damage*—Wiring systems shall be protected against damage from unique conditions inherent on amusement rides and devices.

12.3.2 *Enclosures*—All electrical enclosures used for a portable ride or device shall have a rating for the appropriate environment.

12.3.3 *Switches*—Exposed switches shall be protected against damage from unique conditions inherent on amusement rides and devices.

12.3.4 *Wiring Systems*—Wiring systems and methods shall follow the NEC and other accepted electrical industry standards and procedures.

12.4 *Equipment for General Use*

12.4.1 *Lighting Fixtures*:

12.4.1.1 Lighting fixtures made onto or from structural components of the ride or device must meet the NEC criteria for electrical installation, that is, cord restraints, outlet boxes, wiring, etc. Fixtures shall have provisions for the unique conditions inherent on amusement rides and devices.

12.4.1.2 All fluorescent lighting systems, located on a moving component of the ride or device or within 7 ft, 6 in. of a guest, shall have a protective covering and a means of tube retention for the light tubes.

12.4.1.3 Quartz halogen double-ended bulb: (*1*) Shall have a protective shield or film tape over diffuser lens to protect from falling glass; and (*2*) May not be mounted by the yoke or neck only on any moving or portable component of the ride or device.

12.4.1.4 *Light Sockets*—Due to the nature of decorative lighting flasher systems, the screw shell base of the bulb may be energized. When energized bases are used, warning labels shall be used that indicate the need to de-energize the lamps prior to replacement of light bulbs. These labels shall be installed, as a minimum, on the lighting panel and on each extended light fixture or can.

12.4.2 *Portable Cable*—Due to fine stranding of portable cable, methods and materials shall be used to insure that all devices are used within their rating.

12.4.3 *Motors*—The motor size shall take into account the number of start cycles per hour and unique ambient operating conditions inherent on amusement rides and devices.

12.4.4 *Transformers*—All Y to Y connected transformers shall have a common neutral.

12.4.5 *Power Capacitors*—Labeling or equivalent notification shall be placed on all power capacitors used in the electrical system and appropriate lockout/tag-out procedures developed.

12.4.6 *Collector Ring/Brush Assemblies* shall be of a type and sized to carry 125 % of rated load for each ring and brush assembly.

12.4.6.1 Provisions shall be made for a grounding ring(s) capable of carrying the sum of the overcurrent devices feeding the slip ring set.

12.4.7 Recognized or listed components shall be of the "industrial equipment" type (UL–508A) and used properly within their restrictions. This includes, but is not limited to, terminal blocks, supplementary overcurrent protection, residual current detectors, fans, and relays, both mechanical and solid state.

12.4.8 Electrical equipment with temperature or humidity requirements, or both, shall be installed to insure the equipment manufacturer's requirements are met.

12.5 *Special Equipment*:

12.5.1 Emergency lighting is beyond the scope of this standard. Reference Life Safety Code NFPA 101.

12.5.2 Metal frames structures, which contain electrical devices but have no metal-to-metal direct bonding path, shall be bonded. A separate equipment-grounding conductor installed between the metal parts shall bond non-current-carrying metal parts and main disconnect.

12.5.2.1 Grounding and bonding conductors shall be only of copper material.

12.5.3 *Wet Areas*—Three classification of wet areas exist that determine what NEC code is relevant:

12.5.3.1 *Class 1: Guest Immersion*—NFPA 70 (NEC 2000, Section 680) Permanently Installed Pools.

12.5.3.2 *Class 2: Guest Contact*—NFPA 70 (NEC 2000, Section 680) Fountains.

12.5.3.3 *Class 3: Misting/Splashing/Pooling/Fogging*—Will be treated as a wet location.

12.5.4 *Signs and Outline Lighting*:

12.5.4.1 Systems with incandescent lamp holders shall be marked to indicate maximum wattage and voltage of lamps. Markings shall be permanently installed in letters at least ¼ in. high (6.4 mm) and located either visible while re-lamping, or near or on the most visible lighting control or branch circuit overcurrent protection panel board.

12.5.4.2 Metal poles used as supports for incandescent and fluorescent fixtures and as raceway for wiring shall be grounded with a mechanically affixed ground wire, or be protected by a residual current device (RCD).

12.5.4.3 Wiring terminations at the end of lighting circuits shall terminate in an approved insulated irreversible compression connector, or such means that the possibility of contacting any part of the ride or device while it is energized is reduced.

12.6 *Audio/Communication Systems*

12.6.1 Audio/Communication system wiring, when installed on amusement rides or devices, shall be suitably protected for the unique operating conditions inherent on Amusement Rides and Devices if the system is used to provide audio notifications announcements for safety, operation, evacuation or maintenance of the ride or device, or both.

12.6.2 Exposed wiring to and between speakers for Outdoor Use, shall use Portable cable that is listed for extra hard usage, is UV resistant, and has a grounding conductor that terminates at a bonding point at both ends.

12.7 *Portable Ride Assembly/Disassembly Conditions*:

12.7.1 Wiring methods with connectors/plugs that are not rated to make/break under load shall be permanently marked at each connecting point, or have a listed integral disconnect to make/break.

12.7.2 During assembly/disassembly, no energized points/surfaces shall be exposed to any personnel.

13. Mechanical Systems and Components

13.1 *Scope*:

13.1.1 This section pertains to mechanical systems and components for use in power transmission, patron carry devices, or safety of the ride.

13.2 *Chain*:

13.2.1 Chain and related accessories used in amusement rides and devices shall be produced in compliance with the following standards: American National Standards Institute (ANSI) and European Standard (EN 280).

13.2.2 Chain and related accessories shall be selected and designed for designer/engineer specified loads, speed, corrosion, operating environmental and dynamic conditions, and for wear and fatigue.

13.2.3 Chain manufacture's specifications shall include dimensions, strength, grade, and nominal breaking strength-working load limit, and shall be included in the maintenance instructions.

13.2.4 The capacity of the chain and related accessories, for example, terminations, adapters, shall be verifiable either by certificates, manufacturer's markings, or testing.

13.2.5 Chains in the primary load path that do not pass around sprockets or wheels shall have a minimum factor of safety of five.

13.2.6 Chains in the primary load path that pass around sprockets or wheels shall have a minimum factor of safety of six.

13.2.7 The chain factor of safety is defined as the ultimate tensile strength of the chain divided by the maximum steady state tension. (See Section 8 on Loads and Strengths).

13.2.8 A method shall be used to maintain proper chain contact with sprocket teeth and pulleys.

13.2.9 The amusement ride and device manufacturer shall include in the maintenance instruction the method to measure chain wear and the maximum allowable change in pitch length.

13.2.10 Metallic chain guides shall be lined or appropriately protected.

13.2.11 The amusement ride and device manufacturer shall include cleaning and lubrication details in the maintenance instructions.

13.3 *Wire Rope (Excludes Fiber, Synthetic, etc., Rope and Line)*:

13.3.1 Wire rope can be used in systems such as: drive, suspension, tension, braking, counterweight, etc.

13.3.2 Wire rope consists of individual wires that are twisted into strands that form the rope.

13.3.3 Wire rope used in aerial tramways and aerial lifts shall be in accordance with ANSI B77.1, Passenger Ropeways.

13.3.4 Wire rope and wire rope accessories, for example, terminations, adapters, clamps, shall be designed for designer/engineer specified drive configuration, cycles, load(s), corrosion, dynamics, environment, wear, fatigue, and service conditions.

13.3.5 Wire rope and wire rope accessories in the primary load patch shall have a minimum factor of safety of six.

13.3.6 The wire rope factor of safety is defined as the ultimate tensile strength of the wire rope divided by the maximum steady state tension.

13.3.7 The capacity of the wire rope and related accessories, for example, terminations, adapters, shall be verifiable either by certificates, manufacturer's markings, or testing.

13.3.8 Wire rope systems shall be configured to minimize the forming of kinks or knots on any part of the wire rope system from normal use, and shall be designed to avoid excessive local stressing of individual elements. for example, individual wires or strands within the rope.

13.3.9 Where indicated by the ride analysis, wire rope systems in operation should be configured so that operators and patrons are not exposed to hazards in the event that a rope or associated fitting derails (leaves its controlled or intended path).

13.3.10 Where indicated by the ride analysis, wire rope systems in operation should be configured so that operators and patrons are not exposed to hazards in the event that a wire rope fails (fractures, unravels, fatigue, etc., see Appendix X4, Fig. X4.1).

13.3.11 All splices shall be done according to the rope manufacturer's appropriate wire rope splice specifications.

13.3.12 A method shall be used to maintain proper rope contact with sheaves and pulleys.

13.3.13 For fatigue applications, the minimal sheave to rope diameter (D/d) shall be 30. The sheave diameter is D and the rope diameter is d. When space restraints preclude this ratio, then other mitigating factors should be considered such as more frequent in-service inspections or replacement criteria.

13.3.14 Where determined by the ride analysis, sheave inertia must be considered in the design to minimize scuffing.

13.3.15 When determined by the ride analysis, life cycle tests per OIPEEC standards shall be performed to validate rope fatigue and life calculations (see Appendix X4).

13.3.16 Wire rope guides shall be lined or appropriately protected.

13.3.17 The wire rope manufacturer shall recommend the type and frequency of lubrication and corrosion protection. Ropes that have little or no motion, such as ropes in static tension systems, anchors, and guys, require special consideration for protection against corrosion.

13.4 *Anti-rollback Devices*:

13.4.1 Anti-rollback devices prevent an amusement attraction from unplanned or undesirable movement in the reverse direction.

13.4.2 Anti-rollback devices are not required if under any failure of the Amusement Ride or Device, movement in the reverse direction will not result in injury or damage.

