Designation: F 1292 – 9904

An American National Standard

Standard Specification for Impact Attenuation of Surface Systems Under and Around Surfacing Materials Within the Use Zone of Playground Equipment[1]

This standard is issued under the fixed designation F 1292; 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.

INTRODUCTION

TSurveys by the United States Consumer Product Safety Commission (CPSC)[2] and others have shown that falls from playground equipment onto the underlying surface are a systematic means significant cause of injuries to children. Severe head injuries are the most frequently implicated cause of death in playground equipment-related falls. Use of appropriate impact-attenuating surfacing materials for in the use on playgrounds has been amply demonstrated by zone of playground equipment can reduce the current difficulty in assessing risk of fall-related injury. In particular, it is believed that the relative merits risk of life-threatening head injuries is reduced when appropriate surfacing materials are installed.

This specification specifies impact attenuation performance requirements for playground surfaces and surfacing materials and provides a diversity means of detesrmining impact attenuation performance using a test method that s,imulagtes the impact of a child's head with the surface. The test method quantifies impact in terms, of *g*-max and terminology. Consequently, Head Injury Criterion (HIC) scores. *G*-max is the goal measure of the maximum acceleration (shock) produced by an impact. The Head Injury Criterion or HIC score is an empirical measure of impact severity based on published research describing the relationship between the magnitude and duration of impact accelerations and the risk of head trauma. The standard includes procedures allowing surfacing materials to be performance-rated before installation and for installed surfacing materials to be tested for conformance with the specification.

The purpose of this specification is to reduce the frequency and severity of fall-related head injuries to children by establishing a uniform and reliable means for measure to compare characteristics of comparing and specifying the materials in order to provide the potential buyer with impact attenuation of playground surfaces. Its use will give designers, manufacturers, installers, prospective purchasers, owners, and operators of playgrounds a useful yardstick by which to measure available means of objectively assessing the performance of surfacing materials as a surface under and around playground equipment and hence of evaluating the associated injury risk.

1. Scope

1.1 This specification covers establishes minimum performance requirements for the impact attenuation requirements, when tested of playground surfacing materials installed within the use zone of playground equipment.

1.2 This specification is specific to surfacing used in accordance conjunction with Test Method F 355, playground equipment, such as that described in Specifications F 1148, F 1487, F 1918, F 1951, and F 2075.

1.3 This specification establishes an impact attenuation performance criterion for playground surfacing materials; expressed as a critical fall height.

1.4 This specification establishes procedures for determining the critical fall height of playground surfacing materials under

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Annual Book of ASTM Standards, Vol 14.02.

[2] U.S. CPSC Special Study. Injuries and Deaths Associated with Children's Playground Equipment, April 2001. US Consumer Product Safety Commission, Washington DC.

laboratory conditions. The laboratory test is mandatory for surfaces to conform to the requirements of this specification.

1.5 The laboratory test required by this specification addresses the performance of dry surfacing materials.

1.6 The critical fall height of a playground surfacing material determined under laboratory conditions does not account for important factors that may influence the actual performance of installed surfacing materials. Factors that are known to affect surfacing material performance include but are not limited to aging, moisture, maintenance, exposure to temperature extremes (for example, freezing), exposure to ultraviolet light, contamination with other materials, compaction, loss of thickness, shrinkage, submersion in water, and so forth.

1.7 This specification also establishes a procedure for testing installed playground surfaces in order to determine whether an installed playground surface meets the specified performance criterion.

1.8 The results of a field test determine conformance of installed playground eq surfacipng materials with the criterion of this specification and are specific to the ambient conditions under which a person may fall. This the test was performed.

1.9 The impact attenuation specification applies and test methods established in this specification are specific to all types the risk of material head injury. There is only limited evidence that conformance with the requirements of this specification reduces the risk of other kinds of serious injury (for example, long bone fractures).

NOTE 1—The relative risk of fatality and of different degrees of head injury may be used under playground equipment.

1.2 This estimated using the information in Appendix X1, which shows the relationships between the Head Injury Criterion (HIC) scores of an impact and the probability of head injury.

1.10 This specification relates only to the impact attenuation properties of playground surfacing materials and does not imply address other factors that an injury cannot be incurred if the surface system complies contribute to fall-related injuries. While it is believed that conformance with the requirements of this specification will reduce the risk of serious injury and death from falls, adherence to this specification will not prevent all injuries and deaths.

1.311 The values stated in inch-pound units are to be regarded as standard. The SI units given in parentheses are for information only.

1.4 The following precautionary statement pertains to the test method portions only, Sections 12 and 13, of this specification: *This*

1.12 *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 requirements prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [3]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

F 355 Test Method for Shock-Absorbing Properties of Playing Surface Systems and Materials

F 429 Test Method for Shock-Attenuation Characteristics of Protective Headgear for Football

F 1148 Consumer Safety Performance Specification for Home Playground Equipment

F 1487 Consumer Safety Performance Specification for Playground Equipment for Public Use

F 1918 Safety Performance Specification for Soft Contained Play Equipment

F 1951 Specification for Determination of Accessibility of Surface Systems Under and Around Playground Equipment

F 2075 Specification for Engineered Wood Fiber for Use as a Playground Safety Surface Under and Around Playground Equipment

2.2 *SAE Standard:*

SAE J211 Recommended Practice for Instrumentation for Impact Tests[4]

2.3 *Federal Documents:*

U.S. Consumer Product Safety Commission, Publication 325, Handbook for Public Playground Safety

U.S. Consumer Product Safety Commission, Special Study: Injuries and Deaths Associated with Children's Playground Equipment. April 2002

3. Terminology

3.1 *Definitions of Terms Specific Related to This Standard:* Playground Installations:

3.1.1 *accelerationcritical fall height (CFH)*—the time rate—a measure of change the impact attenuation performance of v a playground surface or surfacing materials; defined as the highest theoretical drop height from which a surface meets the impact attenuation performance criterion specified by this specification. The critical fall height approximates the maximum fall height from which a life-threatening head injury would not be expected to occur.

[3] 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, Vol 15.07. volume information, refer to the standard's Document Summary page on the ASTM website.

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

3.1.2 *around playground equipmentdesignated play surface*—the area under and surrounding playground equipment established as protection—any elevated surface for standing, walking, sitting, or climbing, or a flat surface larger than 2.0 in. (51 mm) wide by 2.0 in. (51 mm) long having less than 30° angle from falls from equipment. horizontal.

3.1.3 *decelerationfall height*—the vertimcal distance between a designated play surface and the playground surface beneath it.

3.1.3.1 *Discussion*—Fall heights for specific types of reduction of velocity. play structure are defined in Specifications F 1148, F 1487, and F 1918.

3.1.4 *playground equipment*—acceleration into gravity at the earth's surface at sea level (32 ft/s (9.8 m/s)). —any fixed physical structure installed in a designated play area that is accessible to children for activities such as climbing, swinging, sliding, rocking, spinning, crawling, creeping, or combinations thereof.

3.1.5 *g-maxplayground surface*—the multiple of *g* that represents a maximum deceleration experienced during an initial—a manufactured or natural material used to cover the ground below playground equipment, including foundations, substrates, and any compliant surfacing materials intended to attenuate impact.

3.1.6 *headformplay structure*—the striking part of a testing apparatus. —a free-standing structure with one or more components and their supporting members.

3.1.7 *head injury criteria (HIC)public use playground equipment*—a measure of impact severity that considers play structure anchored to the duration over which the most critical section ground or not intended to be moved, for use in play areas of the deceleration pulse persists as well as the peak level schools, parks, child-care facilities, institutions, multiple-family dwellings, private resorts and recreation developments, restaurants, and other areas of that deceleration. public use.

3.1.8 *impact attenuationsurfacing materials*—the ability—materials used to cover the surface of the playground use zone.

3.1.8.1 *loose-fill surface s*—a compliant top layer of small, independently, movable components; for example, wood fiber, bark mulch, wood chips, shredded foam, shredded rubber, sand, gravel, and dissipate so forth.

3.1.8.2 *aggregate surface*—a loose fill surface in which the energy compliant top layer is made of panrticulate materials (for example, sand, gravel, crushed marble, slag, cinders, calcined materials).

3.1.8.3 *unitary surface*—a compliant top layer of one or more material components bound together to form a continuous surface; for example, urethane and rubber composites, mouldyed foam, moulded rubber mats.

3.1.9 *impact velocityuse zone*—the velocity of area beneath and immediately adjacent to a play structure or playground equipment that is designated for unrestricted circulation around the equipment and on whose surface it is predicted that a user would land when falling body at from or exiting the time of impact. equipment.

3.1.10 *loose fill systemspecifier*—person or entity responsible for specifying the performance requirements of a playground surface. (For example an architect, or the prospective purchaser, owner, or operator of a playground.)

3.2 *Definitions of Terms Related to Impact Testing:*

3.2.1 *acceleration*—the rate of change of velocity with time, expressed in units of ft/s^{-2}(m/s^{-2})

3.2.2 *drop height*—height from which the missile is dropped during an impact test, measured as the vertical distance between the lowest point of the elevated missile and surface under test.

3.2.3 *g*—the acceleration due to earth's gravity at sea level, having a standard value of 9.80665 m s^{-2}. The standard value may be approximated as 32.174 ft/s^{-2}(9.807 m/s^{-2}). Accelerations may be expressed in units of *g*'s, where 1 *g* = the acceleration due to gravity.

3.2.4 *g-max*—the maximum acceleration of a missile during an impact, expressed in *g* units.

3.2.5 *head injury criterion (HIC)*—a specific integral of the acceleration-time history of an impact, used to determine relative risk of head injury. See Appendix X1.

3.2.6 *HIC interval*—the time interval within the acceleration-time history of an impact over which the HIC integral is evaluated.

3.2.7 *impact*—contact caused by a moving object (for example, an impact test missile) striking another object (for example, a surface) and during which one or both bodies are subject to high accelerations.

3.2.8 *impact attenuation*—property of a playground surface system consisting that, through localized deformation or displacement, absorbs the energy of small independent, movable components; an impact in a way that is, sand, gravel, wood chips, reduces the magnitudes of peak impact force and so forth.

3.1.11 *non-loose fill system peak acceleration.*

3.2.9 *impact test*—a procedure in which the impact attenuation of a playground surface system consisting or surfacing materials is determined by measuring the acceleration of a missile dropped onto the surface.

3.2.9.1 *free-fall impact test*—an impact test in which the trajectory of the missile is not restrained by rails, wires, or mechanisms or structures of any type.

3.2.9.2 *guided impact test*—an impact test in which the trajectory of the missile is restrained by rails, wires, or other mechanism or structure.

3.2.9.3 *impact test results*—one or more measured or calculated values from one or more co impact tests used to define the impact attenuats bion of a playground t surface or surfacing materials.

3.2.10 *impact test site*—point on the sur;face of an installed playground surface that is, foam composites, urethane/rubber blocks, asphalt, and so forth.

3.1.12 *surface system is selected as the target of an impact test.*

3.2.11 *impact velocity*—the velocity (V_0) of a falling body (for example, a missile) at the instant of impact.

3.2.12 *missile*—a rigid object of specified mass having a hemispherical surface of specified radius; used to impart an impact to a surface (see Fig. 1).

3.2.13 *missile reference plane*—the plane of the flat circular face of the hemispherical missile.

3.2.14 *performance criterion*—limiting values of one or more impact test results used to specify minimum impact attenuation performance.

3.2.15 *reference drop height*—a specification of the theoretical drop height of an impact test.

3.2.16 *reference MEP pad*—a modular elastomer programmer pad with consistent and known impact attenuation properties that ~~contribute~~ is used to verify proper functioning of the impact test equipment.

3.2.17 *reference tempera~~b~~ture*—a specification of the temper~~b~~ature conditioning of a surfacing materials on which an impact test is performed.

3.~~1~~2.18 *sample test point*—point on the surface of a sample selected as the target of an impact test.

3.2.19 *theoretical drop height*—the~~q~~ drop height (*h*) that, under standard conditions, would result~~h~~ in an impact velocity equal to a missile's measured impact velocity (V_0). The standard conditions assume that friction and air resistance do not affect the acceleration of the ~~headform at~~ missile and that the ~~moment~~ acceleration due to gravity is equal to the standard value of *g* at sea level. In a free-fall impact test, the actual drop height will approximate the theoretical drop height. In a guided impact test, the theoretical drop height ~~that would generate~~ will be less than the ~~same velocity if~~ actual drop height, due to the ~~test were performed at sea level and there was no~~ effects of friction in the guidance mechanism.

3.3 *Definitions of Terms Related to ~~retard~~ the ~~h~~ Mea~~d~~surement of Acceleration:*

3.3.1 *accelerometer*—a transducer for measuring acceleration.

3.3.1.1 *transducer*—the first device in data channel, used to convert a ~~drop from that height.~~

~~3.2 For~~ physical quantity to be measured into a second quantity (such as an electrical voltage) which can be processed by the ~~definitions~~ remainder of ~~o~~ the channel.

3.3.1.2 *triaxial accelerometer*—a transducer or combination of transducers used for measuring the three vector components of acceleration in ~~this specification, refer~~ three dimensions, relative to ~~Test Methods F 355~~ three orthogonal spatial axes.

3.3.1.3 *uniaxial accelerometer*—a transducer used to measure the component of acceleration relative to a single spatial axis.

3.3.2 *accelerometer data channel*—all of the instrumentation and ~~F 429.~~ procedures used to communicate information about the physical quantity of acceleration from its origin to the point of presentation. The data channel includes all transducers, signal conditioners, amplifiers, filters, digitizers, recording devices, cables and interconnectors through which the information passes and also includes the analytical software or procedures that may change the frequency, amplitude, or timing of the data.

4. Performance Requirements

4.1 ~~All s~~*Surface Performance Parameters*— The average *g*-max and average Head Injury Criterion (HIC) scores calculated from the last two of a series of three im~~u~~pact tests shall be ~~t~~ used as measures of surface performance.

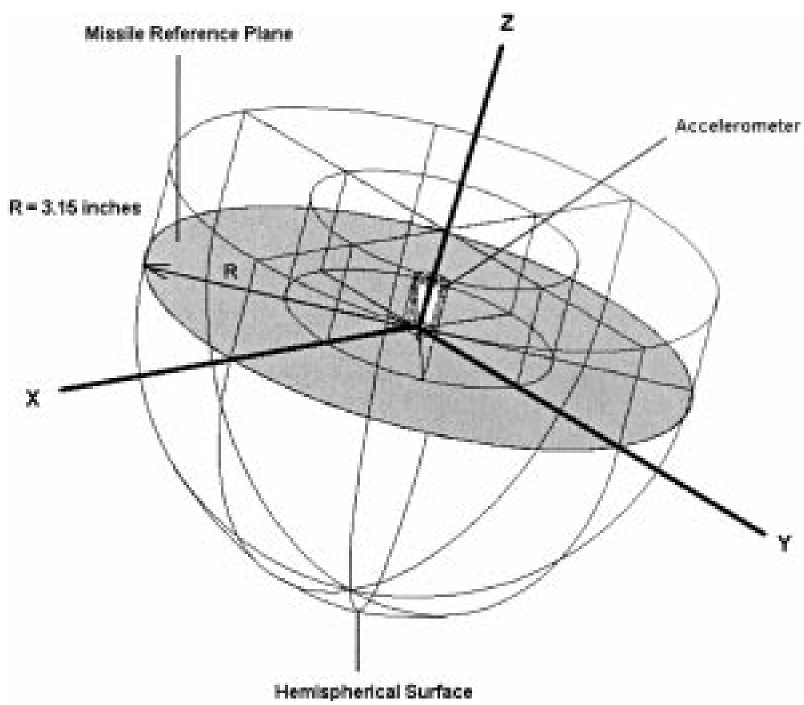


FIG. 1 Missile Reference Plane and Axes

4.2 *Performance Critedrion*—The performance coriterion used to determine conformance with the ~~performance~~ requirements of this specification ~~4.~~ shall be: a *g*-max score not exceeding 200 g and a HIC score not exceeding 1000.

4.3 *Critical Fall Height of Installed Playground Surfaces*:

4.3.1 The critical fall height on,f surfaces ~~may also~~ installed in the use zone of a play structure shall not be less than the fall height of the equipment. The fall height shall be determined as defined by Specifications F 1148, F 1487, or F 1918 for play structures of specific types or in accordance with ~~4.3. Testing in accordance with~~ 3.1.4 of this specification for play structures of unspecified type, unless a higher height is specified.

