This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

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An American National Standard

Standard Specification for Impact Attenuation of Surfacing Materials Within the Use Zone of Playground Equipment[1]

This standard is issued under the fixed designation F1292; 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

Surveys 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 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 in the use zone of playground equipment can reduce the risk of fall-related injury. In particular, it is believed that the 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 means of determining impact attenuation performance using a test method that simulates the impact of a child's head with the surface. The test method quantifies impact in terms of *g*-max and Head Injury Criterion (HIC) scores. *G*-max is the 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 of comparing and specifying the impact attenuation of playground surfaces. Its use will give designers, manufacturers, installers, prospective purchasers, owners, and operators of playgrounds a means of objectively assessing the performance of surfacing materials under and around playground equipment and hence of evaluating the associated injury risk.

1. Scope

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

1.2 This specification is specific to surfacing used in conjunction with playground equipment, such as that described in Specifications F1148, F1487, F1918, F1951, and F2075.

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 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 have the potential to 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

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

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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 surfacing materials with the criterion of this specification and are specific to the ambient conditions under which the test was performed.

1.9 The impact attenuation specification and test methods established in this specification are specific to the risk of 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 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 address other factors that 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.

1.11 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

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 requirements prior to use.*

1.13 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

F355 Test Method for Impact Attenuation of Playing Surface Systems, Other Protective Sport Systems, and Materials Used for Athletics, Recreation and Play

F429 Test Method for Shock-Attenuation Characteristics of Protective Headgear for Football

F1148 Consumer Safety Performance Specification for Home Playground Equipment

F1487 Consumer Safety Performance Specification for Playground Equipment for Public Use

F1918 Safety Performance Specification for Soft Contained Play Equipment

F1951 Specification for Determination of Accessibility of Surface Systems Under and Around Playground Equipment

F2075 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 Related to Playground Installations:*

3.1.1 *critical fall height (CFH)*—a measure of the impact attenuation performance of 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.

3.1.2 *designated play surface*—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 horizontal.

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

3.1.3.1 *Discussion*—Fall heights for specific types of play structure are defined in Specifications F1148, F1487, and F1918.

3.1.4 *playground equipment*—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 *playground surface*—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 *play structure*—a free-standing structure with one or more components and their supporting members.

3.1.7 *public use playground equipment*—a play structure anchored to the ground or not intended to be moved, for use in play areas of schools, parks, child-care facilities, institutions,

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

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

multiple-family dwellings, private resorts and recreation developments, restaurants, and other areas of public use.

3.1.8 *surfacing materials*—materials used to cover the surface of the playground use zone.

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

3.1.8.2 *aggregate surface*—a loose fill surface in which the compliant top layer is made of particulate 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, moulded foam, moulded rubber mats.

3.1.9 *use zone*—the 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 from or exiting the equipment.

3.1.10 *specifier*—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 m s^{-2} (ft 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*—common notation for accelerations expressed in units of *standard gravity*, where 1 g = 1 standard 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 that, through localized deformation or displacement, absorbs the energy of an impact in a way that reduces the magnitudes of peak impact force and peak acceleration.

3.2.9 *impact test*—a procedure in which the impact attenuation of a playground surface 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 impact tests used to define the impact attenuation of a playground surface or surfacing materials.

3.2.10 *impact test site*—point on the surface of an installed playground surface that 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 is used to verify proper functioning of the impact test equipment.

3.2.17 *reference temperature*—a specification of the temperature conditioning of a surfacing materials on which an impact test is performed.

3.2.18 *sample test point*—point on the surface of a sample selected as the target of an impact test.

3.2.19 *standard gravity*—the nominal value of the acceleration due to gravity at sea level having an international standard value of exactly 9.806 65 m s^{-2} (approximately 32.174 ft s^{-2}).

3.2.19.1 *Discussion*—Accelerations may be expressed in units of standard gravity.

3.2.20 *theoretical drop height*—the drop height (h) that, under standard conditions, would result 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 missile and that the 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 will be less than the actual drop height, due to the effects of friction in the guidance mechanism.

3.3 *Definitions of Terms Related to the Measurement of Acceleration:*

3.3.1 *accelerometer*—a transducer for measuring acceleration.