13.4.3 Amusement rides or devices where cars or trains travel uphill, by being conveyed on an ascent ramp, for example, roller coaster lift, or being carried uphill by their own momentum or power, shall be provided with safety devices to prevent reverse direction of the car or train. Adequate load ratings must be considered in the design of this equipment. See Section 8 on Loads and Strengths. Vehicles that provide their own power and have manual or automatic braking systems are excluded from this requirement.

13.4.4 Safety devices include anti-rollback mechanisms or automatically acting brakes that do not depend on temporary stored energy, for example, electrical, hydraulic, pneumatic, etc.

13.4.5 When the primary lift drive device is not configured to be an anti-rollback, no less than two anti-rollback devices are required. Both can be on the vehicle/train, both can be on the track, or one can be on the vehicle/train and one on the track. At least one anti-rollback device must be engaged at all times.

13.4.6 Lift systems, for example, log rides, rapids rides, may have anti-rollback devices on the vehicle/boat, on the side of the track, or on the conveyance device.

13.4.7 Individual cars of trains that are not equipped with a secondary safety device to prevent uncontrolled reverse travel shall be mechanically coupled together and have a secondary safety attachment between cars, for example, safety chain, safety cable, etc.

13.5 *Machine Guards*:

13.5.1 The manufacturer shall provide machine guards or other appropriate measures to inhibit employees and patrons from undesirable contact with belts, chains, pulleys, gears, drivelines, and similar moving machinery. Specific criteria may vary with respect to location.

13.5.2 When the ride analysis determines that parts can break free on power transmissions, for example, u-joint drives, provisions shall be made to contain the components.

13.5.3 Drive shafts will be provided with safety containment.

13.5.4 Chain and sprocket guards shall be provided in compliance with ASME B15.1.

13.6 *Patron Lifting or Elevating Devices*

13.6.1 *Hoists*:

13.6.1.1 Hoist units associated with lifting or elevating patrons shall be visually inspected based on the amusement ride and device manufacture's recommended inspection period, but not to exceed one year.

13.6.1.2 Hoist units (rope and chain hoists) shall be equipped with effective brakes or other equivalent devices. Stopping movement shall conform to Section 11 on Safety Related Electrical/Electronic/Programmable Electronic Control Systems.

13.6.1.3 The hoist unit shall be arranged so that the physical connection between the brake and sprocket cannot be interrupted, that is, the brake shall be inseparably attached together in one unit.

13.6.1.4 Guard against over-travel malfunction of the hoist.

13.6.1.5 End limit protection shall be provided. The intent is not to restrict normal travel limits of the amusement ride or device, but the manufacturer is to provide specified maximum limits of travel.

13.6.1.6 If required by the ride analysis, overload protection shall be provided.

13.6.1.7 That part of the rope drum that contacts the rope shall be designed such that entanglement, overlay, and kinking will be prevented by means of grooving, guiding, etc. A minimum of at least two full turns of rope shall remain on the drum when the attached lifting carriage is operated to its lowest possible position.

13.6.1.8 Hoist drums shall be no less than (D/d) of 30 to 1. D is the diameter of the drum and d is the diameter of the rope.

13.6.1.9 Means shall be provided to minimize variation in tension between all connected ropes or chains where more than one rope or chain is fixed to one common suspension point.

13.6.2 *Power Screw Drives*:

13.6.2.1 Power screw drives associated with lifting or elevating patrons shall be visually inspected based on the amusement ride and device manufacture's recommended inspection period, but not to exceed one year.

13.6.2.2 Power screws used for amusement rides and devices shall be properly designed or selected for the application.

13.6.2.3 End limit protection shall be provided. The intent is not to restrict normal travel limits of the amusement ride or device, but the manufacturer is to provide specified maximum limits of travel.

13.6.3 *Rack and Pinion Drives*:

13.6.3.1 Rack and pinion drives associated with lifting or elevating patrons shall be visually inspected based on the amusement ride and device manufacture's recommended inspection period, but not to exceed one year.

13.6.3.2 Rack and pinions used for amusement rides and devices shall be properly designed or selected for the application.

13.6.3.3 A rack and pinion should have at least one pinion, one rack, and two backup rollers, which shall act on the same sections of rack as the drive pinion. Driving machines utilizing a two-sided rack, where two drive pinions are located so that they are opposite to each other and act as backup roller, shall be deemed to have met this requirement (see Section 1604.1 in ASME A17.1).

13.6.4 Racks shall be fitted with devices at both ends to prevent the pinion from traveling beyond its designed maximum limits of travel at either end of the rack.

13.6.5 The design/configuration of driving pinions shall provide a minimum engagement with the rack of at least ⅔ of the tooth width and ⅓ of the tooth depth.

13.7 *Brakes*

13.7.1 *General*:

13.7.1.1 As it applies to amusement rides and devices, examples of braking devices include, but are not limited to: longitudinal friction brakes, disc or drum brakes, motor end brakes, either onboard or off-board of the patron-carrying vehicle or device. Some rides, for example, swing rides, may not use brakes in an E-stop condition, since it is safer to let the ride come to a controlled stop. If the failure of the braking devices results in an unsafe condition, then the braking devices shall be fail-safe.

13.7.1.2 In certain cases, these devices also may be used as trim or retarding brakes to maintain the desired ride or device speed profile.

13.7.1.3 The selection and design of brakes for amusement rides and devices shall be in conformance with Section 11 on Safety Related Electrical/Electronic/Programmable Electronic Control Systems.

13.7.2 *Stopping and Safety Brakes*:

13.7.2.1 Brakes shall be selected and designed to meet the needs of the ride analysis and perform as required under any designer/engineer specified conditions and use.

13.7.3 *Retarding, Trim, or Reduction Brakes*:

13.7.3.1 Brakes shall be selected and designed to meet the needs of the ride analysis and perform as required under any designer/engineer specified conditions and use.

13.7.4 *Parking Brakes*:

13.7.4.1 Parking brake(s) shall keep the ride from moving during loading and unloading. In some cases, the brake may be a dynamic brake that stabilizes the ride.

14. Fencing, Guardrails, and Handrails for Amusement Rides and Devices Manufactured After January 1, 2003

14.1 When fences and gates are designed and manufactured to provide protection to patron spectators and patron riders or guardrails are used to inhibit falls from elevations in primary circulation areas for patrons, they shall be constructed to meet the following minimum requirements.

14.2 *General*:

14.2.1 Fencing, guardrails, and handrails shall be designed, constructed, and erected to inhibit overturning by patron spectators or patron riders.

14.2.1.1 Fences and gates shall be constructed as to inhibit patron spectator contact with the ride or device, or patron rider contact with fences or gates, or both; and patron spectator-patron rider contact while the ride is in operation.

14.2.1.2 Guardrails that are part of permanent facilities must be capable of withstanding a load of at least 200 lb applied in any direction at any point on the rail.

14.3 *For Level Landings and Ramps*:

14.3.1 When fencing, gates and guardrails are provided on level landings or ramps, they shall be constructed in accordance with the following:

14.3.1.1 They shall be a height of at least 42 in. above the surface on which the patron spectators or patron riders stand.

14.3.1.2 They shall be constructed in such a fashion so as to reject a 4-in. diameter sphere at all openings (see Fig. 20).

14.4 *For Stairs*:

14.4.1 When fencing and guardrails are provided on stairways, they shall be constructed in accordance with the following:

14.4.1.1 Guardrails and fences at stairs shall be installed at 42 in. above the nosing of each tread to the top of the guardrail.

14.4.1.2 They shall be constructed in such a fashion so as to reject a 4-in. diameter sphere at all openings, except as permitted in 14.4.1.3.

14.4.1.3 The triangular openings formed by the riser, tread and fence or guardrail shall reject a 6-in. diameter sphere (see Fig. 21).

14.4.2 When handrails are provided at stairs, they shall be 1-½ in. nominal diameter and installed at 34 to 38 in. above the nosing of each tread to the top of the handrail.

14.4.2.1 The clear space between handrails and the guardrails shall be 1-½ ± ¼ in.

14.4.2.2 They shall extend at least 12 in. beyond the top riser and at least 12 in. plus the width of one tread beyond the bottom riser. At the top, the extension shall be parallel with the floor or ground surface. At the bottom, the handrail shall continue to slope for a distance of the width of one tread from the bottom riser; the remainder of the extension shall be horizontal (see Fig. 22).

14.5 *Gates*:

14.5.1 Where used, entrance, exit, and loading gates shall open away from the ride or device unless equipped with a positive latching or holding device meeting the rail loading requirement of 14.2.1.2.

14.5.2 Gates shall be designed such that if opened during the amusement ride or device cycle, the gate will not contact the amusement ride or device or cause a hazard to patron riders.