4.3.2 The critical fall height of the ~~performance requirements~~ playground surface shall have been determined in ~~4.3 is optional.~~
~~4.2 When tested in~~ accordance with ~~Test Method F 355 or~~ the ~~free fall test method in Annex A1, using an average~~ requirements of ~~the last two~~ Section 13 of ~~three drops, no value shall exceed 200 *g*-max or 1000 HIC for laboratory tests at~~ this specification, using reference temperatures of ~~30,~~ 25, 72, and 120°F ~~(−1,~~ (-6, 23, and 49°C), ~~respectively.~~
~~4.3 When tested in~~ surface performance parameters, and the ~~field at ambient temperature in accordance with Test Method F 355~~ performance criterion.

NOTE 2—The specified temperatures span the range experienced by most playgrounds. If higher or lower surface material temperatures prevail when the playground is used, additional tests at higher or lower temperatures may be specified.

NOTE 3—*Wet/Frozen Test*—The specifier may require that surfacing materials be tested to determine critical fall height under wet or frozen surface conditions, or both. Procedures for wet/frozen conditioning are described in Appendix X5.

4.3.3 The laboratory test used to determine critical fall height shall have been conducted on surfacing material samples identical in ~~Annex A1, using an average of~~ design, materials, components, thickness, and manufacture as the ~~last two of three drops, no value shall exceed 200 *g*-max or 1000 HIC at the~~ installed playground surface.

4.3.4 The laboratory test used to determine critical fall height of materials specified ~~by the initial owner/operator~~ for use in a playground shall have been conducted no more than five years prior to ~~purchase~~ the date of installation of the playground surface.

4.4 *Performance of Installed Playground Surfaces*:

4.4.1 When an insthalled playground surface ~~system, while in use,~~ is tested in accordance with ~~Test Method F 355 or~~ the ~~free fall test method in Annex A1, using an average~~ requirements of Sections 16-19 at the ~~last two of three drops,~~ reference drop height, the surface performance parameters at eavery tested location in the use zone shall meet the performance criteria of ~~three test sites, and exceeds 200 *g*-max or 1000 HIC at ambient temperature, as determined by Section 13, at~~ this specification. The reference drop height shall be the greater of (*1*) the height specified by the ~~initial~~ owner/operator prior to purchase, (*2*) the critical fall height specified when the playground surfache was installed, (*3*) the equipment fall height, or (*4*) the critical height of the surface~~,~~ at the time of installation.

4.4.2 When an installed playground surface is tested in accordance with this section, if the impact test scores at any tested location in the use zone of a play structure do not meet the performance criterion, the surface should be ~~made to comply~~ brought into compliance with the requirements of this specification or the ~~playground equipment on the surface~~ play structure should not be used until the playground surface complies.

4.4.3 *More Stringent Specifications*— The specifier may specify additional impact attenuation performance requirements, providing that such additional performance requirements are more stringent than the performance requirements of this specification.

5. Summary of Test Method

~~5.1 Representative~~

5.1 *Critical Fall Height Test*—The impact attenuation of a playground surface ~~systems~~ or surfacing ~~material samples, or both, are tested in accordance with Test Method F 355 or the free fall~~ materials is measured using an impact test ~~method described~~ in ~~Annex A1. Conduct laboratory tests at various~~ which a missile is dropped onto the playground surface from a predetermined drop ~~heights and test temperatures. Conduct~~ height. The acceleration of the ~~field tests at~~ missile during the ~~drop height specified~~ impact is measured using an accelerometer and associated data recording equipment. The acceleration time history is analyzed to determine *g*-max and HIC scores. For each playground surface sample at ~~the ambient~~ each reference temperature and drop height, scores from the second and third of thre ~~w~~e consecutive drops are averaged to give average scores.

5.2 The critical fall height of surfacing materials is determined by impact testing representative samples at a ~~specified range.~~ range of drop heights. The ~~labo~~ surfacing matoeryial is tested at temperathures of 25, 72, and ~~w~~ 120°F (-6, 23, and 49°C). The critical fall height is determined as the ~~maximum~~ highest theoretical drop height ~~at~~ from which the ~~*g*-max does not exceed 200 or~~ surface performance parameters meet the ~~HIC does not exceed 1000. The field~~ performance criterion.

5.3 *Installed Surface Performance Test*— To test ~~method will determine~~ whether a playground surface installed within the ~~*g*-max and~~ use zone of a play structure meets the ~~HIC from the~~ performance criterion of this specification, an impact test is performed in accordance with Sections 16-19 using a theoretical drop height ~~specified by~~ equal to or greater than the ~~initial owner/operator at~~ equipment fall height of the structure. The test is performed under ambient ~~temperature of~~ conditions and the ~~t~~ results reported.

6. Significance and Use

~~6.1 Data obtained from~~

6.1 The purpose of this specification is to establish minimum impact attenuation requirements for playground surfaces in order to reducae tivhe risk of severe head injury from falls.

6.2 This specification provides a uniform means of quantifying the relative impact attenuation characteristics performance of the playground surface system surfaces and is appropriately used to compare the relative performance of different playground surfacing materials.

6.3 This specification is to be used only as a reference for specifying the impact attenuation performance of playground surfaces.

6.4 This specification provides a uniform means of comparing the impact attenuation performance of installed playground surfaces with the performance requirements of this specification and with other performance requirements expressed in tablerms of drop height. Consequently, the specificationg is appropriately used to determine the actual impact attenuation performance of installed playground surfaceqs under ambient conditions of use.

6.5 In combination with data relating impact test scores to head injury, the information generated by application of this specification may be used to estimate the relative risk of a severe head injury due to a fall.

7. Equipment Operator Qualifications

7.1 If not an employee of an accredited or recognized laboratory, the

7.1 The equipment operator shall be trained and certified by in the proper operation of the test equipment supplier, including written and performance testing, to establish competency in performing appropriate Specification F 1292 testing. by a competent agency.

8. Test Apparatus

8.1 *Themperature Measuring Device*—The thermometer, digital temperature gage, or other sensor used to measure surface temperature shall have a functional range of at least from -20 to +130°F (-7 to +54°C), a resolution of 1.0°F (0.6°C), and an accuracy of ±1.0°F (0.6°C). The temperature sensor shall be capable of penetrating the playground surface to a depth of at least one inch.

8.2 *Impact Test System*—A device or system for performing an impact test in which an instrumented missile is dropped onto a playground surface or surfacing material from a predetermined drop height.

8.2.1 *Missile*:

8.2.1.1 The body of the missile shall be made of Aluminum Alloy 6061-T6, finished with a surface roughness of 1000 µin. (25 µm).

8.2.1.2 The missile shall have a hemispherical impacting surface with an external diameter of 6.3 ± 0.1 in. (160 ± 2 mm). The missile is defined as being in a level position when the missile reference plane is uppermost and lies in a horizontal plane.

8.2.1.3 The missile may include cavities and additional components required to accommodate the attachment of sensors or to attach a supporting assembly. The form of any cavities or additional components shall be generally symmetrical about the *Z*-axis of the level missile such that center of mass lies within 0.08 in. (2 mm) of the *Z*-axis and the moments of inertia about any two horizontal axes do not differ by more than 5 %.

8.2.1.4 A supporting assembly (for example, a handle or ball arm) may be rigidly attached to the missile as a means of connecting it to an external guidance system. The total mass of the drop assembly, which is the combined mass of the missile, accelerometer, and supporting assembly shall be 10.1 ± 0.05 lb (4.6 ± 0.02 kg). The mass of the supporting assembly alone shall not exceed 3.0 lb (1.4 kg).

8.2.1.5 *Missile Axes*—An axis normal to the missile's reference plane, passing through the missile's center of mass, and having its positive direction pointing upwards shall be designated the *Z*-axis. This axis is nominally perpendicular to the surface being tested. Two mutually orthogonal axes lying parallel to the missile reference plane and passing through the missile's center of mass shall be designated the *X*- and *Y*-axes (Fig. 1).

NOTE 4—In this reference frame, the acceleration due to gravity has a negative magnitude and the acceleration of the headform during an impact has a positive magnitude.

8.2.2 *Guidance Mechanism for Guided Impact Tests*—For guided impact tests; the missile may be connected to low-friction guides (such as monorail, dual rails, or guide wires) using a follower or other mechanism in order to constrain the fall trajectory of the missile to a vertically downward path. The guidance system must allow the missile to be leveled prior to a drop and must maintain the missile in a level (±5°) attitude during the drop. The guidance mechanism shall be constructed in a manner that does not impede the trajectory of the missile during its fall or during its contact with the surface being tested; other than necessary impedance caused by friction in the guidance mechanism.

8.2.3 *Support Structure for Free-Fall Impact Tests* —For free-fall impact tests, a support structure (for example, a tripod) shall be used to ensure repeatable drop height and location. The support structure shall be sufficiently rigid to support the weight of the missile without visible deformation. The support structure shall be erected in a manner that does not impede the trajectory of the missile during its fall or during its contact with the surface being tested.

8.2.4 *Drop Height Control Mechanism*— The guidance mechanism of 8.2.2 or the support structure of 8.2.3 shall incorporate a means of repeatedly positioning the missile at a predetermined drop height.

8.2.5 *Release Mechanism*—A manual or electronically operated quick-release mechanism shall be provided as a means of initiating a drop of the missile. The operation of the release mechanism shall not influence the fall trajectory of the missile following release.

8.3 *Acceleration Measurement System*— A transducer or transducers and associated equipment for measuring and recording the acceleration of the missile during an impact with an accuracy of within ±1 % of the true value.

8.3.1 *Accelerometers*—An accelerometer shall be rigidly attached at the center of mass of the missile. The sendsing axis or axes of the accelerometer shall pass through the center of mass of the missile.

8.3.1.1 For a free-fall test, a triaxial accelerometer is required. The three axes of the triaxial accelerometer shall be aligned (±5°) with the missile's *Z*-, *X*-, and *Y*-axes.

8.3.1.2 For a guided test, a single uniaxial accelerometer may be used. The accelerometer shall be rigidly attached at the center of mass of the missile with its axis of sensitivity aligned (±5°) with the missile's *Z*-axis and passing through the center of mass of the missile.

8.3.2 Accelerometers shall have a minimum sensitive range from ±500 g and be capable of tolerating accelerations of at least 1000 g along any axis.

8.3.3 *Accelerometer Calibration*—Accelerometers shall be calibrated by reference to a National Institute of Standards and Technology (NIST) traceable standard using a shaker table to excite a range of frequencies and amplitudes determined suitable by the accelerometer manufacturer. The calibration procedure shall include, as a minimum, the range of frequencies from 2 to 2000 Hz.

8.3.4 Accelerometers shall be recalibrated at a time interval recommended by the equipment manufacturer or every two years, whichever is the lesser time interval.

8.3.5 *Accelerometer Connections*—The means of providing power and signal connections to the accelerometer (for example, a cable) shall be constructed in a manner such that the connecting devices do not influence the trajectory of the missile before or during the impact test.

8.3.6 *Accelerometer Signal Conditioning*— Any signal conditioning of amplifying electronics required for proper operation of accelerometers shall be of a type recommended by the accelerometer manufacturer and shall have impedance and frequency response characteristics that are compatible with the accelerometer. Additional signal conditioning requirements are specified in Annex A1.

8.3.7 *Accelerometer Signal Filtering* :

8.3.7.1 *Anti-aliasing Filter*—To prevent aliasing in the digitized acceleration data, the acceleration signals shall be filtered with an analog low pass filter, complying filter prior to digitization. The anti-aliasing filter shall have a corner frequency of 5000 ± 500 Hz or a maximum of 0.25 times the single channel sampling rate.

8.3.7.2 *Data Channel Filter*—Digitized data shall be filtered using a 4th order Butterworth Filter appropriate for the data channel specification described in 8.3.14.2 and Annex A1. An analog filter may be substituted provided it has 4-pole characteristics and conforms to the data channel specification.

NOTE 5—A computer algorithm for the 4-pole digital Butterworth Filter is provided in Appendix X4.

8.3.8 *Recording Device*—A digital recording device such as a digital storage oscilloscope, a dedicated waveform analyzer of a computer equipped with an analog to digital converter shall be used to capture the acceleration time signal produced during an impact. Analog oscilloscopes and other analog recording devices shall not be used.

8.3.9 *Resolution*—The conversion from analog accelerometer signal to digital data shall be accomplished with a digitizer having a resolution of no less that twelve bits spanning the range ±500 g.

8.3.10 *Sample Rate*—Minimum sampling rate of the recording device shall be 20.0 kHz per accelerometer channel. When a triaxial accelerometer is used, three individual digitizers (one per accelerometer axis), each with a minimum sampling rate of 20 kHz is recommended. Alternatively, a single digitizer with a minimum sampling rate of 60.0 kHz may be used if simultaneous track and hold amplifiers are provided for each accelerometer axis.

8.3.11 *Capacity*—The digitizer shall be capable of recording and storing data continuously for a minimum of 50 ms, beginning at least 5 ms before onset of the impact and ending no earlier than 5 ms after the cessation of the impact.

8.3.12 *Display*—The recording system shall have the capability of displaying the recorded acceleration-time data in order to allow inspection by the operator. A graphical display is recommended, but a tabular printout or other form of display is acceptable. The display shall allow inspection of all the data points recorded from at least 5 ms before the onset of impact until no less than 5 ms after cessation of the impact. The display shall show acceleration data in a manner that allows inspection of all data points lying in the acceleration range from -10 g to a value that exceeds the maximum recorded acceleration value.

8.3.13 *Accelerometer Data Channels*

8.3.14 *Accuracy*—The accuracy of each data channel shall be such that the maximum acceleration recorded during an impact is within ±1 % of the true value.

8.3.14.1 *Frequency Response*—All acceleration data channels, before signal filtering, shall have a flat frequency response ±0.1 dB in a range extending from below a maximum of 1.0 Hz to above a minimum of 2000 Hz.

8.3.14.2 *Channel Frequency Class 1000*—All acceleration data channels, including signal filtering, shall conform to the requirements of a Channel Frequency Class 1000 data channel, as specified by SAE J 211 (see Fig. Recommended Practice J211, with the additional requirement of increased accuracy in the range from 1) to 1000 Hz, as defined in Annex A1.

8.24 TDrop Height Measurement—A means of repeatably determining the missile's drop height with a resolution of 1 in (25 mm) and to an accuracy of ±1 % of the true value is required.

8.4.1 For a free-fall impact test, the drop height shall be measured directly, prior to release of the missile, using a measuring stick, a steel tape, or other appropriate means where possible. An indirect means of determining the theoretical drop height shall also be used. Such indirect means may comprise the velocity measuring system described in 8.4.2, or a means of measuring the time interval between release of the missile and the onset of impact (the fall time), in which case the time interval shall be determined with a resolution and accuracy of 1.0 ms. Both the measured drop height and the theoretical drop height shall be reported.

8.4.2 For a guided impact test, the theoretical drop height must be determined by measuring the velocity of the missile immediately prior to the onset of an impact; at a point in the missile's trajectory no more than 2.0 in. (51 mm.) above the first point of contact between the missile and the surface under test. The velocity measuring system may consist of a light gate device to measure the time an opaque flag interrupts a light sensor or other appropriate means. The velocity measuring device shall not interfere with or impede the trajectory of the missile and shall be capable of accurately resolving recording impact velocity with a resolution of 0.1 ft s^{-1}(0.03 m s^{-1}) and an accuracy of ±1 % of the d true value.

NOTE 6—Sincel theoretical drop height is proportional to the square of impact velocity, the ±2 % tolerance on drop height measurement and the ±1 % tolerance on velocity measurement are equivalent. For a m typical flag and light gate velocimeter to achieve ±1 % accuracy, the flag width must be known to an accuracy of ±0.5 % and the transit time measured with an accuracy of ±20 ms (that is, a timing device with a clock rate of at least 50 kHz is required).

8.5 *Battery-Operated Equipment*—Battery-operated equipment shall have a means of monitoring battery voltage (for example, a voltage gage or indicator).

8.6 *System Integrity Check*—Prior to and following each use, the test apparatus shall be checked for proper operation. The system integrity check shall include, as a minimum, the following steps:

8.6.1 The battery status of each piece of battery-operated equipment shall be checked to ensure adequate power availability and voltage level.

8.6.2 Test the proper operation of the equipment by performing the instrumentation check described in Section 10.

8.7 *Equipment Performance Verification*— In order to conform to the requirement of this specification, testing agencies shall acquire and maintain for inspection the following documentation:

8.7.1 *For Each Accelerometer*:

8.7.1.1 A manufacturer's certificate showing that the accelerometer's frequency response conforms to the requirements of 8.3.5.