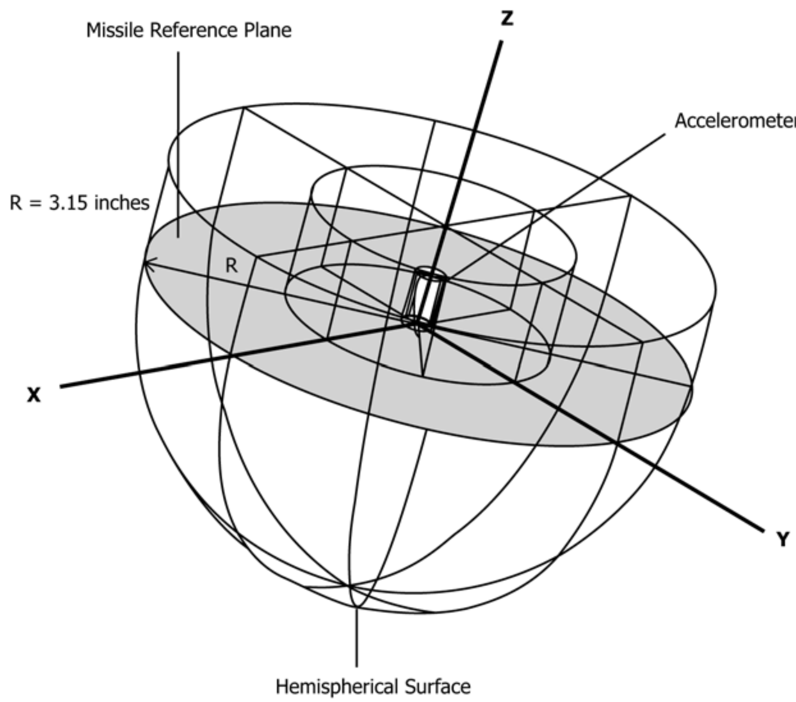


FIG. 1 Missile Reference Plane and Axes

3.3.1.1 *transducer*—the first device in data channel, used to convert a physical quantity to be measured into a second quantity (such as an electrical voltage) which can be processed by the remainder of the channel.

3.3.1.2 *triaxial accelerometer*—a transducer or combination of transducers used for measuring the three vector components of acceleration in three dimensions, relative to 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 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 *Surface Performance Parameters*—The average *g*-max and average Head Injury Criterion (HIC) scores calculated from the last two of a series of three impact tests shall be used as measures of surface performance.

4.2 *Performance Criterion*—The performance criterion used to determine conformance with the requirements of this specification 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 of surfaces 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 F1148, F1487, or F1918 for play structures of specific types or 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 playground surface shall have been determined in accordance with the requirements of Section 13 of this specification, using reference temperatures of 25, 72, and 120°F (-6, 23, and 49°C), surface performance parameters, and the 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 design, materials, components, thickness, and manufacture as the installed playground surface.

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

4.4 *Performance of Installed Playground Surfaces:*

4.4.1 When an installed playground surface is tested in accordance with the requirements of Sections 16 – 19 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 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.

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, bring the surface into compliance with the requirements of this specification or the play structure shall not be permitted to be used until the playground surface complies.

4.4.3 *More Stringent Specifications*—The specifier is permitted to 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 *Critical Fall Height Test*—The impact attenuation of a playground surface or surfacing materials is measured using an impact test in which a missile is dropped onto the playground surface from a predetermined drop height. The acceleration of the missile during the 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 each reference temperature and drop height, scores from the second and third of three consecutive drops are averaged to give average scores. No modification of the playground surface sample shall be permitted between the three impacts.

5.2 The critical fall height of surfacing materials is determined by impact testing representative samples at a range of drop heights. The surfacing material is tested at temperatures of 25, 72, and 120°F (-6, 23, and 49°C). The critical fall height is determined as the highest theoretical drop height from which the surface performance parameters meet the performance criterion.

5.3 *Installed Surface Performance Test*—To test whether a playground surface installed within the use zone of a play structure meets the performance criterion of this specification, an impact test is performed in accordance with Sections 16 – 19 using a theoretical drop height equal to or greater than the equipment fall height of the structure. The test is performed under ambient conditions and the results reported.

6. Significance and Use

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

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

6.3 This specification is to be used 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 terms of drop height. Consequently, the specification is appropriately used to determine the actual impact attenuation performance of installed playground surfaces 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 is suitable to estimate the relative risk of a severe head injury due to a fall.