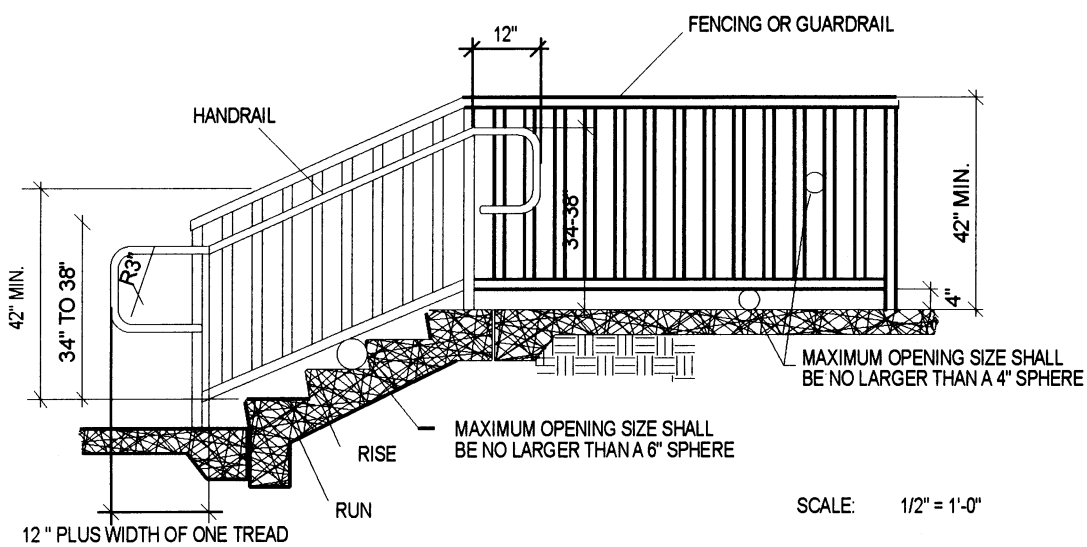


FIG. 20 Fencing or Guardrail and Handrail Diagram for Level Landings or Ramps

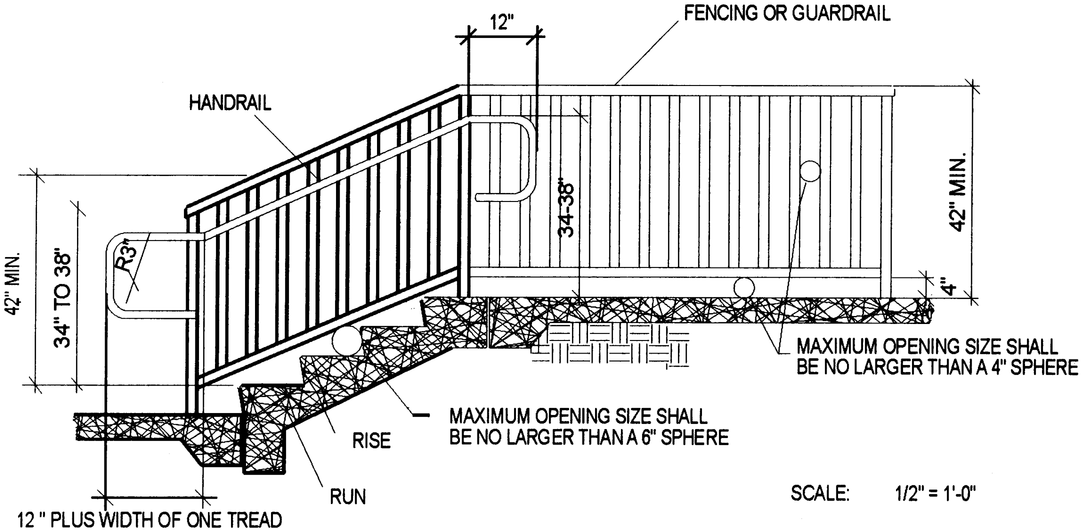


FIG. 21 Fencing or Guardrail and Handrail Diagram for Stairs

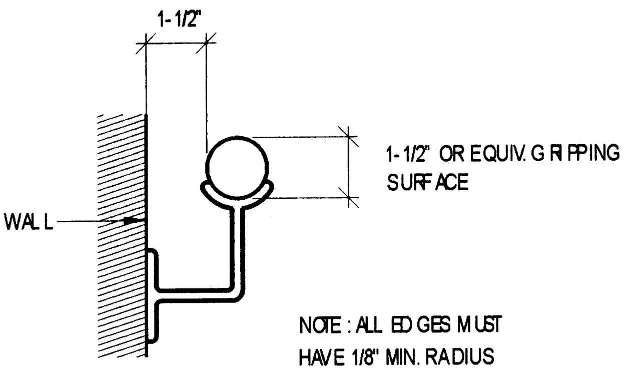


FIG. 22 Handrail Mounting Detail

15. Welding

15.1 Welding procedures shall be in accordance with American National Standards Institute/American Welding Society (ANSI/AWS) or American Society of Mechanical Engineers (ASME), or equivalent standards.

15.2 For this section on Welding, equivalent standards are those that meet the ANSI/AWS and ASME welding process methodology. This methodology is outlined in the paragraphs below:

15.2.1 Full and complete information regarding location, type, size, effective weld length, and extent of all welds shall be clearly shown on the drawings.

15.2.2 Drawings and documentation shall clearly indicate by welding symbols or sketches the details of groove-welded joints and the preparation of material in making them. Special conditions shall be fully explained by added notes or details.

15.2.3 Welding process shall be performed in accordance with a written Weld Procedure Specification (WPS) that specifies the applicable essential variables in accordance with the criteria of the applicable code. The specific values for these WPS variables shall be obtained from the Procedure Qualification Record (PQR) Essential variables may include: weld process, joint design, base material, filler material, shielding, preheats, position, electrical characteristics, technique, and travel speed.

15.2.3.1 The WPS shall state the tolerances on an essential variable as indicated by the applicable standard.

15.2.4 A WPS shall be qualified in accordance with procedures indicated by the applicable standard and documented on the Procedure Qualification Record (PQR), which serves as written confirmation of a successful WPS qualification.

15.2.5 Only welders, welding operators, and tack welders who are qualified in accordance with the applicable standard shall perform welding. Welders, welding operators, and tack welders shall be qualified by testing as indicated by the applicable standard and documented on a Welding Performance Qualification Record (WPQR).

15.2.6 The welding personnel shall follow a WPS applicable to the qualification test.

15.2.7 The WPQR shall serve as written verification of welder qualification and shall list all applicable essential variables as indicated by the applicable standard. (see Form E-1 in ANSI/AWS D1.1/D1.1M, Annex E).

15.2.8 Welding performance standards that do not have acceptance or workmanship criteria shall not be considered an equivalent standard.

15.3 *Welding Process Inspection*:

15.3.1 Inspectors must meet the criteria in accordance with the applicable standard. An inspector can be an engineer or technician who, by training or experience, or both, in metals fabrication, inspection, and testing, is competent to perform the inspection of the work.

15.3.2 The Inspector shall verify that all welds conform to the acceptance or workmanship criteria of the applicable standard, and to the drawings and documentation.

15.3.3 The size and contour of welds shall be measured with suitable gages.

15.3.4 Visual inspection for cracks in welds and base metal and other discontinuities shall be aided by a strong light, magnifiers, or such other devices.

15.3.5 The Inspector shall verify that only materials conforming to the specifications contained within the drawings and documentation are used.

15.3.6 The Inspector shall review all WPSs used for the work and shall verify that the procedures conform to the criteria of the application standard.

15.3.7 The Inspector shall inspect the work on a sampling basis and at suitable intervals during the process to verify that the criteria of the applicable sections of the standard are met.

15.3.8 The Inspector shall inspect the welding equipment used for the work to verify that it conforms to the criteria of the applicable standard.

15.3.9 The Inspector shall verify that electrodes are used only in the positions and with the type of welding current and polarity for which they are classified.

15.3.10 The Inspector shall review for accuracy and applicability the record of qualifications of all welders, welding operators, and tack welders; all WPS qualifications or other tests that are made; and such other information as may be appropriate.

15.4 Records of the qualifications of all welders, welding operators, tack welders, WPS qualifications or other tests that are made, applicable inspections, and such other information as appropriate shall be maintained pursuant to the manufacturer's record retention policy and made available to those authorized to examine them.

16. Fasteners

16.1 *General*:

16.1.1 Fastened connections, that is, bolted, riveted, or other types as applicable, shall be designed in accordance with industry accepted engineering practices and standards for example, AISC manual of steel construction, or other standards producing equivalent results in the country of manufacture.

16.1.2 Fasteners, for example, rivets, bolts, nuts and washers, shall be of a type meeting accepted engineering standards, ANSI, SAE, ASTM, ISO, EN, or other standards producing equivalent results in the country of manufacture.

16.1.3 All bolts, nuts, and washers used in the manufacture of amusement rides and devices shall be appropriately grade marked.

16.1.4 Information defining the exact specification, that is, type, material, strength, and finish for each fastener to be used in the ride or device shall be clearly specified in the designer/engineer documentation.

16.1.5 Through bolting is the preferred connection method for materials and equipment that is not welded. Items that cannot be through bolted or are not intended to be removed for service or maintenance may use other fastening methods, such as blind threaded holes, threaded inserts, and so forth if deemed appropriate by the designer/engineer.

16.1.6 Designing with threaded fasteners in shear should be avoided, where possible. Designs that place fasteners in shear shall be designed so that the fastener is in double shear wherever possible.

16.1.7 Fasteners tensioning information (dry or lubricated) shall be included in the Manufacturer provided drawings (for example, torque value or turn of nut).

16.1.8 Manufacturers shall determine all fastener information to be included in maintenance and inspection instructions.

16.1.9 SAE Grade 8 (ISO Grade 10.9) Fasteners that have been previously torqued to a value greater than 75 % of the ultimate strength should not be reused.

16.2 *Washers*:

16.2.1 Designs shall take into consideration the force under the head of a bolt or nut compared to the compressive yield strength of the clamped material.

16.2.2 Hardened flat washers shall be used under the heads of all bolts and nuts when fasteners SAE Grade 8 (ASTM A490, ISO Grade 10.9) and above where specified torque values are used.

16.2.3 Flange headed bolts and nuts may be used as an alternate to washers.

16.2.4 Designs utilizing oversized or slotted holes shall use appropriately sized (thickness and diameter) washers.

16.3 *Locking Systems*:

16.3.1 Locking spring type washers, for example, split, toothed, star, serrated, shall not be used with fasteners of strength grade levels, SAE grade 5, ISO grade 8.8, or higher with specified torque values. Locking type bendable tab washers are acceptable.

16.3.2 The ride analysis shall identify fasteners that require a means to visually verify that the fastener has not loosened since the last torque (that is, torque stripe, safety wire, torque tabs, etc.).