8.7.1.2 A calibration certificate from a competent agency showing the accelerometer's sensitive range and the calibration factor to a precision of three significant figures.

8.7.2 *For Each Signal-Conditioning Device*—A manufacturer's certificate showing that the device's frequency response conforms to the requirements of 8.3.14.

8.7.3 *For the Acceleration Measurement System*—Documentation from the manufacturer of the acceleration measurement system certifying that each acceleration data channel conforms to the requirements of this specification. Alternatively, if a testing agency has assembled or manufactured its own acceleration testing system, conformance with the requirement of this section may be verified by performing and documenting the results of the tests described in Annex A1.

8.7.4 *For the Drop Height Measurement System*—Documentation from the manufacturer of the drop height or impact velocity measurement system certifying that it conforms to the requirements of this specification. Alternatively, if a testing agency has assembled or manufactured its system, conformance with the requirement of this section may be verified by performing and documenting the results of the tests described in Annex A1.

9. Calculation

9.1 *Theoretical Drop Height*:

9.1.1 The theoretical drop height, *g h, shall be calculated from a measurement of impact velocity, from 0 to 500v, using the formula* $h = v^2/ 2g$*, where g.*

8.3 The is the acceleration transducer must due to gravity.

9.1.2 Alternatively, in a free-fall test, the theoretical drop height, *h*, s may be capable calculated from a measurement of withstanding impacts of at least 1000 fall time, *t*, using the formula without damage.

8.4 Use $h = ½ g t^2$.

9.1.3 *Resultant Acceleration*—If a triaxial accelerometer is used, the ANSI metal Headform C from Test Method F 355 or resultant acceleration at each point in the hemispherical headform from time history of the free fall test method in Annex A1.

8.4.1 The ANSI metal Headform C from Test Method F 355, Procedure C, must impact shall be connected to guides (such calculated as monorail, dual rail, or guide wires) using a follower or other mechanism. Alternatively, $A_R = \sqrt{A_x^2 + A_y^2 + A_z^2}$ where A_R is the hemispherical headform from resultant acceleration and A_x, A_y, and A_z are the free fall test method in Annex A1 may be used if connected to a system accelerations recorded by accelerometers aligned with the *X*, *Y*, and *Z* missile axes.

9.2 *g-max*—The *g*-max of guides. A uniaxial or score is determined as the maximum value of acceleration recorded during an impact. If a triaxial accelerometer must is used, *g*-max shall be used. The guidance system must allow determined as the headform to be leveled prior to and during maximum value of the drop tests in resultant acceleration.

9.3 *Average g-max*—Determine the crown position. The vertical accelerometer must be aligned to within 5° average *g*-max score by averaging the *g*-max score of the vertical axis. The accelerometer must be attached second and third of a series of three impact tests.

9.4 *Determination of Missile Angle*— In a free-fall impact test, the angle of the missile at the center onset of impact and at the insstant of maximum acceleration shall be calculated. For the headform.

8.4.2 The hemispherical headform from purposes of this calculation, the free fall test method in Annex A1 must onset of impact shall be us the data sample at which the resultant acceleration first meets or exceeds a triaxial accelerometer. The vertical accelerometer must be aligned to within 5° threshold value of the vertical axis. 5 g. The accelerometer must angle shall be attached at calculated from the component accelerations. The cosine of mass of the headform.

8.5 The minimum system sampling rate required is 16 000 Hz or 16 000 samples/s.

8.6 The HIC missile angle shall be calculated b as:

$$\cos(\theta_{hedorm}) = \frac{A_z}{A_R}$$

$$\cos(\theta_{headform}) = \frac{A_z}{A_R}$$

9.5 *Head Injury Criterion*[5] —The HIC score of an impact shall be computed as follows:

9.5.1 In the acceleration-time history of the impact, locate the time point T_0 at a point immediately preceding the onset of the impact and the time point T_1 at a point immediately following mathematical expression:
the cessation of the impact.

9.5.2 For each time interval (t_1, t_2) for which $t_1 \geq T_0$, $t_2 > t_1$ and $t_2 \leq T_1$ evaluate and record the trial HIC integral:

$$\text{HIC} \left(= \left((t_2 - t_1) \left(\frac{1}{(t_2 - t_1)} \right) \int_{t_1}^{t_2} adt \right)^{2.5} \max < 1000 \right.$$

$$\text{Trial HIC}(t_1, t_2) = (t_2 - t_1) \left[\frac{1}{(t_2 - t_1)} \int_{t=t_1}^{t_2} a_t \, dt \right]^{2.5}$$

The specified algorithm and verification calculations for HIC are included

where:

a_t = acceleration at time t, defined as Appendix X2.[5]

9. Test Sample

9.1 Each sample of surfacing material shall represent the playground surface system as it resultant acceleration if a triaxial accelerometer is intended to be used in place, including seams, partitions, corners, used.

[5] Chou, C., and Nyquist, G., "Analytical Studies of the Head Injury Criterion," *Society of Automotive Engineers*, SAESAE Paper No. 740082, Society of Automotive Engineers, 1974.

9.5.3 For each time interval (t_1, t_2) calculate and fasteners/anchors or other areas that may result in less than optimal record the trial HIC interval, $t_2 - t_1$.

9.5.4 The HIC score for an impact characteristics.

9.2 In is determined as the case maximum value of non-loose fill playground surface systems, all the minimum sample shall be 12 by 12 in. (300 by 300 mm).

9.3 In the case of loose fill playground surface systems, a box with a minimum inside dimension of 18 by 18 in. (450 by 450 mm) and side walls of sufficient height Trial HIC(t_1, $t2$) scores.

9.5.5 The numerical procedures used to hold the loose fill material at the thickness of intended use and to keep the loose fill materials in place calculate HIC should be constructed around the base provide results that are within ±1 % of the test equipment. The loose fill materials shall be poured to an even depth and the surface leveled and left undisturbed true value.

NOTE 7—A computer algorithm for the entire test period. calculating HIC is provided in Appendix X3.

10. NumberInstrumentation Check

10.1 Check the proper operation of Specimens

10.1 At least nine specimens the test apparatus by performing a series of impact tests on a specific playground surface system reference MEP pad.

10.2 The reference MEP pad may be provided by the equipment manufacturer or by another agency capable of ensuring reproducible reference pads and shall have been assigned a reference drop height and a nominal *g*-max score.

10.3 Perform three impact tests on the reference MEP pad from the reference drop height with an interval of 1.5 ± 0.5 min between impacts.

10.4 Determine the average *g*-max score by averaging the *g*-max scores from the second and third drops.

10.5 Compare the average *g*-max score to the nominal *g*-max score provided with the reference MEP pad.

10.6 If the difference between the recorded *g*-max score and the nominal *g*-max score exceeds either the manufacturers specified tolerance or 5 % of the nominal *g*-max score, the equipment does not conform to the requirements of this specification and may not be submitted for laboratory testing. used.

11. SImpact Test Procedure

11.1 *Data Recording*:

11.1.1 Determine the test ploint of the C conditioninged sample.

11.1.1.1 LIf the sabmple has nonuniform properties (due to uneven thickness, seams, fasteners, ory other factors) the sample test point shall be preconditioned at 50 ± 10 % relative humidity 72 ± 5°F (23 ± 3°C) for the point on the surface of the specimen expected to show the least favorable impact attenuation properties that lies within an area no closer than 3.0 in. (75 mm) to the edge of the sample.

11.1.1.2 If the sample has uniform properties, the sample test point shall be the center of the sample's top surface.

11.1.2 Mount the sample to be tested on a minimum flat, rigid anvil or floor beneath the impact test system.

11.1.3 Align the sample test point with the point of 24 h impact of the missile and fix the sample to the anvil or floor using an appropriate means that does not alter the sample's impact attenuation properties (for example, with double-sided adhesive tape).

NOTE 8—Tests with unitary surface samples show that the variability of *g*-max and HIC scores is increased by a factor of four or more if the sample is not fixed to the underlying surface.

11.1.4 Before the first drop in any series, elevate the missile to the reference drop height. For subsequent drops in a series, the missile shall be elevated to the same point, notwithstanding the formation of cavities of other elevation changes in the surface being tested.

11.1.5 Before the first drop in any series, measure and record the drop height.

11.1.6 Release the missile and record the outputs of the acceleration measuring system and the drop height measuring system. If the trajectory of the missile prior to beginning testing.

11.2 Samples tested at various temperatures, 30, 72, and 120°F, (−1, 23, during impact is impeded by any fixtures, human intervention, or other means, data from the trial shall be discarded.

11.1.7 Record the depth of any cavity in the surface formed by the impact.

NOTE 9—The depth is conveniently determined by measuring the distance between the lowest point of the elevated missile and 49 the surface under test. The cavity depth is the difference between this measurement and the originally measured drop height.

11.2 *Data Check*:

11.2.1 Examine the acceleration display. The recorded acceleration pulse shall conform to the following requirements:

11.2.1.1 The acceleration pulse shall consist of a single primary impact event.

11.2.1.2 Prior to the onset of impact, the recorded acceleration value should be 0 ± 2 g.

1°C,1.2.1.3 The acceleration waveform sphould descend from its maximum value to a stable value of 0 ± 2 g without overshooting the zero baseline by more than 2 g.

NOTE 10—Excessive overshoot of the acceleration signal after an impact is indicative of transducer or signal processing error. Overshoot is frequently symptomatic of inadequate low frequency response in the accelerometer data channel(s).

11.2.2 If the recorded acceleration pulse does not conform to the specifications of 11.2, the test shall be restarted using a freshly conditioned ~~for 4 h minimum. Testing must~~ specimen.

11.3 *Data Analysis*:

11.3.1 Calculate and record the *g*-max and HIC scores.

11.3.2 Calculate and record the theoretical drop height. If the calculated theoretical drop height differs from the measured drop height by more than ±3 in (±76 mm) or by more than ±2.5 % of the measured drop height, data from the trial shall be dis~~t~~carded.

NOTE 11—A difference between theoretical drop height and actual drop height that is greater than ~~1~~ the specified margin may indicate an error in measurement of ~~taking each sample out~~ impact velocity, an error in the measurement of fall time, or that the ~~environmental chamber with~~ fall of the missile was retarded by excessive friction in the guidance mechanism.

11.3.3 If a ~~time interval between drops~~ free-fall impact test is used, calculate the missile angle at the onset of ~~3 ± 0.25 min.~~ impact and at the instant of maximum resultant acceleration, in accordance with 9.4. If the ~~test intervals are not met, an additional conditioning period~~ calculated missile angle at either point exceeds 10° (that is, the cosine of ~~4 h will~~ the missile angle is less than 0.966), data from the trial shall be ~~necessary.~~ discarded.

CRITICAL FALL HEIGHT TEST
(Laboratory Test)

12. ~~Laboratory Procedure (Test Method)~~

~~12.1 Test all samples~~Temperature Conditioning

12.1 The critical fall height of ~~the~~ a playground surface ~~system in accordance with the selected test method, Test Method F 355,~~ or ~~the free fall test method in Annex A1, with the headform impacting in the crown position.~~

~~12.2 Conduct~~ surfacing material shall be determined under laboratory conditions by performing a series of impact tests ~~considering the following criteria:~~

~~12.2.1 Carry forth the impact test~~ at reference temperatures of 25, 72, and 120 ± 2°F (-6, 23, and 49 ± 1°C).

12.2 *Temperature Conditioning*:

12.2.1 Samples shall be preconditioned at 50 ± 10 % relative humidity and 72 ± 5°F (23 ± 3°C) for a minimum of 24 h prior to beginning testing.

12.2.2 For testing at each reference temperature, three samples shall be conditioned at the reference temperature ±2°F (±1°C) for a ~~maximum drop height in whole foot increments, that is, 1, 2, 3 ... *n*, that gives both a deceleration force~~ minimum of ~~200-*g* max~~ 8 h. Testing of a sample must be started within 1 min and ~~an HIC~~ all tests must be completed within 7 min of ~~1000~~ the sample's removal from the conditioning environment. If the testing is not started or ~~less. It~~ completed within the specified interval, the sample must ~~also~~ be conditioned for an additional 8 h.

12.3 *Temperature Stability Requirements* :

12.3.1 Surface temperature shall be measured using the temperature measuring device specified in 8.1. Temperature measurements shall be made at ~~intervals of 1 ft over and under this maximum drop height.~~

~~12.2.2 An impact~~ the sample test ~~consists of three drops at~~ point before the ~~same~~ first impact ~~site, at each height. The~~ and after the third impact in any seri~~t~~es. The probe shall be inserted to a minimum depth of 1 in. (25 mm) or 50 % of the ~~location that exhibits~~ thickness of the ~~least optimal impact characteristics (as described in 9.1). Calculate~~ sample, whichever is least. During testing at the ~~average~~ reference temperature of 25°F (-6°C), the ~~second and third drops.~~

~~12.2.3 The impact test uses~~ temperature of the specimen must not exceed 30°F (-1°C). If the temperature exceeds 30°F (-1°C), the specimen must be reconditioned to the reference temperature for a ~~different sample at all heights at~~ period of 8 h and the ~~given temperatures.~~

~~12.2.4 The impact~~ test ~~samples are to be tested~~ continued.

12.3.2 During testing at the ~~three specific temperatures~~ reference temperature of ~~30, 72, and~~ 120°F ~~(−1, 23, and 49°C, respectively) after~~ (49°C), the ~~required conditioning.~~

~~12.2.5 If for any reason during~~ temperature of the ~~test,~~ specimen must not fall below 115°F (46°C). If the ~~headform holding fixture interferes with~~ temperature falls below 115°F (46°C) the ~~test, note it in the report and discontinue the test. The information recorded shall~~ specimen must be ~~considered invalid.~~

~~12.2.6 When using Test Method F 355, measure and record~~ reconditioned to the ~~impact velocity~~ reference temperature for ~~each drop. It cannot vary more than ±0.5 ft/s from~~ a period of 8 h and the ~~theoretical free fall velocity at the drop height used.~~ test continued.

13. ~~Field Test Procedure (Test Method)~~

~~13.1 Test at~~Unitary Surfaces

13.1 *Number of Specimens*—At least ~~three different impact sites~~ nine specimens of a specific unitary surfacing material shall be submitted for testing, with each sample having minimum surface ~~system in use in accordance with~~ dimensions of 18 by 18 in. (460 by 460 mm). Each specimen shall represent the ~~selected test method, either Test Method F 355 or~~ compliant components of the ~~free fall test method~~ playground surface as it is intended to be used in ~~Annex A1 with the headform in the crown position. The selected impact sites shall include those areas~~ a playground installation, including seams, partitions, corners, fasteners, anchors, or other characteristics that may ~~exhibit~~ result in less than optimal impact characteristics. ~~Th~~ If a surfacing material is intended for installation in combination with other materials such as wear ma~~y~~ts, this combination must be ~~high traffic or compressed areas~~ tested as ~~well as areas containing seams, partitions, corners,~~ it would be installed.

NOTE 12—Samples larger than the minimum 18 by 18-in. (460 by 460-mm) size may be required to accommodate seams and ~~fasteners/anchors.~~

~~13.2 Conduct~~ other characteristics.

13.2 *Sample Preparation*—Samples of unitary surfaces shall be mounted on a concrete floor or flat, steel anvil below the impact test equipment, in accordance with ~~the following criteria:~~

~~13.2.1 Carry forth the~~ 11.1.3.

13.3 *Performance Parameters*—The performance of an individual sample at each reference temperature and reference height shall be determined by performing three impact tests ~~at~~ on the same sample test point from the same drop ~~height, as specified by~~ height using the ~~initial owner/operator.~~

~~13.2.2 The~~ procedure described in Section 11. The interval between impact tests shall ~~have three drops at each of~~ be 1.5 ± 0.5 min. Calculate the ~~impact sites, for a total of nine impacts. Report the~~ average ~~of the second and the third drops for both *g*-max~~*g*-max and HIC ~~values.~~

~~13.2.3 Insert a temperature measuring device into the surface system (within 6 in. (152 mm) of the impact site) at the time of the impact test, to measure the temperature of the surface system, at a ½-in. (12.5-mm) depth or no more than half the depth of the surface system.~~

~~13.2.4 Measure and record the impact velocity for each drop. The impact velocity cannot vary more than ±0.5 ft./sec.~~ scores by averaging results from the ~~theoretical free~~ second and third impacts.

13.4 *Critical Fall Height Test*—Determine critical fall ~~velocity at the drop~~ height using the procedure described in Section 15.