7. Equipment Operator Qualifications

7.1 The equipment operator shall be trained in the proper operation of the test equipment by a competent agency.

8. Test Apparatus

8.1 *Temperature 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 It is possible that the missile will 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 It is acceptable to rigidly attach a supporting assembly (for example, a handle or ball arm) 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, it is acceptable for the missile to 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 sensing 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, it is acceptable to use a single uniaxial accelerometer. 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 20 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 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. It is acceptable for an analog filter to 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, it is acceptable to use a single digitizer with a minimum sampling rate of 60.0 kHz 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*—All acceleration data channels, including signal filtering, shall conform to the requirements of a Channel Frequency Class 1000 data channel, as specified by SAE Recommended Practice J211, with the additional requirement of increased accuracy in the range from 1 to 1000 Hz, as defined in Annex A1.

8.4 *Drop 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. It is acceptable for such indirect means to 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 shall be permitted to 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 recording impact velocity with a resolution of 0.1 ft s^{-1} (0.03 m s^{-1}) and an accuracy of ±1 % of the true value.

NOTE 6—Since 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 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, one method to verify conformance with the requirement of this section is 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, one method to verify conformance with the requirement of this section is 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, h, shall be calculated from a measurement of impact velocity, v, using the formula $h = v^2 / 2g$, where g is the acceleration due to gravity.

9.1.2 Alternatively, in a free-fall test, one method to calculate the theoretical drop height, h, s is by a measurement of fall time, t, using the formula $h = ½\ g\ t^2$.

9.1.3 *Resultant Acceleration*—If a triaxial accelerometer is used, the resultant acceleration at each point in the time history of the impact shall be calculated as $A_R = \sqrt{A_x^2 + A_y^2 + A_z^2}$ where A_R is the resultant acceleration and A_x, A_y, and A_z are the accelerations recorded by accelerometers aligned with the *X*, *Y*, and *Z* missile axes.

9.2 *g-max*—The *g*-max of score is determined as the maximum value of acceleration recorded during an impact. If a triaxial accelerometer is used, *g*-max shall be determined as the maximum value of the resultant acceleration.

9.3 *Average g-max*—Determine the average *g*-max score by averaging the *g*-max score of the 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 onset of impact and at the instant of maximum acceleration shall be calculated. For the purposes of this calculation, the onset of impact shall be the data sample at which the resultant acceleration first meets or exceeds a threshold value of 5 g. The angle shall be calculated from the component accelerations. The cosine of the missile angle shall be calculated as:

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

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 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:

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

where:

a_t = acceleration at time *t*, defined as the resultant acceleration if a triaxial accelerometer is used.

9.5.3 For each time interval (t_1, t_2) calculate and record the trial HIC interval, $t_2 - t_1$.

9.5.4 The HIC score for an impact is determined as the maximum value of all the Trial HIC(t_1, *t*2) scores.

9.5.5 The numerical procedures used to calculate HIC shall provide results that are within ±1 % of the true value.

NOTE 7—A computer algorithm for calculating HIC is provided in Appendix X3.

10. Instrumentation Check

10.1 Check the proper operation of the test apparatus by performing a series of impact tests on a reference MEP pad.

10.2 The reference MEP pad shall 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 manufacturer's specified tolerance or 5 % of the nominal *g*-max score, the equipment does not conform to the requirements of this specification and shall not be used.

11. Impact Test Procedure

11.1 *Data Recording:*

11.1.1 Determine the test point of the conditioned sample.

11.1.1.1 If the sample has nonuniform properties (due to uneven thickness, seams, fasteners, or other factors) the sample test point shall be 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 flat, rigid anvil or floor beneath the impact test system.

11.1.3 Align the sample test point with the point of 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 and 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 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.

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

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

11.2.1.3 The acceleration waveform needs to 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 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 discarded.

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

11.3.3 If a free-fall impact test is used, calculate the missile angle at the onset of impact and at the instant of maximum resultant acceleration, in accordance with 9.4. If the calculated missile angle at either point exceeds 10° (that is, the cosine of the missile angle is less than 0.966), data from the trial shall be discarded.

CRITICAL FALL HEIGHT TEST (Laboratory Test)

12. Temperature Conditioning

12.1 The critical fall height of a playground surface or surfacing material shall be determined under laboratory conditions by performing a series of impact tests 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 minimum of 8 h. Testing of a sample must be started within 1 min and all tests must be completed within 7 min of the sample's removal from the conditioning environment. If the testing is not started or completed within the specified interval, the sample must 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 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. During testing at the reference temperature of 25°F (-6°C), the 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 period of 8 h and the test continued.