16.4 *Holes and Surfaces*:

16.4.1 Holes for fasteners shall be sufficiently perpendicular to the fastener bearing surfaces (bolt and nut) to avoid detrimental bending forces on the fastener. In cases where this is not possible, bearing surfaces for the fastener head and nut shall be made sufficiently perpendicular to the hole through the use of beveled washers or spot machining of the bearing surface(s) being clamped.

16.4.2 Material surfaces within the clamped grip, that is, fastener bearing surfaces and corresponding surfaces of all items being held together by the fastener, shall be free of burrs, foreign materials, and other substances that may prevent solid seating and reliable sustained clamping of the assembled parts when the fastener is tightened to the specified torque.

16.4.3 Consideration shall be given to the characteristics of the materials being clamped, for example, the possibility of cold flow or creep of plastics, paint, or other materials within the joint that might contribute to long-term relaxation.

17. Keywords

17.1 acceleration limits; amusement ride or devices; anti-rollback devices; chain; clearance envelope; containment; control systems; design; electrical; emergency safety device; fasteners; fatigue; fencing; guardrails; hydraulics; impact factor; loads and strengths; mechanical systems; operational hours; pneumatics; restraints; ride analysis; welding; wire rope

ANNEX

(Mandatory Information)

A1. Loads and Strengths

A1.1 *Section 8.1—Loads and Strengths:*

A1.1.1 *Section* 8.1.1—The intent of the Loads and Strengths section is to broadly define the criteria (that is, minimum design requirements and considerations) to be applied by the designer/engineer in the design of the amusement ride or device. These criteria are specifically intended for use in determining the loads and strengths of materials, and performing the calculations and analyses used in the process of design.

A1.1.2 *Section* 8.1.1—The loads and strengths section contains both flexible and finite criteria. The criterion is flexible by allowing the designer/engineer to determine the type(s) of calculation or analyses, or both, to be used in the design process. The criterion is finite with respect to how the inputs and outputs to the overall analysis and calculations shall be determined and treated by the designer/engineer.

A1.2 *Section* 8.3—*35 000 Operational Hour Criteria:*

A1.2.1 *Section* 8.3.1—The designer/engineer can design an amusement ride or device for more than the 35 000 operational hour criteria.

A1.2.2 *Section* 8.3.2—The following example calculations illustrate how the general reduction for load and unload time and the number of operational hours, to be used in the design calculations and analyses for an amusement ride or device, can be determined.

(*1*) For this example, the time for one ride cycle (not including load or unload time between ride cycles) = 4 min. The load and unload time between ride cycles (not including ride cycle time) = 3 min.

Calculating the General Reduction Allowed for Load and Unload Time:

$$\left(\frac{\text{(Load/unload time for one ride cycle)}}{\text{(Load/unload time for one ride cycle)} + \text{(Time for one ride cycle)}}\right) = \text{General reduction for load/unload time}$$

$$\left(\frac{3\text{ min}}{(3\text{ min} + 4\text{ min})}\right) = 0.428 \text{ or } 43\ \%$$

0.428 or 43 % is the calculated value for load/unload time for each operational hour.

A1.2.2.1 Because 8.3.2.1 limits the maximum reduction to 50 %, the maximum reduction in this example is 43 %.

Calculating the Operational Hours to be Used in the Design Calculations and Analyses:

$$[\text{(35 000 Operational Hour Criteria)} \times (1.00 - \text{General reduction for load/unload time)}] = \text{Operational hours for design}$$

$$[\text{(35 000 Operational Hour Criteria)} \times (1.00 - 0.43)] = 19\,950 \text{ Operational hours}$$

In this example, the designer/engineer would use 24 500 operational hours for all applicable design calculations and analyses.

A1.2.3 *Section* 8.3.3—Idle time (the time the ride is ready for operation, but is not being cycled) is not intended or required to be included in the calculations for the operational hours. This is because the actual idle time for an amusement ride or device cannot be accurately defined prior to operation. Therefore, idle time is not included in the calculations for operational hours that are used in the design of the amusement ride or device. After installation of the amusement ride or device, the actual idle time could be recorded and documented and applied in the maintenance and inspection of the amusement ride or device.

A1.2.4 *Section* 8.3.2.1—Ride cycles differ greatly from load cycles. For applicable components, a calculation may need to be performed to determine the number of load cycles that occur within the total number of operational hours calculated and then used in the design calculations and analyses for the amusement ride or device. The following example calculation illustrates how the total number of load cycles can be determined for a specific applicable component on an amusement ride or device.

A1.2.4.1 For this example, the previously calculated operational hours to be used in the design for applicable components = 19 950 operational hours. Because the general reduction for load and unload time was taken into account in the previous calculation, the number or ride cycles per hour (not including load and unload time) = (60 min/(ride cycle time – load and unload time)) = (60 min/(7 min – 3 min)) = 15 ride cycles per hour. The number of load cycles per ride cycle for this particular applicable component = 8 load cycles.

Calculation for Determining the Total Number of Load Cycles for an Applicable Component:

$$\left(\frac{\text{Operational hours for design}}{1}\right) \times \left(\frac{\text{Ride cycles (without load and unload time)}}{\text{Operational hour}}\right) \times \left(\frac{\text{Number of load cycles}}{\text{Ride cycle}}\right) = \text{Total Number of Load Cycles}$$

$$\left(\frac{19\,950 \text{ operational hours}}{1}\right) \times \left(\frac{15 \text{ ride cycles}}{1 \text{ operational hour}}\right) \times \left(\frac{8 \text{ load cycles}}{1 \text{ ride cycle}}\right) = 2\,394\,000 \text{ load cycles}$$

In this example, the calculation shows that the applicable component will experience 2.39×10^6 load cycles throughout the 19 950 operational hours used in the design calculations and analysis.

A1.3 *Section* 8.4—*Exceptions to the 35 000 Operational Hour Criteria*—Section 8.4 only applies to components of the primary structure and does not apply to nonstructural mechanical, hydraulic, electrical, etc. components. Furthermore, 8.4.1 is not intended to suggest that nonstructural, mechanical, electrical, etc. components be required to be designed for the operating hours defined in 8.3 and 8.4. For example, tires on wheels (for example, urethane coverings on steel wheels), bearings, bushings, hydraulic pumps, electrical motors, and electrical relays are not necessarily designed for or manufactured to last throughout the operational hours defined in 8.3 and 8.4. These are examples of components that can be replaced as part of the required maintenance for the amusement ride or device.

A1.3.1 *Section* 8.4.1—Section 8.4.1 allows the designer/engineer to exempt certain defined types of components that of the primary structure, covered in 8.3.1, from the operational hour requirement.

A1.4 *Section* 8.7—*Loads:*

A1.4.1 *Section* 8.7.1—This practice does not address and is not intended to address issues of compliance related to the requirements mandated by Department of Transportation that may apply to amusement rides and devices that travel on or over roadways. Designers/engineers and manufacturers that design amusement rides or devices that are purposely designed for travel on or over roadways (that is, portable rides) should refer to such applicable codes as necessary.

A1.5 *Section* 8.8—*Permanent Loads:*

A1.5.1 *Section* 8.8.1—The term "permanent load" means dead load. Dead loads include the load bearing structure, accessories, and the technical equipment required for operation, including claddings, fabrics, and decoration.

A1.5.1.1 There are special types of permanent loads (dead loads) that do fluctuate with respect to time but happen very slowly and only occur a very limited number of times. Examples of these loads include foundation settlement loads and maintenance loads (that is, fluctuations produced by draining of entrained fluids for maintenance).

A1.5.1.2 The following list is not intended to be a comprehensive or exhaustive list of loads and is provided for consideration in the design process. The designer/engineer is required to determine and evaluate the loads the amusement ride or device is expected to experience during the calculated operational hours.

A1.5.1.3 The following are each considered a part of the overall permanent load:

(*1*) Weight of the equipment,
(*2*) Conduits and piping,
(*3*) Ballast,
(*4*) Cladding,
(*5*) Hard and soft themed and decorative coverings,
(*6*) Cables,
(*7*) Water (nonponding),
(*8*) Entrained fluids (water, hydraulic oil), and
(*9*) Show elements mounted to ride.

A1.5.1.4 *Special cases of permanent loads*:

(*1*) Foundation settlement (refer to ASCE 7),
(*2*) Misalignment,
(*3*) Deliberate preloading of structural components,
(*4*) Active and passive earth pressures, and
(*5*) Structural interaction at interfaces between the ride track structure and facility structure.

A1.5.1.5 To the maximum extent practical, the applicable interfaces or mounts between facility structures and track structures or support structures and machinery should be designed to reduce or eliminate the stresses caused by misalignment.

A1.5.1.6 Most portable rides are self contained and the loading is self limiting by operation, mechanical action, and seating.

A1.6 *Section* 8.9—*Variable Loads:*

A1.6.1 *Section* 8.9.1—The term "variable loads" means live loads. Variable loads consist of the external loads and imposed deformations (for example, imposed loads, gyroscopic loads, dynamic loads, wind and snow loads, temperature, or settlement) acting on a structural component, which may vary with respect to magnitude, direction, and point of application (variation in time and space) during normal operation.

A1.6.2 Many other standards (DIN, EN, AISC, and ASCE) vary with respect to the definition of "live load." However, these standards all agree that live load elements do fluctuate with time. Some standards apply different load factors to different types of live load elements.

A1.7 *Section* 8.10—*Operational Loads:*

A1.7.1 Patron restraint loads occur in several ways. Each of the following needs to be considered.

A1.7.1.1 *Section* 8.10.1—Accelerations acting on the mass of the patrons produce inertia loads that are reacted by the restraint systems in order to hold the patrons in place during movement of the ride vehicle.

A1.7.1.2 Patrons generally unintentionally and intentionally apply significant forces to the restraints at times and during events not necessarily associated with inertia loading caused by motion of the ride. Examples are forces applied during loading and unloading of a ride vehicle when patrons grab onto restraints for balance and to pull themselves into and out of the ride.