14. Loose Fill Surfaces

14.1 *Quantity of Sample Material*—The volume of loose-fill surfacing material submitted for testing shall, as a minimum, be twice the volume of material needed to cover an 18 by 18-in. (460 by 460-mm) area to the required depth. The same material may be used for testing at more than one drop height or temperature provided that it is restored to it's original loose state and reconditioned between tests.

14.2 *Sample Preparation*—Samples of loose-fill surfacing materials shall be contained in a rigid box with an inside dimension of 18 by 18 ± 0.5 in. (457 ± 12 mm) and side walls of sufficient height to hold the loose fill material at the thickness of intended use and to keep the loose fill materials in place during conditioning and testing. The box shall be mounted on a rigid floor or flat anvil below the impact test equipment, in accordance with 11.1.3. The box shall be constructed in a manner that allows the missile to strike the center of the sample. The materials shall be poured to a depth that will allow compaction to a depth representing the in-use condition of the material.

14.3 *Sample Conditioning*—Before any temperature conditioning, loose-fill specimens shall be conditioned using a compactor to apply a uniform pressure of 3.1 ± 0.1 psi (21.1 ± 0.7 kPa) for a period of 1.0 ± 0.1 min. For an 18 by 18-in. (460 by 460-mm) container, the applied force required to achieve this pressure will be 1004 ± 32 lb. Both uncompacted and compacted material depths shall be reported. If a compacted material depth is specified, the laboratory shall determine and report the depth of uncompacted material required to produce a compacted surface of the specified depth.

14.4 *Performance Parameters*—The performance of an individual sample at each reference temperature and reference height shall be determined by performing three impact tests on the same sample test point from the same drop height using the procedure described in Section 11. The interval between impact tests shall be 1.5 ± 0.5 min. Calculate the average *g*-max and HIC scores by averaging results from the second and third impacts.

14.5 *Critical Fall Height*—Determine critical fall height using the procedure described in Section 15.

15. Critical Fall Height Test Procedure

15.1 *Test Procedure*:

15.1.1 At each specified reference temperature; perform the required number of impact tests in accordance with Section 10 to determine performance at the series of reference drop heights. Impact tests at each combination of reference temperature and reference drop height shall be performed on a new sample.

15.1.2 The series of reference drop heights should consist of an increasing sequence at intervals of 1 ft (0.3 m). Increment the reference drop height until the impact test results do not meet the performance criterion specified in 4.2. As a minimum, impact tests must be performed at theoretical drop heights of 1 ± 0.5 ft (0.30 ± 0.15 m) above and 1 ± 0.5 ft (0.30 ± 0.15 m) below the theoretical drop height at which the impact test results approximates the limiting performance criterion.

15.1.2.1 Record the average theoretical drop height, average *g*-max score and average HIC score at each combination of reference temperature and reference fall height.

15.2 *Critical Fall Height*—The critical fall height of the playground surface or surfacing material shall be determined as the maximum theoretical drop height at which impact test results meet the performance criterion at all of the reference temperatures and shall be rounded to the nearest whole foot (0.3 m) equal to or below the actual value.

NOTE 13—*Critical Fall Height Test—Wet and Frozen Surfaces*— Critical fall height may be determined using additional tests performed under simulated wet or frozen surface conditions, or both. The conditioning procedures are described in Appendix X5, in addition to those described in Sections 11-14.

INSTALLED SURFACE PERFORMANCE TEST (Field Test)

16. Test Site Selection

16.1 To determine whether an installed playground surface meets the requirements of this specification, a minimum of three different impact test sites in the use zone of each play structure shall be tested using the impact test procedure described in Section 19.

16.2 For each play structure served by the playground surface, a minimum of three impact test sites shall be selected. When play structures have overlapping use zones, test sites in the overlapping regions may be used for all applicable play structures. Where there is more than one type of surfacing material system in use, then each material shall be tested at a minimum of three test sites.

16.2.1 Each impact test site shall be within the use zone of the play structure.

16.2.2 The impact test sites selected should include any sites expected to have the least impact attenuation. Examples of areas that can be expected to have less impact attenuation (that is, higher *g*-max and HIC scores) include high traffic areas; areas where the playground surface is thin or compacted; areas containing partitions, corners, fasteners, or anchors; and areas contaminated with other materials.

NOTE 14—Test site selection should also consider the potential effects of ambient conditions on impact attenuation. For example, surfacing materials of different colors may absorb and lose heat at different rates. Under some conditions, temperature sensitivity may cause otherwise identical surfacing materials of different colors to have different impact attenuation.

17. Unitary Surfaces

17.1 *Test Site Conditioning*—The playground surface shall be tested in an as-found condition and no conditioning or preparation is required.

17.2 *Performance Parameters*—Determine the performance of each impact test site by performing three impact tests on the same test point using the procedure described in Section 19. The interval between impact tests shall be 1.5 ± 0.5 min. Calculate the average *g*-max and HIC scores by averaging results from the second and third impacts.

18. Loose-Fill Surfaces

18.1 *Test Site Conditioning*—Each intended test site shall be conditioned by impacting four times with a 10 by 10-in. (250 by 250-mm) square hand tamper having a mass of 15.5 ± 0.5 lb (7 ± 1.1 kg), dropped from a height of 24 ± 1 in. (600 ± 25 mm). The tamper shall be dropped in a manner that causes it to land flat, creating a flat and approximately square impression in the surface.

18.2 *Performance Parameters*—Determine the performance of an individual impact test site by performing three impact tests on the same test point using the procedure described in Section 19. The interval between impact tests shall be 1.5 ± 0.5 min. Calculate the average *g*-max and HIC scores by averaging results from the second and third impacts.

19. Installed Surface Performance Test Procedure

19.1 *At Each Test Site*:

19.1.1 The surface temperature shall be measured using the temperature measuring device specified in 8.1. Temperature measurements shall be made at the sample test point before the first impact and after the third impact in any series. The probe shall be inserted to a minimum depth of 1 in. (25 mm) or 50 % of the thickness of the sample, whichever is least.

19.1.2 When an installed playground surface is tested in accordance with the requirements of Sections 16-19 of this specification at the reference drop height the surface performance parameters at every tested location in the use zone shall meet the performance criteria of this specification. The reference drop height shall be the greater of (*1*) the height specified or agreed to by the owner/operator prior to purchase, (*2*) the critical fall height specified when the playground surface was installed, (*3*) the equipment fall height, or (*4*) the critical height of the surface at the time of installation.

19.2 Perform the system integrity check specified in 8.6.2 within 24 h of the test.

19.3 At each selected test site:

19.3.1 Align the test device so that the missile will impact the selected impact test site at the same location for the required number of drops. The device supporting the missile (for example, a tripod) shall be capable of ensuring that each drop takes place from the same reference drop height.

19.3.2 Perform the specified number of impact tests using the impact test described in Section 11.

19.3.3 Determine the average *g*-max and HIC scores of each impact test site.

19.3.4 Record the drop height, and average *g*-max and HIC scores calculated in accordance with 17.2 or 18.2.

19.3.5 Record the surface temperature indicated by the temperature measuring device.

20. Report

1420.1 RAll reports shall include the following information:

14.1.1 The sample identification, including type, source, size,

20.1.1 *Requesting Agency Information* :

20.1.1.1 The name, address, and thickness.

14.1.2 Test procedure used telephone number of the person or entity requesting the test.

20.1.2 *Testing Agency Information* :

20.1.2.1 The name, address, and missile description, including mass, geometry, telephone number of the testing agency.

20.1.2.2 The name and or siegnature of the test operationr.

20.1.2.3 Date(s) tests were performed.

20.1.2.4 Date of the report.

20.1.3 *Description of the Test Apparatus* :

20.1.3.1 Test equipmengt type and manufacturer.

20.1.3.2 Date of most recendt accelerometer calibrations, certinficlate.

20.1.4 *Test Resudlts*—The following shall be reported for each series of impact tests:

20.1.4.1 Whether the sample was dry, wet, or frozen.

20.1.4.2 The ambient air temperatures, reference temperature, and surface temperature measured after the final drop heights employed.

14.1.4 Individual in each series.

20.1.4.3 The drop values height, impact velocity or fall time, and the theoretical drop height.

20.1.4.4 The *g*-max and HIC scores for each drop and the average *g*-max and HIC scores for the last two drops of each series.

20.2 *Laboratory Test for the Determination of Critical Fall Height*—The report shall also include the following information:

20.2.1 *Description of Samples*:

20.2.1.1 The number of samples submitted.

20.2.1.2 The name of the person or entity that manufactured the samples.

20.2.1.3 The commercial name of playground surface product, if one exists.

20.2.1.4 Date of sample manufacture.

20.2.1.5 Date of sample receipt by testing agency.

20.2.1.6 Any discrepancies between the samples and any description thereof provided by the manufacturer or requestor of the test.

20.2.2 *Description of Sample Materials and Construction*:

20.2.2.1 The description of the test sample shall be sufficiently detailed to distinguish differences in structure and materials that may affect performance. The description shall include, as a minimum, a description of the composition of each layer of the specimens, and the thickness of each layer to the nearest 0.1 in. (0.25 cm).

20.2.2.2 For surfacing incorporating loose-fill materials, the description shall include the type and approximate size or size distribution of particulate materials (for example, sand, gravel, crushed marble, rubber buffings, rubber crumb, wood chips, or bark mulch) in each layer.

20.2.2.3 Surfacing materials may only be described as "Engineered Wood Fiber" if they conform to the requirements of Specification F 2075 and reference is made to an acceptable certificate or other documentation of such conformance.

20.2.2.4 For unitary surfacing materials, the sample description shall include the design and material composition of any prefabricated components (for example, rubber or plastic tiles), and the manufacturer's name or designation of the component, or both.

20.2.3 *Test Outcome*—The critical fall height, expressed to the nearest whole foot equal to or below the measured value.

20.2.4 *Statement of Specificity*—The following statement: "The results reported herein reflect the performance of the described samples at the time of testing and at the temperature(s) reported. The results are specific to the described samples. Samples of surfacing materials that do not closely match the described samples will perform differently."

20.3 *Field Test of Conformance with Performance Requirements g-max*—The report shall include the following information:

20.3.1 *Description of the Playground Surface*:

20.3.1.1 The address of the test site.

20.3.1.2 The commercial name of the playground surface product, if one exists.

20.3.1.3 A description of the type and HIC values.

14.1.5 The theoretical drop heights used.

14.1.6 The deceleration/time trace composition of the surfacing materials.

20.3.1.4 Names, addresses, and phone numbers of the manufacturer, supplier, and installer of the playground surface, to the extent they are available.

20.3.1.5 The area covered by the playground surface.

20.3.2 *Description of Each Use Zone* :

20.3.2.1 A description of the play structure in 0.5-ms intervals. each use zone tested.

20.3.2.2 The location of test sites relative to the play structure in each use zone tested.

NOTE 1—The preferred method 15—Appropriately annotated photographs are an acceptable means of exhibiting describing play structures and test sites.

20.3.2.3 The depth of any loose-fill surfaces or the d thickness of any unitary surfaces, if known or measurable.
20.3.2.4 If a compaction procedure was used, the depth of the material both before and after compaction shall be reported.
20.3.2.5 The condition of the playground surface, including observations of excessive wear, moisture content, and so forth.
20.3.3 *Test Outcome*—A statement as to whether or not the test sites conformed to the performance specifications of this specification.
20.3.4 *Statement of Specificity*—The following statement: "The results reported herein reflect the performance of the tested playground surface at the time of testing and at the temperature(s) and ambient conditions reported. Performance will vary with temperature, moisture content, and other factors."
20.4 *Summary Report*—A summary report may be prepared, provided both the testing agency and the entity requesting the test retain copies of a complete report conforming to 20.1-20.3.
20.4.1 All summary reports shall include Requesting Agency Information (see 20.1.1.1) and Testing Agency Information (see 20.1.2)
20.4.2 Summary reports of laboratory tests shall also include:
20.4.2.1 The commercial name and a brief description of the surfaces tested.
20.4.2.2 The average thickness of the surfaces tested.
20.4.2.3 For each reference temperature or wet or frozen condition, or both: the average theoretical drop height, average *g*-max score, and average HIC score of the impact test series with the highest conforming scores.
20.4.2.4 The critical fall height, expressed to the nearest whole foot equal to or below the measured value.
20.4.2.5 A statement of specificity (see 20.3.4).
20.5 Summary reports of field tests shall also include:
20.5.1 A description of the playground surface according to 20.3.1 but optionally excluding the requirements of 20.3.1.4.
20.5.2 The highest average *g*-max and average HIC scores recorded in chart form any use zone.
20.5.3 The test outcome (see 20.3.4).
20.5.4 For each use zone that digd not meet the requirements of this specification:
20.5.4.1 The location of the use zone.
20.5.4.2 The highest average *g*-max and average HIC scores recorded in the use zone.
20.5.5 A statement of specificity (see 20.3.4).

215. Precision

15.1 Potential sources and Bias
21.1 A statement of bias cannot be made because no absolute reference samples exist.
21.2 Appendix X1 describes the relative contributions of different kinds of measurement error or deviations are as follows:
15.1.1 to errors in *g*-max, HIC, and critical fall height.
21.3 In a preliminary interlaboratory study, three samples (two reference MEP pads and a unitary surface sample) were tested by five laboratories, using a total of seven different impact test systems. Based on this study the interlaboratory reproducibility limit of the test method is estimated to be ±5 % for g-max and ±10 % for HIC. The estimate assumes that laboratories will conform to the equipment requirements of this specification and that the tested specimen has minimal inherent variability. Variations in the time needed to conduct the test result in variable levels of recovery of the material during the room temperature tests. This variation is accentuated in non-room temperature tests by the addition of changing temperature conditions within the sample to the variable recovery of the material.
15.1.2 Variations in the impact velocity brought about by changes in drop height or friction in the drop guidance mechanism.
15.1.3 Use of missiles other than those referenced in this specification may cause substantial variations in results.
15.2 An
21.4 An interlaboratory study was conducted in 1996-97 during the development of this test method. 1996-97. Seven laboratories ran performed pairs of tests on eight surface materials using Test Method F 355, Procedure C. The same laboratories also ran pairs of tests on the same surface materials using the free-fall test method. In both series of tests, *g*-max*g*-max and HIC values were determined. From the results of these tests, precision statistics were calculated in compliance with Practice E 691.
15.2.1 The precision results are summarized in Tables 1-4.
15.2.2 A statement on bias cannot be made because no reference surfaces are available.
15.2.3 An earlier interlaboratory study was completed in 1989.[6] E 691. The technique samples used to analyze the study data resulted in a ± figure being generated for test method precision. Applying this test were actual playground surfacing materials, including loose-fill surfacing materials, rather than reference surfaces. Therefore, the reported precision includes variability due

[6] Available from ASTM Headquarters. Request RR:F08-1002.
[6] National Highway Traffic Safety Administration (NHTSA), Department of Transportation., 1997, FMVSS201, Head Impact Protection, 49 CFR 571.201.

TABLE 1 Precision Statistics for g-max, Test Method F 355, Procedure C[A]

Material	Average	Repeatability Standard Deviation Standard Deviation (Sr)	Reproducibility Standard Deviation Standard Deviation (SR)	Repeatability Limit Limit (r)	Reproducibility Limit Limit (R)
D	52.4	2.0	7.8	5.6	21.8
D	53.4	4.8	8.6	13.5	24.1
E	62.9	9.1	11.4	25.5	31.9
E	57.2	10.1	11.2	28.2	31.4
H	107.2	3.8	7.9	10.6	25.8
H	104.1	3.9	7.4	10.8	22.6
A	125.0	2.6	9.5	7.3	26.6
A	121.5	2.4	7.9	6.6	22.0
C	143.8	1.9	7.7	5.3	21.6
C	146.4	3.8	8.9	10.5	24.8
G	193.2	15.2	17.1	42.6	47.9
G	186.9	10.5	13.1	29.3	36.7
B	202.0	2.6	14.6	7.3	40.9
B	207.5	5.3	15.5	14.7	43.3
F	234.3	3.2	12.0	9.0	33.6
F	240.7	7.1	16.1	19.8	45.1

[A] Average of Test Method F 355 Procedure C and Free-Fall Test Method of Specification F 1292.