12.3.2 During testing at the reference temperature of 120°F (49°C), the temperature of the specimen must not fall below 115°F (46°C). If the temperature falls below 115°F (46°C) the specimen must be reconditioned to the reference temperature for a period of 8 h and the test continued.

13. Unitary Surfaces

13.1 *Number of Specimens*—At least nine specimens of a specific unitary surfacing material shall be submitted for testing, with each sample having minimum surface dimensions of 18 by 18 in. (460 by 460 mm). Each specimen shall represent the compliant components of the playground surface as it is intended to be used in a playground installation, including seams, partitions, corners, fasteners, anchors, or other characteristics that have the potential to result in less than optimal impact characteristics. If a surfacing material is intended for installation in combination with other materials such as wear mats, this combination must be tested as 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 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 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 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.

13.4 *Critical Fall Height Test*—Determine critical fall 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. It is acceptable to use the same material for testing at more than one drop height or temperature provided that it is restored to its 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. No modification of the playground surface sample shall be permitted between the three impacts. 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 shall 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 shall be permitted to 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 shall 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. No modification of the playground surface shall be permitted between the three impacts. 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. No modification of the playground surface shall be permitted between the three impacts. 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

20.1 All reports shall include the following information:

20.1.1 *Requesting Agency Information*—The name, address, and telephone number of the person or entity requesting the test.

20.1.2 *Testing Agency Information:*

20.1.2.1 The name, address, and telephone number of the testing agency.

20.1.2.2 The name and signature of the test operator.

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 equipment type and manufacturer.

20.1.3.2 Date of most recent accelerometer calibration certificate.

20.1.4 *Test Results*—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 temperature, reference temperature, and surface temperature measured after the final drop in each series.

20.1.4.3 The drop 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 have the potential to 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 shall only be permitted to be described as "Engineered Wood Fiber" if they conform to the requirements of Specification F2075 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*—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 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 each use zone tested.

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

NOTE 15—Appropriately annotated photographs are an acceptable means of describing play structures and test sites.

20.3.2.3 The depth of any loose-fill surfaces or the 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*—The preparation of a summary report is acceptable 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) 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 any use zone.

20.5.3 The test outcome (see 20.3.4).

20.5.4 For each use zone that did 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).

21. Precision 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 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.

21.4 An interlaboratory study was conducted in 1996-97. Seven laboratories performed pairs of tests on eight surface materials using Test Method F355, 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 and HIC values were determined. From the results of these tests, precision statistics were calculated in compliance with Practice E691. The samples used in this test were actual playground surfacing materials, including loose-fill surfacing

TABLE 1 Precision Statistics for g-max[A]

Material	Average	Repeatability Standard Deviation (Sr)	Reproducibility Standard Deviation (SR)	Repeatability Limit (r)	Reproducibility Limit (R)
D	53.4	4.8	8.6	13.5	24.1
E	57.2	10.1	11.2	28.2	31.4
H	104.1	3.9	7.4	10.8	22.6
A	121.5	2.4	7.9	6.6	22.0
C	146.4	3.8	8.9	10.5	24.8
G	186.9	10.5	13.1	29.3	36.7
B	207.5	5.3	15.5	14.7	43.3
F	240.7	7.1	16.1	19.8	45.1

[A] Average of Test Method F355 Procedure C and Free-Fall Test Method of Specification F1292.

TABLE 2 Precision Statistics for HIC[A]

Material	Average	Repeatability Standard Deviation (Sr)	Reproducibility Standard Deviation (SR)	Repeatability Limit (r)	Reproducibility Limit (R)
D	144.7	19.1	33.1	53.4	92.7
E	166.0	46.6	63.6	130.4	178.1
H	592.7	24.3	95.3	67.9	266.9
A	592.9	80.6	123.7	225.7	346.2
C	749.0	28.8	107.2	80.7	300.0
G	1 212.0	59.9	185.9	167.6	520.5
B	1 381.5	110.1	191.4	308.1	535.9
F	1 849.0	156.6	293.5	438.5	821.7

[A] Average of Test Method F355 Procedure C and Free-Fall Test Method of Specification F1292.

materials, rather than reference surfaces. Therefore, the reported precision includes variability due to the samples as well as variability due to the test method itself.