A1.7.1.3 Patrons may pull or push on restraints while the restraint system is locked in either the up or down position in an attempt to move the restraint into or out of the restrained or unrestrained position (that is, prior to the operator engaging or releasing the restraint system).

A1.7.1.4 Patrons may attempt to intentionally damage a restraint system by applying their full strength to the restraint system, and the design should possess sufficient strength to preclude yielding or significant deformation, or both, under this loading condition. In cases where more than one patron is restrained by a particular system, the design shall consider that all patrons will apply the same excessive (that is, abusive) forces.

A1.7.2 *Section* 8.10.2—Operational loads include:

A1.7.2.1 *High Cycle*:

(*1*) Drive/actuation forces,
(*2*) Moving loads,
(*3*) Braking forces,
(*4*) Operational dynamics/vibration,
(*5*) Kinematic induced loads,
(*6*) Hydrostatic/hydrodynamic,
(*7*) Unbalanced load (centrifugal),
(*8*) Misalignment—(that is, rotating shafts),
(*9*) Aerodynamic,

(*10*) Movement of show elements mounted to ride vehicle, and

(*11*) Patron restraint—adult patron (both inertial and direct force).

A1.7.2.2 *Low Cycle*:

(*1*) Emergency evacuation,

(*2*) Runaway condition (that is, loads generated when drives/actuators operate at their full rated capacities),

(*3*) Patron restraint, large adult patrons,

(*4*) Fuel consumption,

(*5*) Earthquake,

NOTE A1.1—This practice does not require portable amusement rides and devices to be designed for seismic loads. However, when a portable amusement ride or device is designed for seismic loads, a description of these loads will be stated in the strength calculations, and included in the operating and maintenance instructions. See section on Manufacturer's Responsibility in Practice F 770 and section on Manufacturer's Responsibility in Practice F 853.

(*6*) Collision with emergency end stops, and

(*7*) Shock due to failure of redundant component (that is, cable suspended ride with dual cables).

A1.7.2.3 *Low or High Cycle*:

(*1*) Reverse operation,

(*2*) Emergency stops,

(*3*) Anti-rollback,

(*4*) Patron load/unload forces,

(*5*) Possible failure modes producing loads on secondary structure (that is, safety cables and links, etc.), and

(*6*) Loads generated by special testing requirements (for example, increased weight, velocity, or acceleration during cycle testing).

A1.8 Primary structures shall be analyzed to verify that fatigue failures do not result from loads that fluctuate a relatively large number of times. A number of stress cycles between 10 000 and 100 000 cycles is considered significant in the context of fatigue damage. Knowing if the precise number of stress cycles will need to be considered as a fatigue case depends on each application and on the *S-N* curve for the material being considered. A simple approach to quantifying this number of stress cycles consists of calculating the yield strength based (nonfatigue) allowable stress. This value of stress (*S*) can then be checked on the *S-N* curve for the application to obtain the corresponding number of allowable stress cycles (*N*). If the number of allowable stress cycles from the *S-N* curve is more than the number of cycles the calculated load will fluctuate in the application, then the allowable stress is greater than the yield-strength calculations. In other words, for this example, the fatigue behavior is less critical than strength allowables and therefore fatigue strength does not need to be checked. Some loading events must be evaluated against finite life criteria, while other loads may need to be evaluated for a higher fatigue life criterion as determined by the designer/engineer.

A1.8.1 Examples of finite life loading conditions include certain E-stop events and possibly some maintenance operations that may be expected to occur a significant number of times.

A1.8.2 Examples of high cycle loading conditions include, but are not limited to, loads that occur during normal operations of the ride based upon nominal patron weights. A good example of this would be patrons applying loads to the restraint system due to accelerations induced by the operation of the ride.

A1.9 *Section* 8.12—Environmental loads to consider in the design include:

A1.9.1 Snow and ice,

A1.9.1.1 Rainwater and ponding accumulation,

A1.9.1.2 Earthquake (seismic),

A1.9.1.3

NOTE A1.2—This practice does not require portable amusement rides and devices to be designed for seismic loads. However, when a portable amusement ride or device is designed for seismic loads, a description of these loads will be stated in the strength calculations, and included in the operating and maintenance instructions. See section on Manufacturer's Responsibility in Practice F 770 and section on Manufacturer's Responsibility in Practice F 853 .

A1.9.1.4 Wind (nonoperational), and

A1.9.1.5 Self-Straining—changes in temperature, time variant ground forces (for example, settling).

A1.9.2 *Section* 8.15—*Design*:

A1.9.2.1 *Section* 8.15.1—The structural analysis shall consider all appropriate combinations of loading and shall evaluate the resulting strains, stresses, deflections, and so forth against the appropriate material allowable criteria.

A1.9.2.2 *Section* 8.15.2—There are many methods available to perform structural analysis (hand calculations, finite element analysis, and so forth) and it would be too restrictive (and likely too difficult) to force designers to always utilize a single specific method when more than one technique can be appropriately utilized to compute stress levels. Furthermore, test and measurement can sometimes be substituted for rigorous analysis. However, it is not always practical to verify via testing. For example, verifying that large structures exposed to very high wind loads are structurally adequate is not always practical, so some form of structural analysis is usually warranted.

A1.9.2.3 Identification of loads and determination of the proper stress allowables are two key elements required to ensure that amusement rides and devices possess adequate structural capability.

A1.9.2.4 In any case, no matter if stresses are determined by analysis, testing, or both, loads and stress allowables must be determined irrespective of how stresses are evaluated. For example, if structural adequacy is to be verified via testing, the subject structure must be exposed to all appropriate loads (and there may be several loading conditions to apply) and the resulting measured parameters (strain, deflections, and so forth) must be evaluated against some criteria to determine if they are acceptable. Consequently, it is the designer/engineer's responsibility to determine that:

(*1*) All appropriate loading conditions are considered in the design and,

(*2*) The stresses produced by the expected loading conditions do not exceed the established material allowables.

A1.9.2.5 Note that this standard does not explicitly prescribe methods to compute stresses and strains, nor does it specify procedures to compare stresses and strains to design stress allowables. It is expected that the computation of stresses and strains and evaluation of those results, with respect to specific design stress allowables, will be performed by competent and experienced personnel utilizing established and recognized analysis techniques.

A1.9.2.6 In general, the procedure to be used to verify that structures possess adequate structural capability consists of the following basic steps:

(*1*) Identification of all expected external and internal loading, including where these loads will be applied.

(*2*) Calculation of, or empirical measurement of, stresses and strains.

(*3*) Determining the appropriate stress allowables (that is, strengths of materials).

(*4*) Comparing the computed or measured values for stresses or strains, based upon expected loading conditions, to the values for the respective design stress allowables.

(*5*) If the calculated stresses are determined to be greater than the material allowables, validation of analytical predictions with empirical testing is recommended.

A1.9.2.7 *Section* 8.15.3—The following are possible load cases the designer/engineer should consider:

(*1*) Static and operational loads generated during normal operation,

(*2*) Occasional static and dynamic loads generated during operation (for example, frequent emergency stops, single point failures, and multiple point failures),

(*3*) Static and dynamic loads generated during maintenance operations (that is, asymmetrical jacking),

(*4*) Patron loads that are even, uneven, and exceptional under-load and overload conditions,

(*5*) Loads generated by patrons or any other persons,

(*6*) Loads generated by mechanisms at their full-rated pressure, flow, and torque (for example, electric and hydraulic motors, actuators),

(*7*) Loads generated by hydrodynamic pressure (for example, due to travel through water, water waves, close proximity to waterfalls or moving boats),

(*8*) Loads generated by operating the amusement ride or device at maximum performance levels,

(*9*) Loads generated by special testing requirements (for example, increased weight, velocity or, acceleration during cycle testing),

(*10*) Loads resulting from shipping, handling, and installation,

(*11*) Loads imparted by other equipment, adjacent or otherwise,

(*12*) Environmental loads imposed during operation (for example, seismic loads, operational wind loads, temperature loads (that is, expansion/contraction). This practice does not require portable amusement rides and devices to be designed for seismic loads. However, when a portable amusement ride or device is designed for seismic loads, a description of these loads will be stated in the strength calculations, and included in the operating and maintenance instructions. See section on Manufacturer's Responsibility in Practice F 770 and section on Manufacturer's Responsibility in Practice F 853, and

(*13*) Environmental loads imposed on ride structure without operational loads.

A1.9.2.8 *Section* 8.15.4—The calculations shall include forces, loads, and stresses caused by differential movements of supports due to settlement, elastic and plastic deformations, including the effects caused by such movements of the interfacing structures or machine elements, or both.

A1.10 *Section* 8.16—*Impact Factor for Strength and Fatigue Analysis:*

A1.10.1 *Section* 8.16.1—Load/impact Factors utilized in fatigue analyses account for several effects and are often determined based upon engineering judgment and experience, particularly when empirical data is not available and is not practical to obtain via a prototype. Impact forces are most likely to arise in the structure or in individual parts during operation (for example, at rail joints, abrasive wear). The key to selection of load/impact factors is stated in 8.16.3 and 8.16.4. Specifically, the factors utilized must be confirmed by measurement once structures are built, and if the factors utilized to determine loads in the "original" stress and fatigue analysis do not bound the measured loads, a significant amount of work may be required to be revised. Consequently, it is generally in the designer/engineer's best interest to select load/impact factors conservatively. It may not be practical or even necessary to build a "prototype" of a roller coaster in order to determine the exact load/impact Factors required for the fatigue of specific components. The designer/engineer often has empirical data from existing rides that can be utilized to estimate what peak loads will be, based upon the nominally expected loads (that is, the impact factor times the nominal inertial loads). Once the amusement ride or device is built, the factors utilized in the analyses will be "measured," and having to redesign components because load/impact factors were not high enough is not desirable.