TABLE 2 Precision Statistics for g-max, Free Fall Test Method HIC[A]

Material	Average	Repeatability Standard Deviation Standard Deviation (Sr)	Reproducibility Standard Deviation Standard Deviation (SR)	Repeatability Limit Limit (r)	Reproducibility Limit Limit (R)
D	54.4	7.6	9.4	21.3	26.3
D	144.7	19.1	33.1	53.4	92.7
E	51.5	11.0	11.0	30.8	30.8
E	166.0	46.6	63.6	130.4	178.1
H	100.9	3.9	6.9	10.9	19.3
H	592.7	24.3	95.3	67.9	266.9
A	118.0	2.1	6.2	5.9	17.4
A	592.9	80.6	123.7	225.7	346.2
C	148.9	5.6	10.0	15.7	28.0
C	749.0	28.8	107.2	80.7	300.0
G	180 .6	5.7	9.1	16.0	25.5
G	1 212.0	59.9	185.9	167.6	520.5
B	21 3.0	7.9	16.3	22.1	45.6
B	1 381.5	110.1	191.4	308.1	535.9
F	247.1	10.9	20.2	30.5	56.6
F	1 849.0	156.6	293.5	438.5	821.7

[A] Average of Test Method F 355 Procedure C and Free-Fall Test Method of Specification F 1292.

to the 1996-7 study, samples as well as variability due to the results described in Tables 5 and 6 were obtained. test method itself.

NOTE 2—The method used to generate Tables 5 and 6 is not as statistically accurate as 16—Based on preliminary interlaboratory testing performed during the analysis used development of this specification, the precision of the test method in 15.2.1. It this specification is provided estimated to be ±5 % for i *g*-max and ±10 % forma HIC. In other words, future test results; intralaboratory or interlaboratory, laboratory or field, may be expected in a range from -5 to +5 % of the *g*-max result, and from -10 to +10 % of the HIC result. (For example, a 180 *g*-max indicates a *g*-max range of 171 to 189. A 900 HIC indicates an HIC range of 810 to 990.) Users of this specification shoulyd be aware of this fact when establishing critical fall height.

1622. Keywords

1622.1 critical fall height; head impact; head injury criterion; HIC; impact; impact attenuation; impact test; injury; play; playground; play structure; shock; surface system

ANNEXES

(Mandatory Information)

A1. FREE FALL TEST METHOD

A1. INSTRUMENTATION VERIFICATION PROCEDURES

A1.1 A nonguided headform may be In order to meet acceptable levels of interlaboratory and intralaboratory repeatability and reproducibility, the instrumentation used to make tests in accordance with this specification must meet specific requirements for resolutimon, accuracy, precision, and calibrat tion. Differences in instrumentation among laboratories have been identified as a major cause of playground surface systems or surfacing material samples.

A1.2. Terminology

A1.2.1 *Definition of Term Specific to* poor reproducibility. *This Annex:*

A1.2.1.1 *free fall*—the trajectory of annex describes procedures for verifying that instrumentation conforms to the headform requirements of this specification.

A1.2 It is not restrained by rails, wires, or a mechanism or structure requirement of any type.

A1.3 Apparatus

A1.3.1 *Headform Design*— The headform as a 10.1 ± 0.1 lb (4.6 ± 0.05 kg) hemispherical missile this specification that testing agencies retain documentation demonstrating that the frequency response, accuracy, and resolution of diameter 6.300 ± 0.200 in. (160 ± 5 mm). An optional handle the instrumentation conform to the requirements of this specification. Such documentation may be affixed to in the form of calibration certificates or metrology laboratory reports.

A1.3 *Accelerometer Data Channel Verification—End-to-End Calibration*— The frequency response of accelerom peters, signal covnditioners, data acquisition devices, and so forth, can be determined from calibration certificates. However, the total weight frequency response of the headform and handle combination does not exceed 10.1 ± 0.1 lb (4.6± 0.05 kg).

A1.3.2 *Accelerometer*— Rigidly attach a triaxial accelerometer at the center of mass of these devices is unknown, because the headform.

A1.3.2.1 One axis interconnecting cables, connectors, and other components of the system can affect the frequency response. (These extraneous effects can often be minimized by using compatible components from the same manufacturer.) It is recommended that the accelerometer must data channel be mounted parallel within 5° calibrated using an end-to-end calibration procedure of the whole data acquisition and processing system. This procedure should be performed by an accredited metrology laboratory. To conform to the primary axis requirements of impact of this specification, the headform. This axis frequency response of the accelerometer shall have a linear output signal from 0 to 500 *g* system should fall within the limits shown in Table A1.1 and Fig. A1.1.

A1.3.2.2 The remaining two axes of the accelerometer must define

A1.4 *Accelerometer Data Channel—Minimum Verification Requirements*— If an end-to-end calibration is not performed, testing agencies shall, as a plane normal minimum, determine that their test apparatus conforms to the primary axis. Both low-frequency response and accuracy requirements of these axes shall have a linear output signal from 0 to ± 500 *g*.

A1.3.2.3 All axes of this specification by performing the accelerometer must be capable following tests:

A1.4.1 *Accelerometer Low-Frequency Response (Time Constant) Test*—The purpose of withstanding impacts of 1000 *g* without damage.

A1.3.2.4 Connect the output signal of the accelerometer this test is to determine that the recording device by accelerometer, signal conditioner, and analog filter have a flexible multiple conductor cable. sufficient response at low frequencies. The cable shall required low-frequency response (8.3.15.1) may be sufficiently flexible so as to not influence the trajectory specified in terms of minimum time constant of 2.0 s. Appendix X2.2 describes the headform before or during the impact test. The fully extended length effects of an improper time constant on accelerometer signals. To measure the cable shall be at least two times time constant, perform the drop height specified by following procedures:

A1.4.1.1 Connect the initial owner/operator. The cable shall be of self-coiling design. The cable shall be attached accelerometer signal normally input to the headform and data acquisition system to a recording device by (for example, a single multiple contact electrical connector with integral locking action.

A1.3.2.5 The axis nominally perpendicular to the impact surface shall digital oscilloscope or computer data acquisition system) . This signal should be annotated *Z*. The axes forming the plane nominally parallel to the impact surface shall be annotated *X* and *Y*. This coordinate system complies with the right handed coordinate system, Orientation 2, of SAE J 211.

TABLE A21.1 HIC Values for 10Lims Half Sine

NOTE 1—The recs orf Moding devfiee will not produce HI C vFC 1000 Dalues with greater t Chan ±5 % from thnese val

Dynamic Accues.racy

Frequency, Hz	Dynamic Accuracy	
	Peak GdB, Min	dB, Max
HIC	T1 (seconds)	T2 (seconds)
0.1	-0.1	0.1
50	73	0.1
1	-0.1	0.1
10017	0.1	0084
100	-0.1	0.1
1 00	413	0.0017
1 000	-0.2	0.1
	4	0.0084
1 650	-4	0.1
150	1140	0.1
2 000	-10	0.1
3 50017	0	.0084
3 500	-30	-19.4
200	2341	0.7
5 000		-31.7
10 017	0	.0084
10 000		-55.7

A1.3.3 *Recording Equipment*—The recording equipment shall meet the following criteria:

A1.3.3.1 *Acceleration Time*—The acceleration-time recording equipment shall have three input channels, each matched to the resultant output signal levels of the triaxial accelerometer. Each input channel and accelerometer pair shall have a frequency response adequate to measure the peak acceleration to an accuracy of ±5 % of the true value. The total system, accelerometers signal conditioner and recorders, shall be capable of measuring impulses up to 500 *g* at frequencies from 2 to an accuracy of ±5 %. analog filter, as shown in Fig. A1.2. The minimum system sampling rate required is 20 000 Hz per input channel or 20 000 samples/s per input channels. The data recording device must should be capable of simultaneously sampling each recording across the whole output range of the three input channels at the specified sampling rate. Three independent digitizers or a single digitizer signal conditioner with three track and hold amplifiers is acceptable. Each acceleration data channel should comply with SAE J 211. A low pass filter having a 4-pole Butterworth transfer function and resolution of ±1 mV, for a corner frequency minimum of 1650 Hz meets this requirement. Digitizer resolution shall be 10 s at a minimum sample rate of twelve bits.

A1.3.3.2 *Displacement - Time*—Provision will be made to record the time, in seconds, from the release of the headform to the time of initial impact. 100 s^{-1}. The velocity at impact will accelerometer should be calculated by multiplying the fall time by the acceleration due fixed and not subject to gravity (32.2 ft/s/s) to yield motion or vibration while measurements are made.

A1.4.1.2 Turn on the velocity in feet per second. The time measurement function will be part of the signal conditioner, recording device and will not require operator intervention other necessary electronics, allowing them to start and stop warm up, as recommended by the measurement.

A1.3.3.3 *System Integrity*—Portable recording equipment shall provide continuous battery voltage monitoring. If recording equipment battery voltage falls below a level required for proper equipment operation, manufacturers.

A1.4.1.3 Prepare the recording function shall be inhibited and device to receive the person performing signal. Turn off the test alerted by an indicator lamp or message signal conditioner. After 5 ± 1 s turn on the LCD interface of signal conditioner and record the output for a minimum of 10 s. A longer recording device. Auxiliary power means, such as automobile battery voltage converters or wall receptacle connected chargers, time may be requsired to restore battery voltage to obtain a satisfactory recording.

A1.4.1.4 If the acceptable operating level. Impact tests may be performed with accelerometer, signal conditioner, or analog filter have a finite low-frequency response, the recording device connected to recorded signal will show an exponential decay towards zero as the auxiliary power source. Prior to use signal “settles” (Fig. A1.3).

A1.4.1.5 Select two points in the recording equipment and headform shall be checked for proper operation by impact test recorded data that fall on a reference surface material sample. The sample shall be provided by the recording device manufacturer exponential curve and be furnished with reference impact test data including serial number that are separated by a minimum of sample, drop height, ambient temperature, subsurface condition, *g*-max, 2 s and HIC. Average the results a minimum of one tenth the last two output range of three drops, and compare to the reference *g*-max and HIC. The manufacturer of the triaxial headform is to provide the criteria signal conditioner (for example, 1.0 V for a ±5 .0-V output range). Record the requirement for recalibration time and voltage at each of the headform, recorder, these two points as (T_0,V_0) and reference pad. The impact test on (T_1,V_1).

A1.4.1.6 Determine the reference sample will not be construed to be a calibration of time constant using the instrument, which can only be performed following equation:

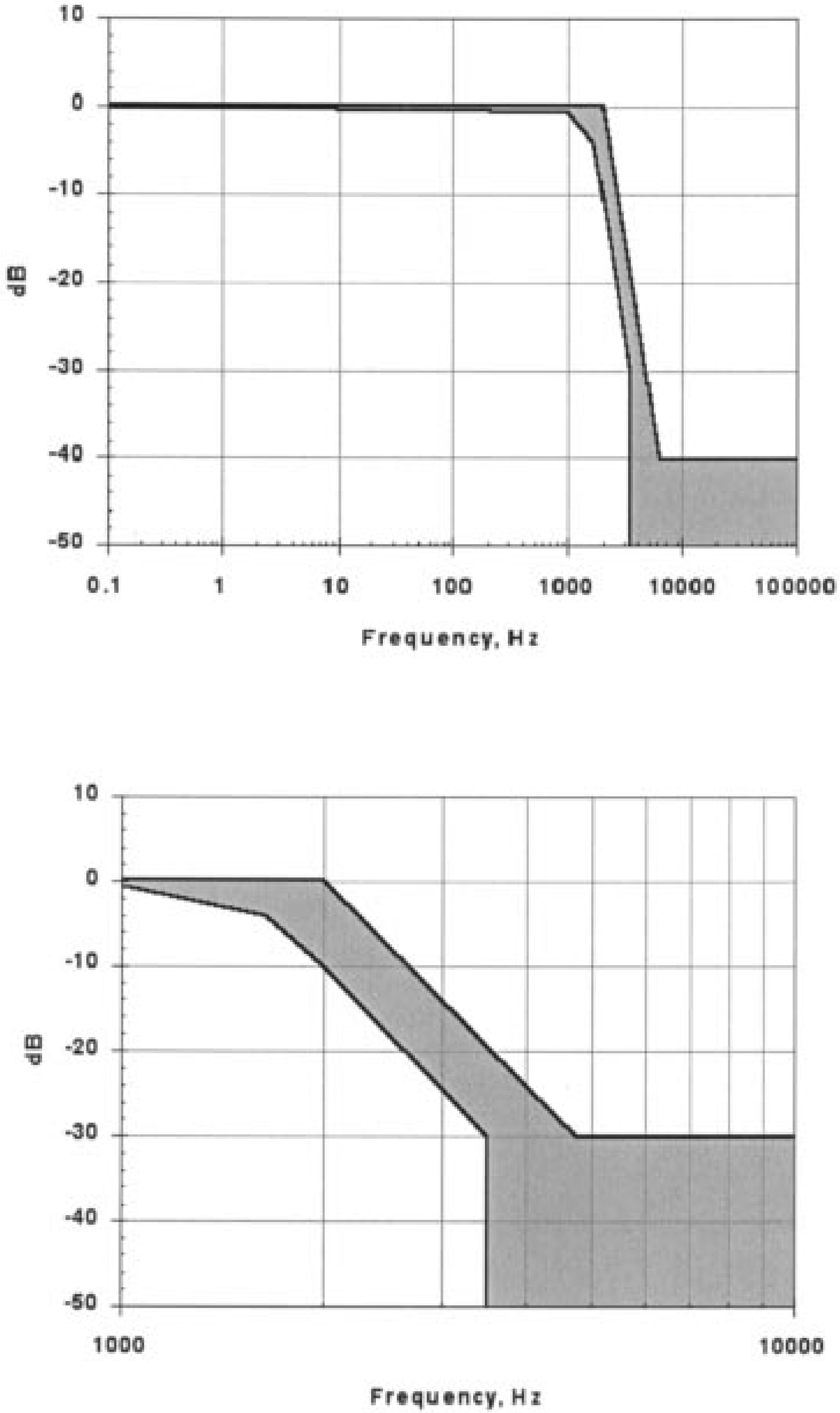


FIG. A1.1 CFC 1000 Data Channel Dynamic Accuracy

$$T_C = -\frac{(T_1 - T_0)}{\log_e (V_1/V_0)}$$

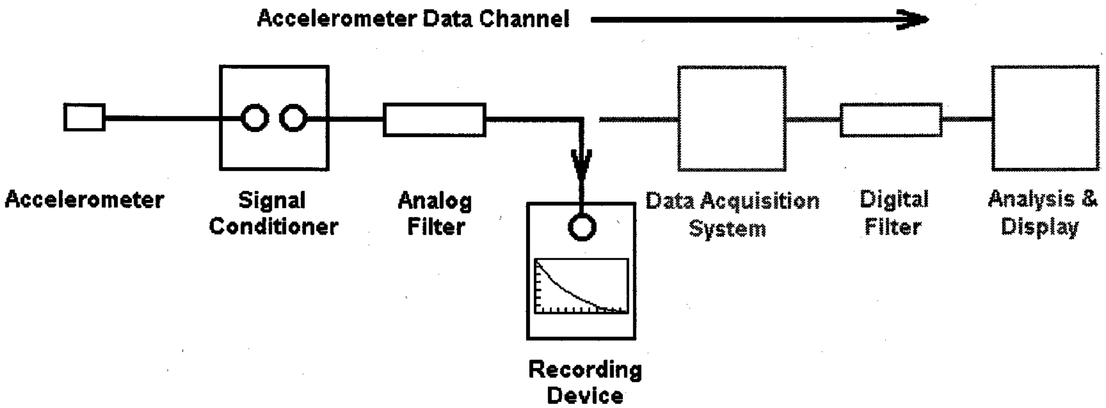


FIG. A1.2 Schematic of the Time Constant Test

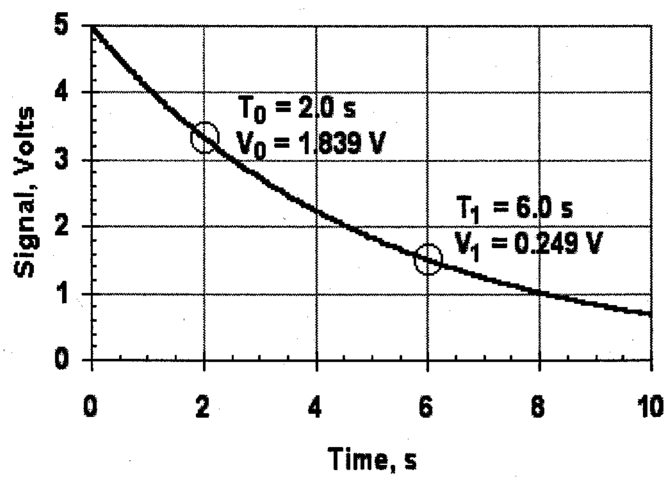


FIG. A1.3 Example Recording from Time Constant Test

For the example shown in a properly equipped metrology laboratory.