NOTE 16—Based on preliminary interlaboratory testing performed during the development of this specification, the precision of the test method in this specification is estimated to be ±5 % for *g*-max and ±10 % for 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. A900 HIC indicates an HIC range of 810 to 990.) Users of this specification should be aware of this fact when establishing critical fall height.

22. Keywords

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

ANNEX

(Mandatory Information)

A1. INSTRUMENTATION VERIFICATION PROCEDURES

A1.1 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 resolution, accuracy, precision, and calibration. Differences in instrumentation among laboratories have been identified as a major cause of poor reproducibility. This annex describes procedures for verifying that instrumentation conforms to the requirements of this specification.

A1.2 It is a requirement of this specification that testing agencies retain documentation demonstrating that the frequency response, accuracy, and resolution of the instrumentation conform to the requirements of this specification. Options include documentation in the form of calibration certificates or metrology laboratory reports.

A1.3 *Accelerometer Data Channel Verification—End-to-End Calibration*—The frequency response of accelerometers, signal conditioners, data acquisition devices, and so forth, can be determined from calibration certificates. However, the frequency response of the combination of these devices is unknown, because the 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 data channel be calibrated using an end-to-end calibration procedure of the whole data acquisition and processing system. It is recommended that this procedure be performed by an accredited metrology laboratory. To conform to the requirements of this specification, the frequency response of the system needs to fall within the limits shown in Table A1.1 and Fig. A1.1.

A1.4 *Accelerometer Data Channel—Minimum Verification Requirements*—If an end-to-end calibration is not performed, testing agencies shall, as a minimum, determine that their test apparatus conforms to the low-frequency response and accuracy requirements of this specification by performing the following tests:

A1.4.1 *Accelerometer Low-Frequency Response (Time Constant) Test*—The purpose of this test is to determine that the accelerometer, signal conditioner, and analog filter have a

TABLE A1.1 Limits of Modified CFC 1000 Data Channel Dynamic Accuracy

Frequency, Hz	Dynamic Accuracy	
	dB, Min	dB, Max
0.1	-0.1	0.1
1	-0.1	0.1
100	-0.1	0.1
1 000	-0.2	0.1
1 650	-4	0.1
2 000	-10	0.1
3 500	-30	-19.4
5 000		-31.7
10 000		-55.7