A1.10.2 *Section* 8.16.2—Moving load includes the following:

A1.10.2.1 Vehicle,

A1.10.2.2 Kinematic induced loads,

A1.10.2.3 Moving structures (that is, arms on a rotating ride), and

A1.10.2.4 Patron weights.

A1.10.3 *Section* 8.16.3—Forces arising from startup and braking are not considered as being impact forces but regular imposed loads. Another example of regular imposed loads is those loads generated by hydraulic or pneumatic cylinders.

A1.10.4 *Section* 8.16.4—The load impact factor generally accounts for two effects: (*1*) dynamic amplification, and (*2*) uncertainties associated with the calculation and analysis of dynamic loads.

A1.10.4.1 When a structure is subjected to impulsive or shock loads, the peak deflections, internal forces and reaction forces can be significantly higher or lower than if the same loads were applied "slowly" (that is, quasi-statically). The response of a structure to the application of a particular loading condition is dependent upon the duration and profile (that is, load versus time) of the loading condition as compared to the fundamental period (that is, the inverse of the fundamental material frequencies).

A1.10.4.2 In general, the magnitude of amplification (or reduction) of a structure's response to "dynamic" loads as compared to the response to "static" loads can be determined by rigorous dynamic analysis or direct measurement or both. However, rigorous dynamic analysis or testing or both can be expensive and time consuming and is not always practical given other alternatives. In some cases, the structure does not physically exist and therefore direct testing and measurement is not possible.

A1.10.4.3 One alternative is to apply expected loads or accelerations or both using "static" analyses and ratio the results by the expected amplification (or reduction) factor as appropriate (or the loads can be ratioed prior to application). The actual amplification (or reduction) factor utilized should be based upon the expected duration of impulse or shock load as compared to the fundamental natural periods of the particular structure being analyzed.

A1.10.4.4 The second aspect of the load impact factor pertains to accounting for the uncertainty associated with the calculation and analysis of dynamic loads. For example, rigorous dynamic analysis can be utilized to predict reaction forces applied to guide wheels as a roller coaster ride vehicle traverses a track. In this case, an idealized track geometry is typically assumed; however, the actual loads and accelerations measured after a ride is built and operational are generally found to fluctuate (often significantly) from the nominally expected loads. This is partially due to manufacturing imperfections in the track system (that is, noncontinuous smooth bends in track tubing, mismatch at joints, weld beads, etc.). Thus, the impact factor must account for uncertainties in dynamic loading. The selection of impact factors and their value is often based upon previous experience and engineering judgement.

A1.10.4.5 Impact factors of no less than 1.2 are applied to analytically predicted dynamic loads to account for "shock" and "uncertainty" effects. In cases where empirical verification of actual loads are measured, the structural adequacy of existing rides can be verified utilizing impact load factors closer to unity, if deemed prudent by the designer/engineer.

A1.10.5 *Section* 8.16.5—An example of a component that may have a designer/engineer-defined maximum allowable wear limit that could affect the impact or vibration loads is tire wear.

A1.11 *Section* 8.20—*Serviceability*:

A1.11.1 *Section* 8.20.1—Serviceability in the context of this practice refers to the satisfactory function and performance of an amusement ride or device (and not the ease of maintenance). For instance, serviceability includes verification that maximum deflections that occur during normal operation do not cause interferences or excessive distortions or both that would concern patrons and operators.

A1.12 *Section* 8.21—*Design for Strength*:

A1.12.1 *Section* 8.21.1—There are two approaches that have been used extensively in general structural engineering design practice in North America and Europe for the last several years.

A1.12.2 *Section* 8.21.2—Of these two, Allowable Stress Design (ASD) is the more traditional practice.

A1.12.3 In the ASD method, stresses are calculated in the structure for expected (that is, unfactored, maximum loads). The calculated stresses, sometimes referred to as working stresses, are compared with the material design allowable stress. These material design stress allowables are defined in various design specifications and references (for example, AWS Structural Welding Code for Steel, etc.). Typically, the design stress allowable for metals is equal to approximately 66 % of the yield strength. Specifying the allowable stress to be significantly less than the yield strength of the material ensures an acceptable level of safety for the structure.

A1.12.4 The second and most widely accepted contemporary design approach is the Load and Resistance Factor Design (LRFD) method.

A1.12.5 In the LRFD method limit states are identified and checked. The two most important limit states applicable to ride structures are: (*1*) Static strength, and (*2*) Fatigue strength.

A1.12.6 LRFD requires that adequate static strength be demonstrated by checking the strength of the structure against the applied loads. The strength is calculated by well-established analytical methods but downgraded by resistance factors to account for statistical effects in materials and manufacturing methods. The loads used in LRFD are generally maximum expected loads factored up to account for the probabilistic nature uncertainties of these loads. The safety of the structure is ensured in LRFD by the appropriate choices of resistance and load factors that are specified in various design specifications (for example, AWS Structural Welding Code for Steel).

A1.13 *Section* 8.22—*Load Combinations for Strength Using ASD:*

A1.13.1 *Section* 8.22.1—Live load, *L*, includes the estimated or measured live load multiplied by the appropriate impact factor. Refer to Section 8.16 on Impact Factor for Strength and Fatigue Analysis. This section is derived from Section 2.4 on Combining Nominal Loads Using Allowable Stress Design in ASCE 7.

A1.14 *Section* 8.24—*Section 8.24—Load Combinations for Strength Using LRFD:*

A1.14.1 *Section* 8.24.2—Using actual weights and loads eliminates the need to use a load factor normally applied to account for uncertainties associated with using assumed weights and loads.

A1.14.1.1 *Section* 8.24.2—The design strength is the nominal strength multiplied by the resistance factor.

A1.15 *Section* 8.27—*Design for Fatigue:*

A1.15.1 *Section* 8.27.1—Listed below are some approaches applicable for specific materials:

A1.15.1.1 *Metals*—Unwelded material: stress range or Goodman; welded material: stress range or Goodman.

A1.15.1.2 *Composites*—Refer to: STP 1330, Composite Materials: Fatigue and Fracture, 7th Volume; and MIL 17, The Composite Material Handbook.

A1.15.1.3 *Timber*—Refer to ASCE 16.

A1.16 *Section* 8.28—*Load Factors for Fatigue:*

A1.16.1 *Section* 8.28.1—In the context of LRFD, this statement infers a load factor of 1.0 is applied to all loads in a fatigue analysis.

A1.16.1.1 One exception shall always be the impact factor. An impact factor of not less than 1.2 shall always be applied to the moving loads, unless the design, manufacture, or operation of the structures requires a higher value.

A1.16.1.2 The use of a fatigue load factor of 1.0 is contingent upon the fatigue related loads being the peak expected magnitudes (that is, amplifications due to shock, impulse, jerk, and dynamic effects are included) and the fatigue stress allowables are design values (rather than mean or typical properties) as discussed in subsequent sections.

A1.17 *Section* 8.29—*Load Combinations for Fatigue:*

A1.17.1 *Section* 8.29.1—In general, several load combinations must be evaluated and the difference between the stresses computed in the various combined loading conditions shall then be utilized to identify the expected fluctuation in stress levels and mean stresses, if applicable. For example, if three possible load combinations are identified to bound the extreme fluctuations, the fatigue analysis should consider the difference in stresses that occur between the three possible permutations (that is, load combinations 1 to 2, 2 to 3, and 1 to 3).

A1.17.2 Note also that as opposed to the strength analysis, at least one of the loading combinations may consider a state where the loads are the lowest so as to produce the highest change in stresses in relation to load combinations that produce the highest stress states. Where appropriate, load combinations should also address the fact that some loads may reverse to produce stresses that may be similar in magnitude, but opposite in sign. It should also be noted that the maximum fluctuation in stresses might not be produced at all locations due to the same two load combination conditions.

A1.17.3 The most appropriate method for checking the fatigue strength of a structure is based on an allowable stress type of calculation. This method is therefore consistent between ASD and LRFD approaches.

A1.17.4 In LRFD terminology, the fatigue limit state includes the structural response under expected maximum loads (that is, stresses due to unfactored loads) being checked against a fatigue allowable stress. The allowable stress, consistent with ASD methodology, is reduced from the expected fatigue strength. It is this reduction in allowable stress that ensures the safety of the structure against fatigue failure. If there is no reduction in fatigue allowable stress compared with fatigue strength, there will be a 50 % probability of fatigue failure, which is clearly unacceptable. This is a very important consideration in the design of ride structures because the fatigue limit state is the most demanding in most design applications.

A1.18 *Section* 8.30—*Fatigue Material Allowable Properties:*

A1.18.1 *Section* 8.30.1—The use of mean fatigue property data downgraded by two standard deviations (2σ) provides an appropriate level of safety for general design purposes. Using this adjusted fatigue property data approach will reduce the probability of failure to 2.3 %. The acceptability of this probability of failure is cited in the literature **(5)**. It is noted that the "Mean-2σ" approach is incorporated in British Standard BS 5400–10. It is noted that the design *S-N* curves developed in BS 5400—10 are generally consistent with curves given in AWS, AISC, and DIN, which make no reference to the factor of safety associated with their use.

A1.18.1.1 In lieu of computing a two standard deviation reduction from the mean fatigue strength based upon rigorous statistical analysis (when "design" fatigue strength data is not available), an alternate method based upon a strength reduction factor is presented in the third edition of Shigley. Several references, including Shigley, Juvinall, and Dowling, resent data that indicates that the standard deviation of high cycle fatigue strengths of metals utilized in engineering applications is less than 8 %, and based upon this, Shigley has derived a table of "reliability" (that is, strength reduction) factors corresponding to various reliabilities. Note also that the results presented by Shigley also appear to be consistent with data presented in the ASM Atlas of Fatigue Curves. Due to the larger uncertainty associated with the "reliability factor" approach (as compared to rigorous statistical analysis), it is recommended that the reliability factor of 0.75 associated with a three standard deviation reduction (corresponding to 99.9 % reliability) be utilized. This corresponds to a 25 % reduction of mean or typical fatigue strength data.