A1.3.3.4 *Calibration*— Check Fig. A1.3:

$$T_C = -\frac{(6.0 - 2.0)}{\log_e(1.839/0.249)} = -\frac{4.0}{\log_e(7.386)} = 2.0\ \text{s}$$

A1.4.1.7 If the recording equipment, headform, and reference surface material sample annually for proper calibration by returning them to measured time constant is less than 2.0 s, the manufacturer's calibration laboratory or repair depot qualified by equipment does not meet the manufacturer.

A1.3.3.5 *Impact Data and Waveform Display* —The recording device shall have a graphic display device capable frequency response requirements of indicating the *g*-max, HIC, this specification.

A1.4.2 *Verification of g-max and impact waveform.*

A1.3.3.6 *Drop Height Measurement and Control-Drop Height*, shall be measured from HIC Calculations Using Known Inputs—This test determines whether the data acquisition system, digital filter, and calculation procedures of the surface a test system conform to be tested to the surface requirements of this specification. The test requires the headform expected accelerometer output to initially impact the surface. Measurement shall be made with replaced by a steel rule or steel tape measure. Use a support structure or tripod to ensure repeatable drop height synthesized pulse of predetermined shape, width, and location. amplitude (Fig. A1.4). The support structure or tripod shall pulse may be sufficiently rigid generated by a programmable signal generator, a computer-linked digital to support, with minimum deflection, the weight of the headform. The support structure analog converter, or tripod must allow for other appropriate means providing the testing of the surface at any location within the playspace. A quick-release mechanism shall be provided output has a range equivalent to connect the headform to the support arm. The operation that of the release mechanism shall not influence the trajectory of the headform during free fall. Erect the support structure or tripod in such signal conditioner output, a manner so as to prevent the headform from coming in contact with any part minimum resolution of ±1 mV, and the support structure or tripod before impact with the surface being tested.

A1.3.4 *Calculation*:

A1.3.4.1 *Triaxial Acceleration Component Summing*—The components capability of acceleration in each of refreshing the three

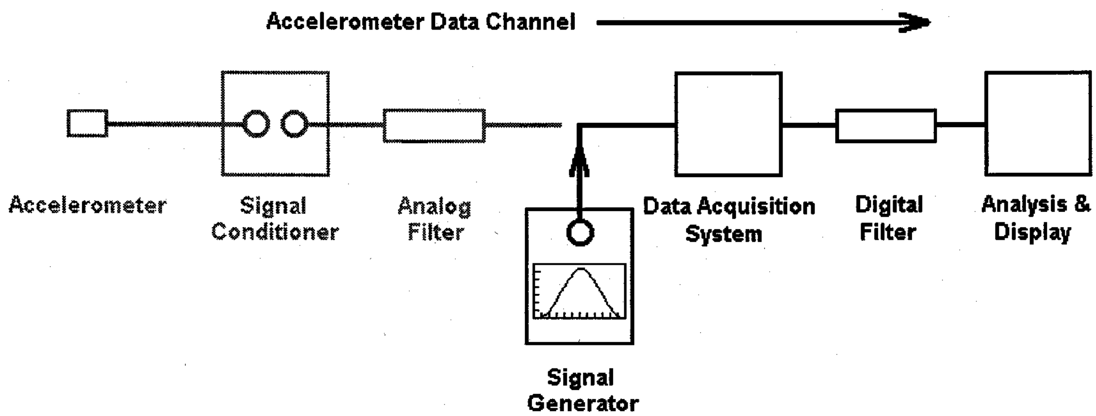


FIG. A1.4 Schematic of the Calculation Verification Test

axes must be vector summed to determine composite acceleration generated signal at a minimum rate of the headform. Perform vector addition on each set of three samples 50 kHz.

A1.4.2.1 The pulse to determine the composite acceleration for the respective sample period. The vector addition shall be based on generated is a cosine wave of the following mathematical expression: form:

(A1.1) $a[n] = (az[n]2 + ay[n]2 + ax[n]2)0.5$

$$V = A\left(1 - \cos\left(2\pi\frac{t}{T}\right)\right)$$

AtT

where:

$a_{[n]}V$ = composite acceleration at sample point [n], the output voltage,
$a_{z[n]}A$ = acceleration value of Z axis at sample point [n], the pulse height (amplitude),
$a_{y[n]}t$ = acceleration value of Y axis at sample point [n], time, and
$a_{x[n]}T$ = acceleration value of X axis at sample point [n]. target pulse width.

A1.3.4.2 *g-Max*

The constant A is calculated from the target g-max and the accelerometer sensitivity (c) used in the calculation of g-max and HIC — The g-max scores, using the formula:

$$A = c\ g_{max}$$

This function produces a waveform of the type shown in Fig. A1.5 and was selected because of its similarity to real impact waveforms. Also, the function allows HIC shall scores to be determined calculated directly from first principles.

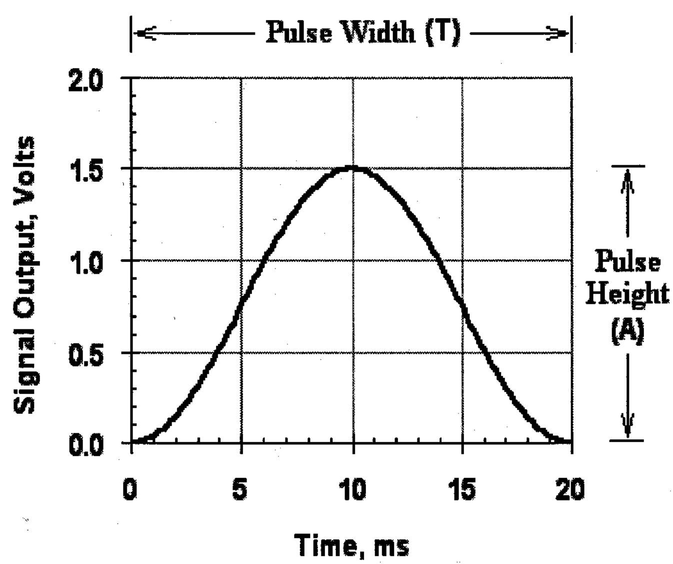


FIG. A1.5 Example of a Synthesized Impact Waveform

A1.4.2.2 To perform the composite acceleration values. The specified algorithm test, take the following steps:

(1) Program the signal generating device to produce pulses of the form described in A1.4.2.1. To complete the test, pulses with each of the combination of pulse width (*T*) and v the reference g-max score shown in Table A1.2 will be required. In each case, determine the amplitude (*A*) of the waveform by multiplying the reference *g*-max by the accelerometer sensitivity.

(2) Connect the output of the signal generator to the input of the data acquisition system.

(3) Prepare the data acquisition system to receive a signal. Send the signal from the signal generator. Acquire and process the acquired data in the normal way.

(4) Record the *g*-max, HIC, and HIC interval scores reported by the test system.

(5) Repeat the test for each of the six combinations of pulse width (T) and reference g-max in Table A1.2.

(6) Compare the *g*-max, HIC, and HIC interval scores produced by the test equipment with the target scores in Table A1.2.

A1.4.2.3 If any recorded value differs from the target value by more than ±1 %, the test equipment does not conform to the requirements of this specification.

APPENDIXES

(Nonmandatory Information)

X1. INJURY RISK CURVES

X1.1 Most of what is known about the relationship between impact magnitude and head injury risk comes from experiments using cadavers and human volunteers subject to high accelerations and impacts under laboratory conditions. The data from these experiments form the basis of automotive and aircraft impact protection standards. There has been no research directly relating the magnitude of an impact from a playground fall to the severity of the injuries sustained. We, therefore, rely on data from automotive industry experiments to provide insights into injury risk.

X1.2 Fig. X1.1 shows the probability of different degrees of injury occurring as a result of impacts with a given HIC score. These "Expanded Prasad/Mertz Curves" are based on data from cadaver experiments in which the relationship between HIC scores, skull fracture, and brain damage were observed.[6,8] The two solid curves in this figure show the probabilities of no injury and of fatal head injury. Broken lines show the probability of minor, moderate, and critical head injuries, defined as Appendix X2.

A1.4 Procedure

A1.4.1 For portable recording devices, verify battery voltage follows:

X1.2.1 *Minor Head Injury*—A skull trauma without loss of consciousness; fracture of nose or teeth; superficial face injuries.

X1.2.2 *Moderate Head Injury*—Skull trauma with or without dislocated skull fracture and brief loss of consciousness. Fracture of facial bones without dislocation; deep wound(s).

X1.2.3 *Critical Head Injury*—Cerebral contusion, loss of consciousness for more than 12 h with intracranial hemorrhaging and other neurological signs; recovery uncertain.

[8] Prasad, P. and Mertz, H. J., "The Position of the United States Delegation to the ISO Working Group on the Use of HIC in the Automotive Environment," *SAE Paper No. 851246*, Society of Automotive Engineers, Warrendale PA, 1985.

TABLE A21.2 HIC Valnput Wavesfor 20ms H Chalf Sine

NORACTE 1—THERECORDING DEVSTICE WILLS ANOT PRODUCE HIC v TALUES WITH GRATGERTHAN ±5 % FR SCOM THRESE VALUES.

Waveform		Target Scores		
PulseAk G Width (ms)	Reference g-max	g-max (g)	HIC	HIC Interval (ms)
T1 (seconds)	T100	100	302(seconds).9	5.08
10.0	100	100	302.9	5.08
50	146	0.0033	0.8	5.0167
10.0	150	150	834.8	5.08
10.0	200	200	1 713.7	5.08
20.0	100	827	0.0033	0.0167
20.0	100	100	605.9	10.15
20.0	150	2281	0.0033	0.0167
20.0	150	150	1 669.6	10.15
20.0	200	4684	0.0033	0.0167
20.0	200	200	3 427.4	10.15

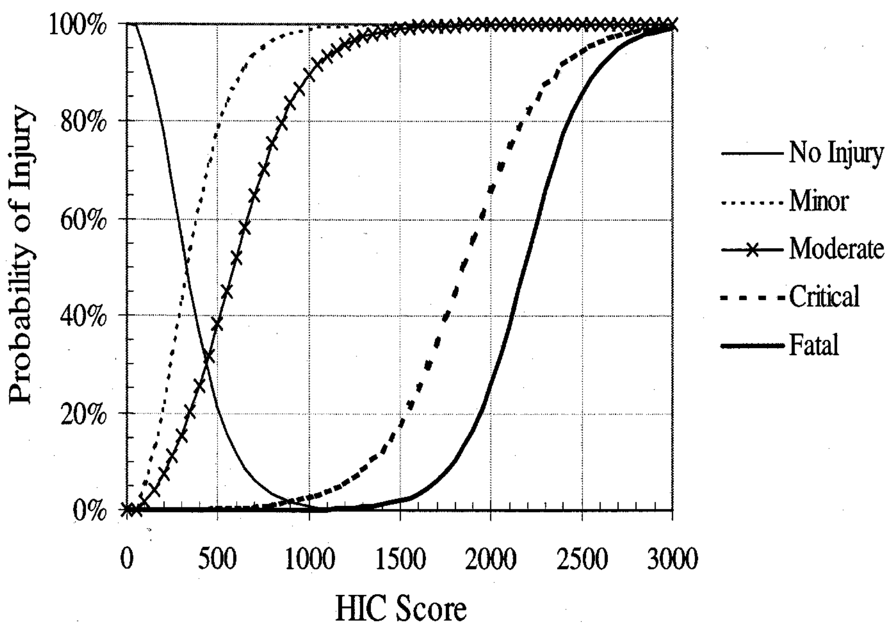


FIG. X1.1 Probability of Specific Head Injury Level for a Given HIC Score

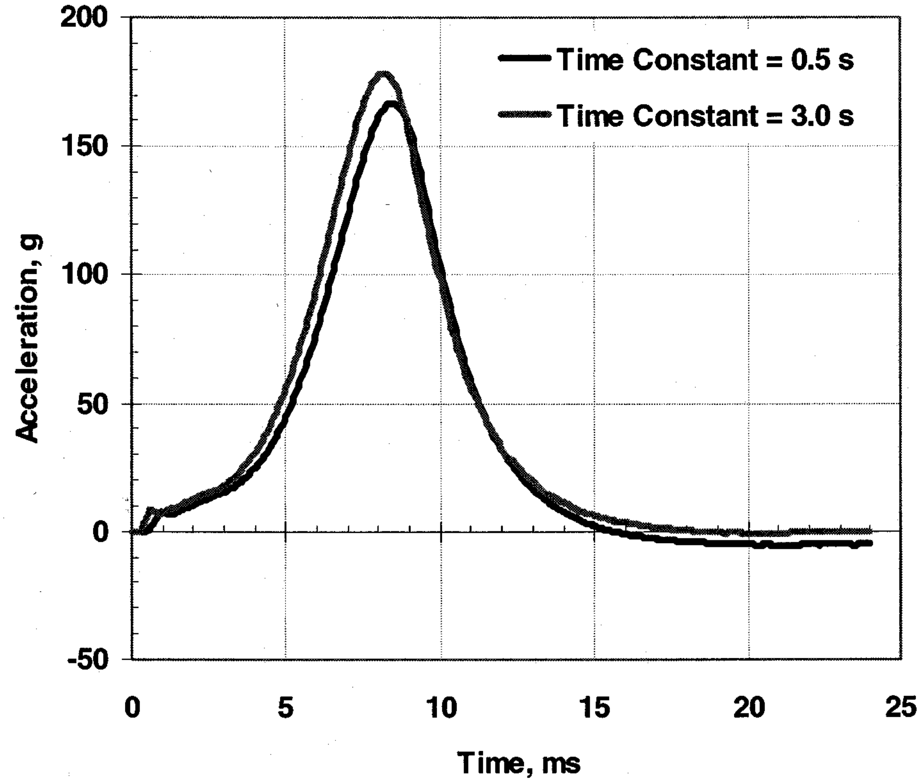
X1.3 As an example of how Fig. X1.1 is interpreted; if a person experiences a head impact equivalent to a HIC score of 500, there is a 79 % chance that they will suffer a minor injury. At 38 %, the risk of a moderate injury at this HIC level as recommended by manufacturer.

A1.4.2 Perform is also significant. The risk of this impact producing a severe or fatal head injury is very low, however. It is also notable that the system integrity chance of experiencing a 500 HIC impact without suffering an injury of any kind is only 21 %.

X1.4 *Discussion* —HIC injury risk curves should be interpreted cautiously ing the testing equipment manufacturer's supplied surface sample. Verify context of injuries resulting from playground falls. The data on which the Prasad/Mertz Curves are based are from adult cadavers subjected to frontal impact. The extent to which this data is valid for children experiencing non-frontal impacts to the head is not known. Also, a rigid missile such as that test results specified by this specification produces HIC scores that are somewhat higher than those generated by a cadaver or a headform with lifelike properties.[9] HIC scores determined in agreement accordance with those quoted this specification will overestimate the probability and severity of head injury if they are interppreted using Fig. X1.2, will tend to be overestimated. Consequently, the criteria established by this specification are more conservative than if a lifelike headform were used. The more conservative criteria are warranted by the t absence of specific data for the head injury tolerance of children falling from playground equipment manufacturer.

A1.4.3 Erect and by the support structure or tripod on fact that the p layimiting HIC score ouf 1000 is set at the threshold of fatal injury risk. As the Prazad-Mertz curves show, a 1000 HIC criterion limits the probability of a fatal injury, but still infers a significant risk of severe, non-fatal injury. The position probability of experiencing a 1000 HIC impact with no injury is very low (less than 1 %).

[9] Saczalski, K.J., States, J.D., Wagar, I.J, Richardson, E.Q., A Critical Assessment of the Use of Non-Human Responding Surrogates for Safety System Evaluation. SAE Paper # 760805, 1976, Society of Automotive Engineers, Warrendale PA.




```
/*
 * @(#)hiccomp.c v1.0 kpc 04/28/88 -- HIC 68k  hic computation module



 * this module computes hic for a passed in waveform
 *
 * we assume that the limits have been determined for the waveform
 * and are set in the hicinfo struct
 */

#include    "hic.h"
#include    <stdio.h>


/*
 * compute integral from partial sums array
 *  from i1 to i2
 */
#define INTEG( i1, i2 )          (s[i2] - s[i1])
#define AVE( i1, i2 )            ( INTEG(i1,i2) / (SUMTYPE)((i2)-(i1)) )
#define HIC( i1, i2 )            (power2( AVE(i1, i2))*(SUMTYPE)(i2-i1))


static int      debug = 0;       /* debug mode? */


/*
 * compute hic with sliding endpoints
 */
void        hiccomp( ip, chan )
IMPINFO     *ip;
short       chan;
{
    Idx     maxn;
    short   improve;             /* loop until no improvement in answer */
    short   i,j;                 /* limits for ave */
    short   g;                   /* guess */
    short   iter;                /* iteration count */

    SUMTYPE ave;                 /* current best average */
    SUMTYPE aveg;                /* next guess at best average */
    SUMTYPE hicv;
    SUMTYPE hicvs;               /* special hic value */

    HICINFO     *hp;
    SUMTYPE     *s;              /* to hold the partial sums */

    double          power2();
    extern char     *malloc();


    /* hp = ip->chan[0]; */
    hp = ip->chan[chan];

    maxn = hp->imax - hp->i0 + 1;


#define SAME        (0)
#define LOWER       (-1)
#define HIGHER      (1)

/* is it near zero? */
#define ZERO( v )       ((v) < eps && (v) > -eps)
#define ZEROF( v )      ((v) < epsf && (v) > epsfn)

#define min( a, b )     ((a>b)?(b):(a))
#define max( a, b )     ((a>b)?(a):(b))

/* debugging aid */
#if 0
#define CTR( x )        x
#else
#define CTR( x )
#endif

/*
 * variables for the algorithm
 */
static SUMTYPE          *s;         /* partial sums array */

static SUMTYPE          eps;         /* my epsilon for comparisons */
static DTYPE            epsf;        /* my float epsilon for comparisons */
static DTYPE            epsfn;       /* my negative epsilon */

/* counts, # of equal value, # of ave ok, # of bracket pairs, # of hicv's */
static unsigned short   ev, av, fv, hv;
/* more counts, # of times the prev hic val was used, # of times cur val used
static unsigned short   pv, cv;
static short            dbg = 0;    /* debugging flag */

static    Idx           i, j;       /* 1st & 2nd limit */
```

```
 */
void        hiccomp3( ip, chan )
IMPINFO     *ip;
short       chan;       /* data channel # used to compute HIC */
{
    double          power2();       /* we will need this */
    extern char     *malloc();

    HICINFO         *hp;

    hp = ip->chan[chan];

    eps = 1.0e0;                /* if it is within 1g then its close */
    epsf = eps;                 /* float version of eps */
    epsfn = -eps;               /* float negative eps */

    /* init vars */
    hicv = 0.0;
    hici = 0;
    hicj = 0;

    /* loop & cycle counters */
    ev = av = fv = hv = pv = cv = 0;

    /* number of samples in 50.0 msec (50000 usec = 50.0 msec) */
    wind = 50000L / ip->samptime;
    ipk  = hp->ipk - hp->i0;

    /* how many pnts are there? */
    npnts = 1 + hp->imax - hp->i0;
    dp    = hp->acc + hp->i0;       /* base addr for part of array we need */


    if( (s = (SUMTYPE *)malloc((npnts+3)*sizeof(SUMTYPE))) == NULL )
    {
        printf("hiccomp3: malloc bomb (%d bytes)\n",
            (npnts+3)*sizeof(SUMTYPE));
        return;
    }

    /* compute partial sums array */
    partsum( s, dp, npnts );

    fprintf(stderr, ".");
    fflush( stderr );

    /*
     * The starting point scans over every point upto the peak g Idx
     */
    i = max( 0, ipk-wind );
    for( ; i<ipk; i++ )
    {
        /* precompute data for this 'i' */
        v = dp[i];
        v53 = v * (5.0F/3.0F);
        a0 = s[i];

        /* setup loop ctl vars */
        prevf = curf = 0;



      tmp = i + wind;
      n = min( tmp, npnts );

      tmp = i + MINWIDTH;
      j = max( ipk, tmp );

      w = j - i;

      for( ; j<n; j++,w++ )
      {
          v2 = dp[j];
          diff = v2 - v;

          if( ZEROF(diff) )
          {
              /*
               * points are "equal"
               * so check the average value of this interval
               */
              CTR( ev++ );
              curf = 0;
              ave = (s[j] - a0) /(SUMTYPE)(w);

              diff2 = ave - v53;
              if( ZERO( diff2 ) )
              {
                  /*
                   * the average value is close to 5/3*dp[i] !!
                   * here is where we compute a HIC!
                   */
                  CTR( av++ );
                  hicg = (SUMTYPE)(w) * power2( ave );

                  if( hicg > hicv )
```

X2. EFFECTS OF MEASUREMENT ERRORS

X2.1 This appendix documents the sensitivity of test results to different sources of measuremeent error.

X2.1.1 Thae sensitivity and error estimatessho were calculated using a modell owf the impact test. The model assumes a Hertzian impact between a rigid hemispherical headform dropped from eight feet and a linear elastic surface with properties such that *g*-max = 200 g.

X2.1.2 Table X2.1 shows the effect of ±1 % error in each component measurement on *g*-max, HIC, and CFH measurements. For example, a 1 % deviation in the missile radius results in a 0.2 % error in *g*-max, and 0.5 % error in HIC and CFH results. It is notable that any error in *g*-max is amplified in the calculation of HIC by a power of 2.5. Errors in CFH are greater than those in *g*-max and HIC because the relationship between *g*-max, HIC, and CFH. Also, the process of determining CFH compounds errors in HIC and velocity measurements, making it more sensitive to small errors. In general, test results are least sensitive to discrepancies in missile mass and geometry. Results are especially sensitive to errors in the components of impact velocity measurement. If a flag/photogate system is used, a 1 % error in either the desired point repeatedly on flag width measurement or the surface from transit time (Δt) causes an error more than 4 % in the drop critical fall height estimate. Ind a free-fall test, a 1 % error in the measurement of fall time causes a 10.8 % error in critical fall height.

X2.1.3 Table X2.2 shows the error in each component measurement that results in an error of ±3 in. in the calculated CFH.

X2.1.4 Table X2.3 shows the of the measurement tolerance limits specified by this specification on errors in *g*-max, HIC, and CFH results. The values shown assume a test with a fall height of 8 ft and a *g*-max score of 200 g. While tolerances of ±1 % are specified for acceleration and impact velocity measurements, any error in these measurements is amplified (by a power of two or greater) in the initial owner/operator.

A1.4.4 *Release calculation of HIC and CFH. Consequently, the ±1 % tolerance implies that either measurement could contribute to an error of ±2.5 % in CFH Measurement. If both acceleration and impact velocity (or drop height) are at the limits of their specified tolerances a total error of up to ±10 % in CFH Measurement is possible.*

X2.2 *Accelerometer Time Constant*:

A1.4.5 Observe the impact waveform on the display

X2.2.1 Differences in accelerometer time constant of the recording device and confirm that it contains only one impact event. have been identified as a major source of interlaboratory variability. The impact waveform should start at 0 *g*, increase to time constant determines the *g*-max low frequency response of the drop, and return accelerometer to 0 *g*. An impact waveform not showing this shape should be discarded. The increase mechanical inputs, with longer time constants indicating better low frequency response. A very short time constant (~0 s) results in ac response and decrease portions of the waveform may be smooth accelerometer is insensitive to constant or j slowly changing inputs. A very long time constant (>10 s) indicates near-DC response and will depend upon the material being impacted upon.

A1.4.6 *Record and Report the Following Information*:

A1.4.6.1 The test surface identification, indicating type, source, size, and thickness.

A1.4.6.2 Test procedure used and headform description, accelerometer is sensitive to low frequencies, including mass, geometry, and orientation.

A1.4.6.3 Testing conditions, including sample temperatures and drop heights employed.

A1.4.6.4 Individual drop values and the average those that vary little with time.

X2.2.2 This specification requires linear accelerometer sensitivity down to 1 Hz or below. An accelerometer with a time constant of the second 2 s or greater and third drop values appropriate signal conditioning will generally meet this requirement. Typically, accelerometers are manufactured for both *g*-max and HIC values.

A1.4.6.5 The drop heights specified by the initial owner/operator.

NOTE A1.1—The preferred method purposes of exhibiting measuring vibration, and have shorter time constants (<1 s) than the minimum required for the impact a wcceleration measulrements required by this specification. Many accelerometers must be modified by the manufacturer in chart form (see Fig. 1).

TABLE X2.1 Effects of a 1 % Measurement Errors on g-max, HIC, and Critical Fall Height Results

Component Measurement	Missile		Acceleration	Flag Width	Velocimeter	Fall Time	Impact Velocity	Drop Height
	Mass lb	Radius in.	g	in.	Δt ms	s	fps	ft
Nominal value	10.12	3.15	200	1.00	0.0037	1.188	22.70	8.00
±1 % error	±0.10	±.03	±2.0	±0.01	±0.00004	±0.012	±0.23	±0.08
Error in ...								
g- max	±0.4 %	±0.2 %	±1.0 %	±1.2 %	±1.0 %	±2.5 %	±1.2 %	±0.6 %
HIC	±1.0 %	±0.5 %	±2.5 %	±3.0 %	±2.5 %	±6.4 %	±3.0 %	±1.5 %
Critical fall height	±1.0 %	±0.5 %	±4.9 %	±5.1 %	±4.4 %	±10.8 %	±5.1 %	±2.5 %

TABLE X2.2 Magnitude of Measurement Error Giving ±3 in. Error in Critical Fall Height Results

Component Measurement	Missile Mass lb	Missile Radius in.	Acceleration g	Flag Width in.	Velocimeter Δt ms	Fall Time s	Impact Velocity fps	Drop Height ft
Nominal value	10.12	3.15	200	1	0.0037	1.188	22.7	8
% error	±3.0 %	±6.3 %	±1.0 %	±0.5 %	±0.5 %	±0.3 %	±0.6 %	±1.2 %
Abs error	±0.31	±0.20	±2.0	±0.006	±0.00002	±0.004	±0.14	±0.10
Error in ...								
g-max	±1.2 %	±1.2 %	±1.0 %	±0.7 %	±0.7 %	±0.7 %	±0.7 %	±0.7 %
HIC	±3.1 %	±3.1 %	±2.0 %	±1.9 %	±1.9 %	±1.9 %	±1.9 %	±1.9 %
Critical fall height	±3.1 %	±3.1 %	±3.1 %	±3.1 %	±3.1 %	±3.1 %	±3.1 %	±3.1 %
Critical fall height	±3 in.	±3 in.	±3 in.	±3 in.	±3 in.	±3 in.	±3 in.	±3 in.

TABLE X2.3 Effects of a Specified Measurement Tolerances on g-max, HIC, and Critical Fall Height Results

Component Measurement	Missile Mass lb	Missile Radius in.	Acceleration g	Flag Width in.	Velocimeter Δt ms	Fall Time s	Impact Velocity fps	Drop Height ft
Nominal value	10.12	3.15	200	1	0.0037	1.18	22.7	8.0
Tolerance	0.1	0.05	1.0	0.005	0.00002	0.001	0.227	0.2
% Tolerance	±1 %	±2 %	±1 %	±0.5 %	±0.5 %	±0.1 %	±1.0 %	±2.0 %
Error in ...								
g-max	±0.4 %	±0.4 %	±1.0 %	±0.6 %	±0.6 %	±0.5 %	±1.2 %	±1.5 %
HIC	±1.0 %	±1.0 %	±2.5 %	±1.5 %	±1.5 %	±0.9 %	±3.0 %	±3.0 %
Critical fall height	±1.0 %	±1.0 %	±4.2 %	±2.5 %	±2.5 %	±3.2 %	±5.1 %	±5.1 %
Critical fall height	±1.0 in.	±1.0 in.	±4.1 in.	±2.4 in.	±2.4 in.	±3.1 in.	±4.9 in.	±4.9 in.

A1.4.7 Make three consecutive drops at intervals of 3± 0.25 min, unless otherwise specified.

A1.5 Report

A1.5.1 A detailed report will order to be prepared conform to document the result requirements of the drop tests. this specification. As shown in Fig. A1.1 X1.1, an accelerometer with a time constant that is too low produces a suggested format for this report.

A2. INSTRUMENTATION REQUIREMENTS

A2.1 To adequately perform surface impact tests complying with Specification F 1292, characteristic signal, tending to "overshoot" the instrumentation employed must meet minimum requirements for resolution, accuracy, precision, and calibration.

A2.2 Accelerometers

A2.2.1 In guided head form systems, a single axis or triaxial accelerometer may be used. zero baseline after the impact. The active axis lack of appropriate low-frequency response also results in the accelerometer must be rigidly attached underestimation of *g*-max and HIC scores.

X2.3 *Interval Between Impacts*—Variations in the time needed to conduct the head form and within ±5° test result in variable levels of the axis recovery of impact of the head form.

A2.2.2 In free fall head form systems, a triaxial accelerometer material during the room temperature tests. This variation is required. One axis accentuated in non-room temperature tests by the addition of changing temperature conditions within the accelerometer must be rigidly attached sample to the head form and within ±5° variable recovery of the primary axis of impact. The remaining two axes will form a plane parallel to material.

X2.4 *Impact Velocity* —Variations in the impact surface within ±5°.

A2.2.3 The accelerometer oriented parallel to velocity brought about by changes in drop height or friction in the drop guidaxnce mechanism.

X2.5 *Missiles* —Use of impact must have an output missiles other than those referenced in this specification may cause substantial variations in results. Missile with masses greater than the specified range from 0 to 500 will result in lower *g* minimum.*g*-max and HIC scores.

X3. COMPUTER ALGORITHM FOR CALCULATING HIC

X3.1 The secondary axes in a triaxial accelerometer must have following example pseudo-code computes the HIC score of an output range from 0 acceleration pulse to ±500 *g* minimum. All axes must be capable within 0.5 % of withstanding theoretical values. For clarity, the program has been written as a maximum shock procedure, with filtered input data and results passed as global variables. It is also assumed that the data presented to the routine has already been filtered.

```
// GLOBAL VARIABLES
var
// Data Acquisition Information
    SampleFrequency: integer;    // Data acquisition rate, samples/second
    nSamples          : integer;    // Number of 1000 g.
```

A2.2.4 The frequency response of all accelerometers shall cover the complete range from 2 to 2000 Hz.

A2.2.5 Nominal accelerometer output will be 10.0 mV/*g*.

A2.3 Recording Device

A2.3.1 A digital electronic recorder will be used to capture impact wave forms. The recorder may be in the HIC interval

```
    HICinterval := (IHIC1-IHIC0)/SampleFrequency;
    end;

    end.
```

```
// GLOBAL VARIABLES
  var
  // Data Acquisition Information
     SampleFrequency: integer;   // Data acquisition rate, samples/second
     nSamples          : integer;   // Number of acquired data samples
  // Input Data
     AccelData: array [0..nSamples] of real; // Array of acceleration data in g units
// Outputs
     HICmax      : real;          // HIC score
     HICinterval   : real;          // HIC interval

// HIC CALCULATION PROCEDURE
  procedure HIC_Calculation;
  // LOCAL VARIABLES
  var
  // Intermediate Results
     integral          : array [0..nSamples-1] of real; // HIC Integral Values
     iHIC0,iHIC1   : integer;    // HIC interval boundaries
     HIC                 : real;          // Intermediate HIC    result
  // Counters
     i,j                    : integer;

  begin
  // Initialise results
   iHIC0 := 0;
   iHIC1 := 0;
  HICmax:=-1.0;
  // Calculate Integral
  integral [0]:=0.0;
  for i:=1 to nSamples do integral [i]: =integral [i-1] +(AccelData [i]+AccelData [i-1])/2;

  // Scan all possible HIC intervals for maximum score
  for i := 0 to nSamples-1 do
  for j := i+1 to nSamples do
  begin
     HIC:=(integral [j]-integral [i])/(j-i);
     if HIC>0.0
        then HIC:=Power (HIC,2.5)
        else HIC:=0.0;
     HIC:=HIC*(j-i)/SampleFrequency;
     if HIC>HICmax then
        begin
           HICmax:=HIC;
           iHIC0:=i;
           iHIC1:=j;
        end;
  end;

  // Calculate the HIC interval
  HICinterval := (IHIC1-IHIC0)/SampleFrequency;
  end;

  end.
```

X3.2 *Verification* —When correctly implemented, the algorithm computes the theoretical HIC scores (within ±0.02 %) for the cosine pulses described in A1.4.2.1 and Table X3.1, assuming a digital storage oscilloscope or dedicated wave form digitizer. Analog oscilloscopes are not acceptable.