A1.18.1.2 *Section* 8.30.1.2—In the case where the raw fatigue property data is available, the "Mean-2σ" value can be calculated by standard statistical techniques. In the absence of such data, however, an assumption about the randomness of the fatigue properties is needed to provide a basis for the *S-N* downgrading. British Standard, BS 5400—10, gives a range of ratios of standard deviation to mean value between 13 and 18 % for welded joint details believed to be due to the variability of weld quality achieved by certified welders. In the case of parent material properties, the standard deviation of fatigue strength expressed as a percentage of the mean strength values is in the 8 to 12 % range.

A1.18.1.3 The data that corresponds to a high cycle count (that is, *N*> ~1.00E + 07) has a mean stress value of 6.3 ksi (43.4 MPa) and a standard deviation, σ, of 1.8 ksi (12.4 MPa). Thus the "Mean-2σ" value is 2.7 ksi (18.6 MPa) and this is the recommended design endurance limit. Note that for all the points shown, none of the tested specimens would have failed at that stress level. It is possible that if more samples had been tested and they followed the same statistical distribution as the data shown, approximately 2 % of the data points would have been below 2.7 ksi (18.6 MPa). However, this is deemed an acceptable level in normal practice.

A1.18.1.4 Surface finish and other material conditions that can affect fatigue behavior shall also be taken into account. Technical references such as Mechanical Engineering Design by Joseph Shigley **(4)**, or Handbook of Mechanical Engineering **(3)** address these issues. Examples of other conditions to be considered include:

(*1*) Size factor,

(*2*) Temperature,

(*3*) Corrosion,

(*4*) Notch factors,

(*5*) Miscellaneous effects factor,

(*6*) Exposure to brominated water, and

(*7*) Loading mechanism (that is, bending, tensile, shear, axial).

A1.18.1.5 It is normally prudent to keep stresses within a structure less than the endurance limit for the material being used. This implies that the structure will last indefinitely without cracking for the given loading duty cycle. This approach is well suited for the amusement ride industry because of the high stress cycle count associated with the operation of most equipment. Unfortunately, this approach is not always feasible. In some cases economic factors dictate a finite life for some components. In other cases, the presence of an endurance limit cannot be justified on the basis of available material data. The effect of corrosive agents on some metals, especially when in a welded configuration, leads to an *S-N* curve that does not exhibit a distinct flattened region at high cycle count. In such a case, the need to perform a finite life calculation is critical. See Fig. A1.1.

A1.18.2 *Section* 8.30—*Performing Cumulative Damage Analysis*:

A1.18.2.1 If the ride analysis defines primary structure that should be designed for a finite fatigue life, the steps listed in the following paragraphs should be considered by the designer/engineer.

A1.18.2.2 The first step in a finite life calculation is to identify the stress cycles in a component as induced by the loading history. For example, if we consider a point on a roller coaster rail, this will experience a cycle with a particular stress range each time an axle goes by and will also see a stress cycle associated with the loading of the entire train. The amplitude of this longer cycle would probably be different from the axle stress cycles. The fatigue damage associated with both types of stress cycles would need to be evaluated.

A1.18.2.3 In complex loading situations such as for motion base systems, the identification of stress cycles becomes very difficult and specialized techniques must be adopted. Rain-flow counting is one widely accepted method for this process. Standard fatigue texts should be referenced for detailed treatment of such techniques.

A1.18.2.4 Once the stress cycles have been identified in the structures duty cycle, the next step is to calculate the fatigue damage associated with each type of stress cycle. In other words, the fatigue life must be calculated for each type of stress cycle. Thus, for the roller coaster rail example cited earlier, it would be necessary to calculate the life of the rail detail when subjected to the loads from axle number 1, 2 , ... *n* independently. The life associated with the stress cycle caused by the entire distributed train weight would also be required.

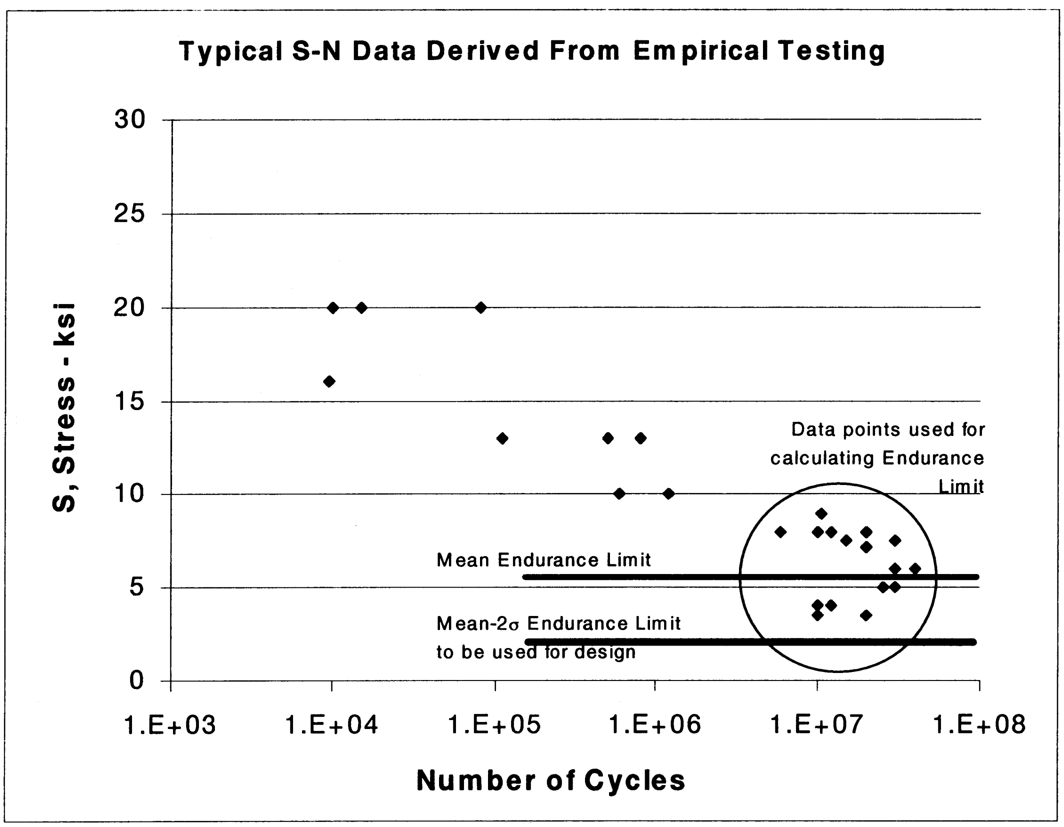


FIG. A1.1 Typical S-N Data Derived from Empirical Testing

A1.18.2.5 The final step in the finite fatigue life calculation is the combination of the life predictions for the various types of loading cycles. This is generally called the cumulative damage calculation and the method generally attributed to Miner and Palmgren is used for this step. In this case the cumulative damage is the linear combination of the damage associated with each type of stress cycle. Note that fatigue damage is defined as the inverse of the fatigue life. Thus if the net fatigue life at a particular point, denoted as N years, is the result of fatigue damage from n separate loading events, each with a predicted life of Ni years, the Palmgren-Miner rule gives:

$$N = \left[\frac{1}{\Sigma(1/N_i)} \right] \tag{A1.1}$$

A1.18.2.6 This evaluation completes the finite life fatigue calculation. The resulting fatigue life prediction N is then compared to the specified number of operational hours of the attraction. See 8.3, 35 000 Operational Hour Criteria.

A1.18.2.7 There are many methods available to perform structural analysis (for example, hand calculations, finite element analysis, etc.).

APPENDIXES

(Nonmandatory Information)

X1. Patron Restraint, Clearance Envelope, and Containment Design Criteria

X1.1 *Section* 6—Table X1.1 summarizes the various restraint classes and their characteristics.

X1.2 *Section* 6.5—Secondary safety devices such as latching belts, straps, or other devices that limit the travel of a

TABLE X1.1 Restraint System Classes and Characteristics

	Class 1	Class 2	Class 3	Class 4	Class 5	Secondary 5
Number of Patrons Per Restraint						
Individual or collective		•	•			•
Individual				•	•	
Final Latching Position Relative to the Patron						
Fixed or variable		•				•
Variable			•	•	•	
Type of Latching/Locking						
Patron or operator may latch		•	•			
Automatic or manual lock, by operator only						•
Automatic lock				•	•	
Type of Unlatching/Unlocking						
Patron or operator may unlatch		•	•			
Automatic or manual lock, by operator only				•	•	•
Type of External Correct or Incorrect Indication						
None required		•				
Visual check by operator required			•	•		•
Primary system failure detectable within one ride or device cycle			•			
External indication required					•	
Failure causes cycle stop or inhibits cycle start					•	
Means of Activation						
Manually or automatically opened and closed		•	•	•	•	•
Redundancy of Latching/Locking Device						
Redundancy not required		•	•			•
Redundant locking device function required				•	•	
Restraint Configuration						
Two restraints or one fail-safe restraint required					•	

primary restraint device are acceptable. When properly designed, these devices may be considered to be an indication of minimum closure of the primary restraint device.

X1.3 *Section* 6.5—The design of the patron restraint and patron containment system are interrelated and should be coordinated with each other while addressing the intent of the amusement ride or device. Generally a highly contoured seat and lateral support in combination with the restraints may be the most desirable design.

X1.3.1 *Section* 6.5.6—Redundant restraint devices means independent restraints in the sense that the secondary device, for example, lap bar, containment enclosure, etc., is able to restrain the patron in case of failure of the primary restraint.