A2.3.2 Each digitizer input will have a minimum resolution sample rate of twelve bits spanning 20 000 Hz.

X4. ALGORITHM FOR DIGITAL BUTTERWORTH FILTER

TABLE X3.1 Theoretical and Calculated Values of Synthesized Cosine Pulses

Pulse Width (T) ms	Reference *g*-max	Theoretical HIC	Calculated HIC	Error	Error %
10.0	100	302.9	302.9	0.0	0.013
10.0	150	834.8	834.7	-0.1	-0.012
10.0	200	1 713.7	1713.5	-0.2	-0.011
20.0	100	605.9	605.9	0.0	0.004
20.0	150	1 669.6	1669.5	-0.1	-0.006
20.0	200	3 427.4	3427.2	-0.2	-0.005

X4.1 This specification specifies the full output range use of the respective accelerometer.

A2.3.3 Minimum digitizer sampling rate will be 20.0 kHz. In triaxial head form systems, three individual digitizers (one per axis), each with a 20.0 kHz sampling rate, will be used. Alternatively, a single 60.0 kHz digitizer may be used if simultaneous track and hold amplifiers are provided Butterworth Digital Filter for each accelerometer axis.

A2.3.4 Minimum digitizer memory length will be to allow a minimum smoothing acceleration data. Also, the response spectrum of 2 modified Channel Frequency Class (CFC) 1000 acceleration data channels is defined in terms of the impact wave form to be recorded.

A2.3.5 Analog filtering on all accelerometer input channels will be used to prevent Butterworth digital signal aliasing. response. The CFC 1000 data channel requires a fourth order (4-pole) Butterworth filter will have with a cut-off -3dB corner frequency of 1.0 kHz, with a minimum 1686.1 Hz. Instead of implementing a two pole roll-off.

A2.3.6 Provision to measure head form velocity at impact will be provided.

A2.3.6.1 A light gate device may be used to measure fourth order filter, it is recommended that the time an opaque flag interrupts a light sensor. The light gate will data be located so as to be activated with the head form no more than 1 in. from impact with the surface being tested. Velocity of head form shall be calculated by dividing the length of the opaque flag (inches) by the time the light sensor was activated (seconds) to velocity in inches per second. Conversion to units of feet per filtered twice, once forwards and once backwards using second may be obtained by dividing the inches per second value by 12.0

A2.3.6.2 For free fall head forms, recording the time from when the head form was released to the time the accelerometer output signal begins may also be used. Head form velocity shall be calculated by multiplying the time of flight (seconds) by 32.2 ft/s/s (acceleration due to gravity) to yield head form velocity in feet per second.

A2.3.6.3 Either velocity measurement will be performed order (2-pole) filter twice with a minimum timer resolution -3dB corner frequency of 1.0 ms.

A2.3.6.4 Actual head form velocity will not deviate from theoretical velocity by more than ± 0.5 ft/s. Theoretical velocity shall be determined from conservation of energy, namely kinetic energy at impact must be equal to potential energy before release: 2077.5 Hz. This approach eliminates phase shift in the filtered data.

X4.2 The 2-pole (second order) Butterworth Digital Filter is defined by:

(A2.1) $m\,g\,h = 12\,m\,v2$

$$F_t = \sum_{i=0}^{2} a_i A_{t-j\Delta} + \sum_{j=1}^{2} b_j A_{t-j\,\Delta}$$

At Δai and bj

where :

$m F_t$ = weight of head form (lb), filtered acceleration datum at time t,
$g A_t$ = acceleration due to gravity (32.2 ft/s/s), input acceleration datum at time t,
$h \Delta$ = actual drop height (ft), sample interval, and
$v a_i$ and b_j = velocity at impact (ft/s). filter coefficients

Solved for velocity, equation Eq A2.1 becomes:

$$v = \sqrt{(2gh)} \quad \text{(A2.2)}$$

Thus, a head form dropped from a height of 10.0 ft will have a velocity at of

$$v = \sqrt{((2) \times (32.2) \times (10.0))}$$

$$v = 25.4 \text{ ft/s}$$

A2.4 Calibrations

A2.4.1 Accelerometers will be calibrated by comparison to a National Institute of Standards and Technology (NIST) traceable standard. Both the reference accelerometer and the test accelerometer will be excited by a shaker table at frequencies and amplitudes as determined suitable by the accelerometer manufacturer. Maximum recalibration interval will be one (1) year or as recommended by manufacturer.

A2.4.2 Recording devices will be calibrated by replacing the accelerometer input signal(s) with a wave form of known shape, period, and amplitude. Tables A2.1 and A2.2 provide calculated HIC values for half-sine wave forms applied to a 12 bit, 20.0 kHz digitizer.

A2.5 Calculation of Peak and HIC

A2.5.1 The peak *g* of an impact wave form shall be determined to be the *g* value with the largest positive amplitude. The recording device will have the capability to sequentially scan all digitized data of the impact wave form and report the higher value recorded.

A2.5.2 The HIC value of an impact wave form will be calculated in accordanceThe correct filter coefficients vary with 8.6 of Specification F 1292. The dt term shall be an integer multiple of the data sampling rate and in no case will be greater then 0.1 ms. The recording device will have the capability to perform the calculation rate. Table X4.1 shows coefficients for all possible combinations of *t*1 and *t*2 (HIC integration interval) and to report the highest HIC value calculated. Manual selection of *t*1 and *t*2 intervals will not be allowed.

APPENDIXES

(Nonmandatory Information)

X1. RATIONALE

X1.1 This specification addresses the impact attenuation requirements of surfacing materials used under and around playground equipment. A Consumer Product Safety Commission study of playground equipment-related injuries treated in U.S. hospital emergency rooms indicated that the majority resulted from falls from equipment to the underlying surface.

X1.1.1 Because head impact injuries from a fall have the potential for being life threatening, the more shock absorbing and attenuating a surface can be made, more is the likelihood that the severity sample rate of the injury will be reduced. In addition, the measurement of a peak deceleration of the head during impact plus the time duration over which the head decelerates to a halt is significant. Therefore, a mathematical formula is used to derive a value known as head injury criteria (HIC). Head impact injuries are not believed to be life threatening if the HIC does not exceed a value of 1000.

X1.1.2 However, it should be recognized that safety surfacing meeting these test measurements will not prevent nonlife-threatening injuries from occurring. The Consumer Product Safety Commission states, "It is self evident that a fall onto a shock absorbing surface is less likely to cause a serious injury than a fall onto a hard surface. However, it should be recognized that all injuries due to falls cannot be prevented no matter what playground surfacing material is used."

X1.2 This specification is limited to a test for *g*-max, HIC, and conditions that affect them, that is, drop height, temperature, and so forth. Other physical property factors could be taken into account in the comparison of surface systems but currently are beyond the scope of this specification. These factors should be considered and included after being studied.

X2. HIC CALCULATION PROGRAM

X2.1 See 20 000 Hz. Fig. X2.1. X4.1 shows the response function of the filter in relation to the specified limits of the modified CFC 100 data channel. Section X4.3 describes a computer algorithm for implementing the 4-pole filter using forward and reverse passes of the 2-pole filter.

X4.3 *Computer Algorithm for 4th Order, Zero Phase Shift, Butterworth Digital Filter*—The example pseudo-code below implements a fourth order, zero phase shift on an array containing a single channel of acceleration data. For clarity, the program has been written as a procedure, with input data and filtered data passed as global variables.

TABLE X4.1 Second Order Butterworth Filter Coefficients for a CFC 1000 Data Channel Sampling Rate = 20000 Hz

Coefficient	a_0	a_1	a_2	b_1	b_2
Value	0.071893	0.143786	0.071893	1.111586	-0.399159

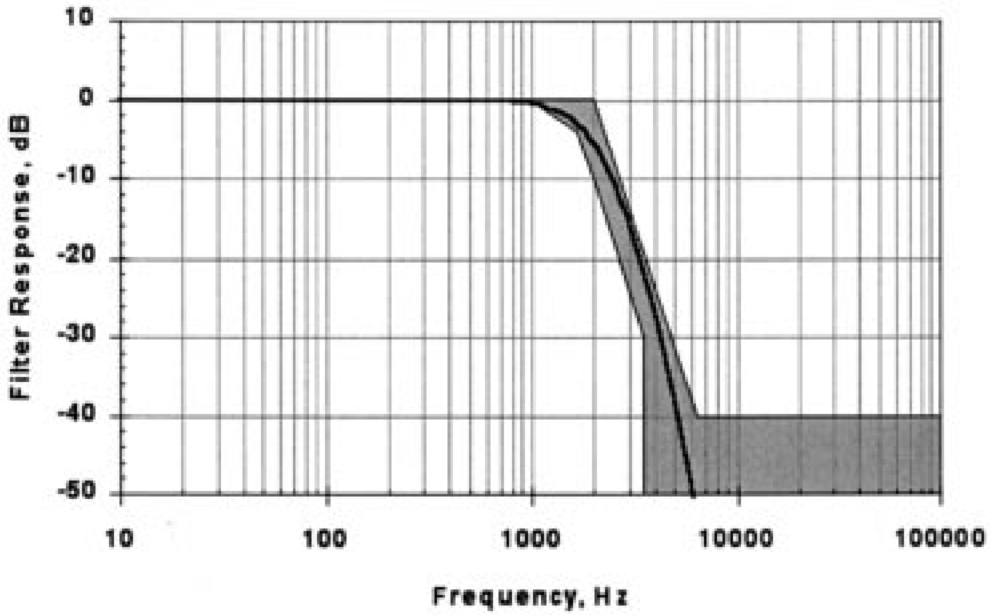


FIG. X4.1 Filter Response Function

```
// GLOBAL VARIABLES
const      nSamples;                  // Number of acquired data samples
var
// Data Acquisition Information
     SampleFrequency: integer;    // Data acquisition rate, samples/second
     nSamples          : integer;    // Number of acquired data samples
// Input Data which will be replaced with the filtered data
AccelData: array [0..nSamples] of real; // Array of acceleration data in g units

// Butterworth Filter
procedure Butterworth_Filter
// LOCAL VARIABLES
var   temp: array [0..nSamples] of real; // Intermediate results
     a,b:array [0..2] of real;    // Filter coefficients
   i,j: integer;                              // Counters
begin
   a [0] = 0.071893;
   a [1] = 0.143786;
   a [2] = 0.071893
   b [1] = 1.111586;
   b [2] =-0.399159;

// First pass in forward direction
temp:=AData;
for i:=2 to ScanSize-1 do
        AData [i]:=a [0]*temp [i] + a [1]*temp [i-1] + a [2]*temp [i-2]
                                    + b [1]*Adata [i-1]+ b [2]*Adata [i-2];

// Second pass in backward direction
   temp:=AData;
   for i:=ScanSize-3 downto 0 do
        AData [i]:=a [0]*temp [i] + a [1]*temp [i+1] +a [2]*temp [i+2]
                                    + b [1]*Adata [i+1]+b [2]*Adata [i+2];
end;
```

X5. WET/FROZEN CONDITIONING

X5.1 Specifiers may optionally request that laboratory testing include additional tests that simulate the performance of the playground surface under wet or frozen conditions, or both. Such additional testing is recommended if the installed surface will be used under such conditions. For consistency among laboratories it is recommended that wet/frozen testing be performed in accordance with the following procedures.

NOTE X5.1—This test simulates playground surfaces with optimal drainage. The performance of playground surfaces with poor drainage will be adversely affected by accumulation of water.

X5.2 *Apparatus* :

X5.2.1 Fig. X5.1 (A) is a schematic of the apparatus used to condition specimens for wet/frozen testing. Samples to be conditioned are supported on an 18 by 18-in. (460 by 460-mm) rack (for example, a metal grid, expanded metal sheet or perforated metal plate) that allows free drainage of water, mounted inside a water-retaining container. The height of the container should be such that there is a minimum of 8 in. of clear space above the top surface of the sample being tested. The container shall be lined with a flexible porous material (for example, cheese cloth) that will allow free drainage of water but will not allow surface material particles to pass through.

X5.2.2 Beneath the rack, a minimum of 8 in. of vertical space is required to collect water. Alternatively, another container of appropriate volume or a drainage system may be used, provided the method used does not allow water to accumulate above the support rack.

X5.3 *Sample Preparation* :

X5.3.1 *Loose-Fill Materials*—Pour specimen material into the container, distributing it evenly to the required depth.

X5.3.2 *Unitary Materials*—Place the surface specimen in the container. Seal the edges between the walls of the container and the top edges of the sample using waterproof adhesive tape or other appropriate means.

X5.4 *Calculation of Water Volume*—This conditioning procedure uses a quantity of water equivalent to a 6 in. depth across the exposed surface of the specimen. To determine the volume of water required, measure the area of exposed surface. For square rectangular specimens of unitary surfaces, this area will be the product of the length and width of the specimen. For loose-fill surfaces, the area will be product of the internal length and internal width of the square or rectangular container. With the surface

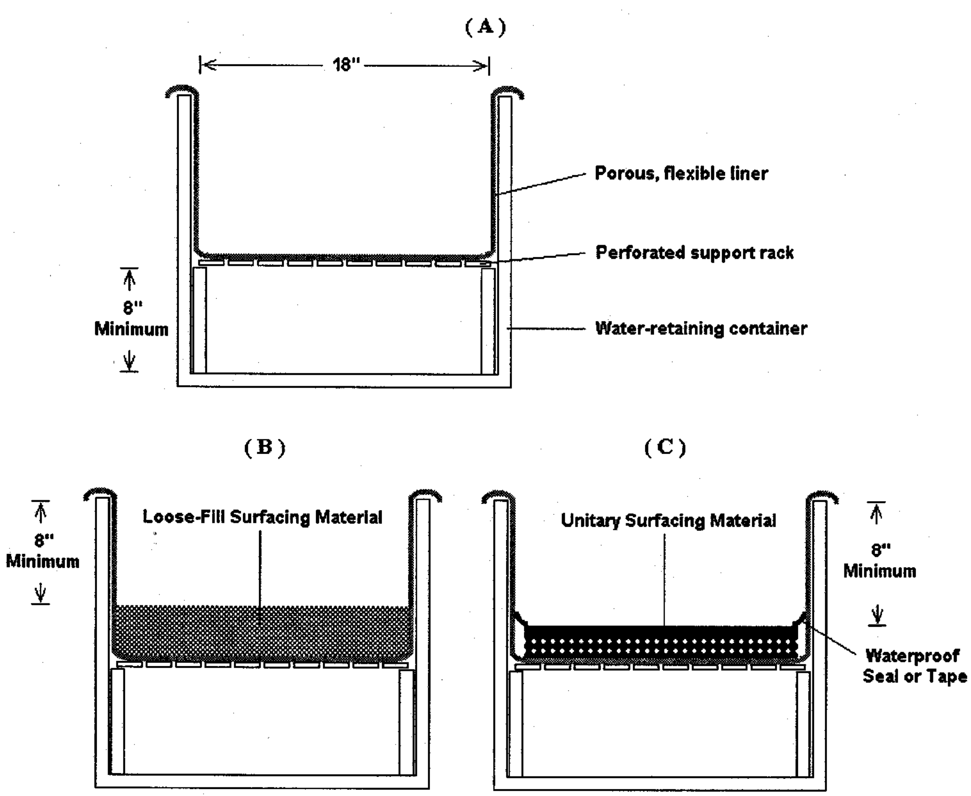


FIG. X5.1 Schematic of Apparatus for Wet/Frozen Conditioning area, SA, expressed in inches, the volume of water required is 6 × SA cubic inches, equivalent to 3.47 × SA fluid ounces or 0.217 × SA pounds of water.

X5.5 *Application of Water*:

X5.5.1 Spray or otherwise gradually distribute the required quantity of clean water uniformly over the surface of the specimen.

X5.5.2 Allow the water to drain for 15 min.

X5.5.3 Remove the sample from the container, allowing any water remaining on the surface of the specimen to drain off.

X5.5.4 For loose-fill surfacing materials, place the wet sample and liner into the test box and condition as specified in 14.2 and 14.3.

X5.6 *Wet Test* —Begin testing within 5 min of conditioning the surface.

X5.7 *Frozen Test* —If the specimen is to be tested frozen, condition the sample in a freezer at a temperature of 15°F (-10°C) for a minimum of 24 h before testing. Begin testing within 5 min of removing the sample from the conditioning chamber. The temperature of the sample should not exceed 26°F (-3°C) during the test.