X2. Acceleration Limits

X2.1 *Section* 7—*Acceleration Limits*—Accelerations can vary greatly depending on the type and design of the amusement ride or device and the effect of these accelerations may be dependent on many factors that may be considered in the design, including:

X2.1.1 Direction, magnitude, and onset of acceleration,

X2.1.2 Duration of acceleration (impact versus sustained; see Section 3 on Terminology),

X2.1.3 Sequence/reversal of accelerations,

X2.1.4 Angular accelerations,

X2.1.5 Patron restraint and containment,

X2.1.6 Patron anthropomorphic data,

X2.1.7 Seating and restraint surface padding,

X2.1.8 Friction of seating and restraint surfaces,

X2.1.9 Patron position, and

X2.1.10 Objects in patron seating area that patron may impact.

X3. Electrical Requirements

X3.1 *Section* 12.3.1–*Physical Damage*—Below are examples of unique conditions of physical damages to wiring inherent on amusement rides and devices:

X3.1.1 *Excessive Bending and Flexing*, either by design, length, type of wire, or other means. All conductors shall be protected from damage due to continued use or excessive flexing.

X3.1.2 *High Levels of Petroleum/Synthetic Lubricants and Compounds*. Overexposure to grease, oil, etc. shall be prevented. All flexible cord used in those areas shall be of a listed oil-resistant outer jacket.

X3.1.3 *Pulling/Stretching* occurring on longer runs of portable cord, used to facilitate folding, bending, etc. Supplementary cord restraints shall be used at all locations where cord enters, exits, or passes through the materials of the ride or device.

X3.1.4 *Excessive Heat*—Conductors, wire or cord shall not run through, or pass adjacent to high temperature areas, which exceed the temperature rating of the connector(s). Cord that will be exposed to direct sunlight shall be UV resistant, listed for the application, and derated for expected ambient temperatures. Derate per NEC Table 310-16, Correction Factors.

X3.1.5 *Over Amperage*—Those rides or devices having nonlinear loads producing harmonics, or having flashing/alternating light systems, shall have conductors sized for 125 % of continuous load, with neutral conductors of the same size.

X3.1.6 *Scuffing, Tearing, and Abrasion*—Design criteria shall include allowances for traumatic damage potential to conductors and equipment. These allowances shall include all periods of operation, including but not limited to, setup, operation, maintenance, inspection, teardown, and transport. A minimum 2 in. (50.8 mm) clearance between moving parts and unprotected conductors shall be maintained at all times, regardless of the status of the ride.

X3.1.7 *Environment*—Wiring systems shall consider the environment they will be exposed to during normal operation of the amusement ride or device. This includes, but is not limited to, moisture, UV light, extreme heat and cold, submersion, and other conditions.

X3.2 *Section* 12.4.4–*Transformers*—Due to certain design requirements for specialized windings to feed unique equipment, for example, synchronous linear induction motors, NEC section 250-21 should be utilized.

X3.3 *Section* 12.4.5–*Power Capacitors*—It is recommended that conductors for power capacitors be rated at 135 % of capacitor current rating.

X3.4 *Section* 12.4.6—Due to the uniqueness of amusement rides and devices and the environment they typically operate in, the following guidelines should be considered during the design process:

X3.4.1 Collector rings should be protected from accidental physical contact by a shield that prevents the intrusion of a round rod ⅛ in. (3.2 mm) in diameter by 2 ft (61 cm) in length from contacting any part that could be energized under normal conditions.

X3.4.2 Collector ring assemblies should be protected from materials, liquid, etc., that may be introduced incidentally to the ride or device.

X3.4.3 Collector ring assemblies should include at least one spare ring/brush assembly on each installed assembly and sized to the largest current carrying ring/brush component of the assembly.

X3.5 *Section* 12.5.2—Metal poles used with portable rides and devices should avoid wiring through the bottom of the pole due to vibration from the ride or the mounting of the pole, or both, for example, setting on earth. This could cause unusual or accelerated chaffing or wear on the conductors. All wiring should enter the side of pole through an approved box or conduit body with an approved cord grip.

X3.5.1 *Section* 12.5.2.1—Because of the power supplies used with fluorescent system, for example, switching power supplies, harmonics may require that the neutral conductors on fluorescent systems be sized to carry 200 % of the calculated circuit load, if the circuit contains 20 or more lamps.

X4. Mechanical Systems and Components

X4.1 *Section* 13.3.10—See Fig. X4.1, Typical Types of Wire Rope Deterioration.

X4.2 *Section* 13.3.15—OIPEEC is an international association of people with an interest in the endurance and other aspects of wire rope technology, including selection, degradation, inspection, and testing. Information is available at the following E-mail address: oipeec.com.

Typical Examples of Wire Rope Deterioration

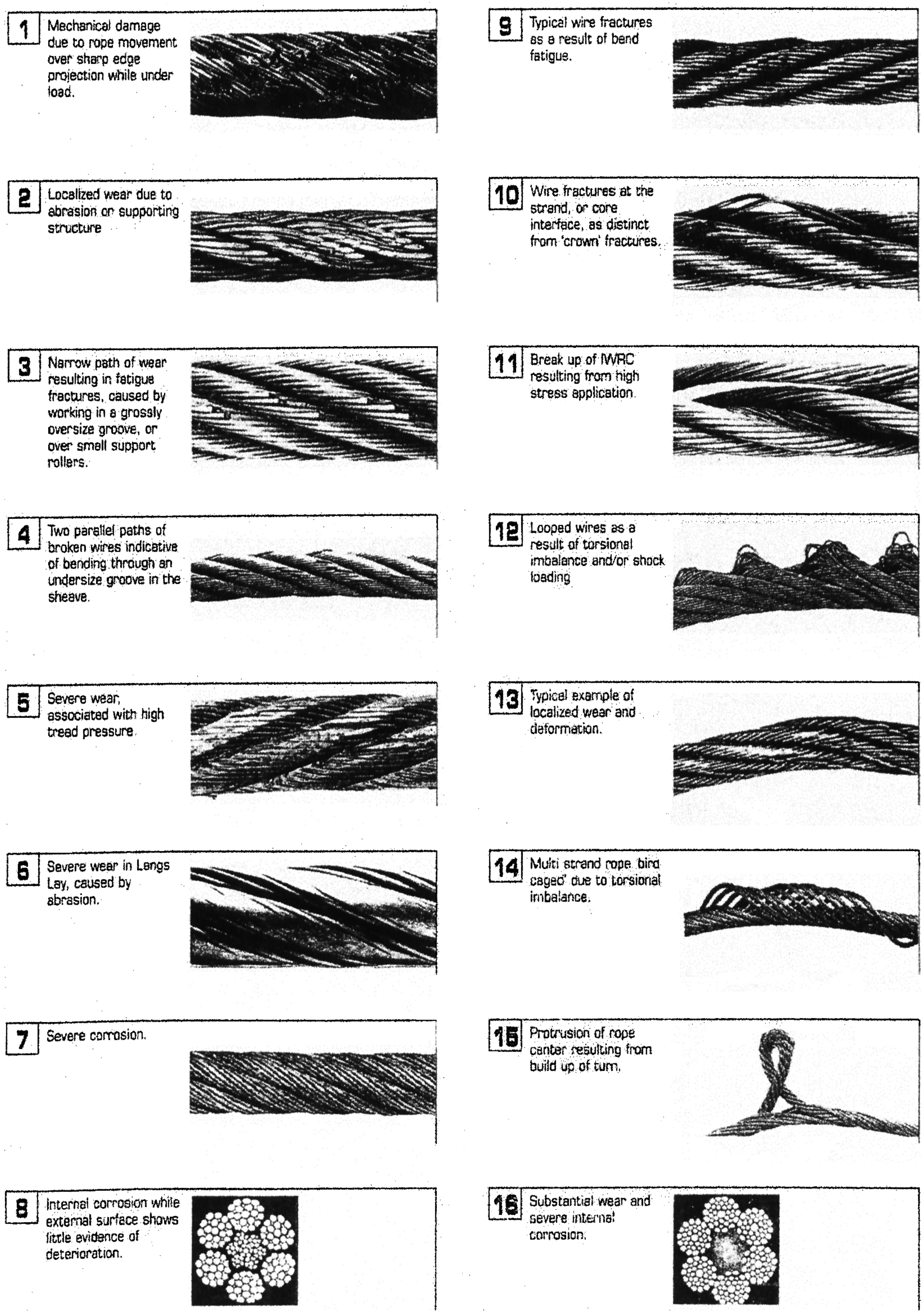


FIG. X4.1 Typical Examples of Wire Rope Deterioration

X5. Fencing, Guardrails and Handrails for Amusement Rides and Devices Manufactured After January 1, 2003

X5.1 *Section* 14.2.1—Horizontal members in a fence or gate may be used to improve construction or efficiency, but should be minimized to reduce the ease of climbing.

REFERENCES

(**1**) Bardagjy, J., Diffrient, N., and Tilley, A., *Humanscale 4/5/6*, The MIT Press, Cambridge, MA, 1981.

(**2**) Bardagjy, J., Diffrient, N., and Tilley, A., *Humanscale 7/8/9*, The MIT Press, Cambridge, MA, 1982.

(**3**) Beitz, W., Heinrich, D., and Kuttner, K.H., *Handbook of Mechanical Engineering*, Springer Verlag, Berlin, Germany, 1994.

(**4**) Budynas, R., Mischke, C., and Shigley, J., *Mechanical Engineering Design*, McGraw-Hill, New York, NY, 1988.

(**5**) Maddox, S.J., *Fatigue Strength of Welded Structures*, Abington Publishing, Cambridge, England, 1993.

(**6**) Mischke, C., and Shigley, J., *Standard Handbook of Machine Design*, McGraw-Hill, New York, NY, 1996.

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org).