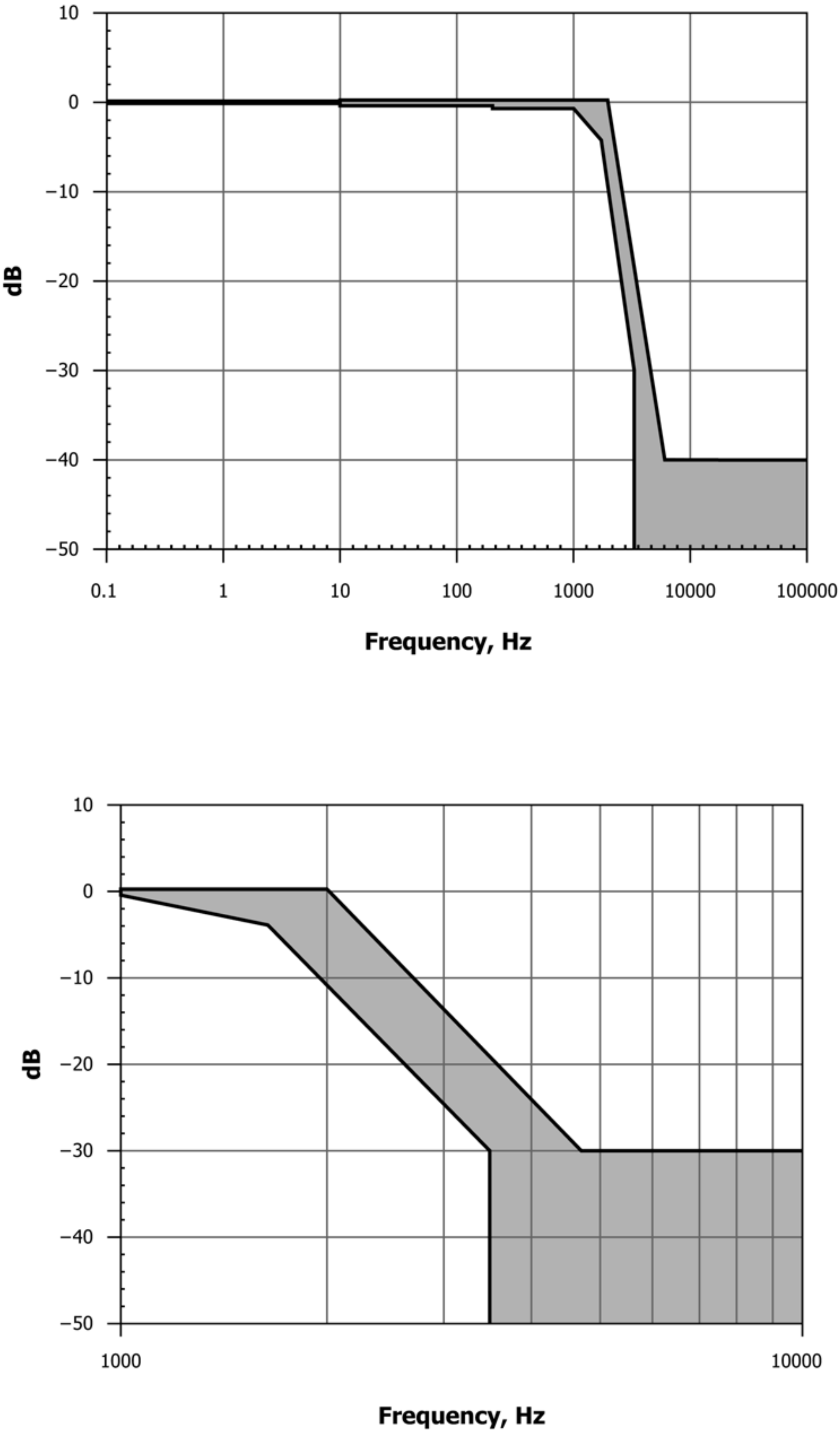


FIG. A1.1 CFC 1000 Data Channel Dynamic Accuracy

sufficient response at low frequencies. It is acceptable to specify the required low-frequency response (8.3.14.1) in terms of minimum time constant of 2.0 s. Appendix X2.2 describes the effects of an improper time constant on accelerometer signals. To measure the time constant, perform the following procedures:

A1.4.1.1 Connect the accelerometer signal normally input to the data acquisition system to a recording device (for example, a digital oscilloscope or computer data acquisition system). This signal needs to represent the resultant output of the accelerometer signal conditioner and analog filter, as shown in Fig. A1.2. The data recording device needs to be capable of recording across the whole output range of the signal conditioner with a resolution of ±1 mV, for a minimum of 10 s at a minimum sample rate of 100 s^{-1}. The accelerometer shall be fixed and not subject to motion or vibration while measurements are made.

A1.4.1.2 Turn on the signal conditioner, recording device and other necessary electronics, allowing them to warm up, as recommended by the manufacturers.

A1.4.1.3 Prepare the recording device to receive the signal. Turn off the signal conditioner. After 5 ± 1 s turn on the signal conditioner and record the output for a minimum of 10 s. It is possible that a longer recording time will be required to obtain a satisfactory recording.

A1.4.1.4 If the accelerometer, signal conditioner, or analog filter have a finite low-frequency response, the recorded signal will show an exponential decay towards zero as the signal "settles" (Fig. A1.3).

A1.4.1.5 Select two points in the recorded data that fall on the exponential curve and that are separated by a minimum of 2 s and a minimum of one tenth the output range of the signal conditioner (for example, 1.0 V for a ±5 .0-V output range). Record the time and voltage at each of these two points as (T_0,V_0) and (T_1,V_1).

A1.4.1.6 Determine the time constant using the following equation:

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

For the example shown in 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 measured time constant is less than 2.0 s, the equipment does not meet the frequency response requirements of this specification.

A1.4.2 *Verification of g-max and HIC Calculations Using Known Inputs*—This test determines whether the data acquisition system, digital filter, and calculation procedures of a test system conform to the requirements of this specification. The test requires the accelerometer output to be replaced by a synthesized pulse of predetermined shape, width, and amplitude (Fig. A1.4). Options for generating a pulse include a programmable signal generator, a computer-linked digital to analog converter, or other appropriate means providing the output has a range equivalent to that of the signal conditioner output, a minimum resolution of ±1 mV, and the capability of refreshing the generated signal at a minimum rate of 50 kHz.

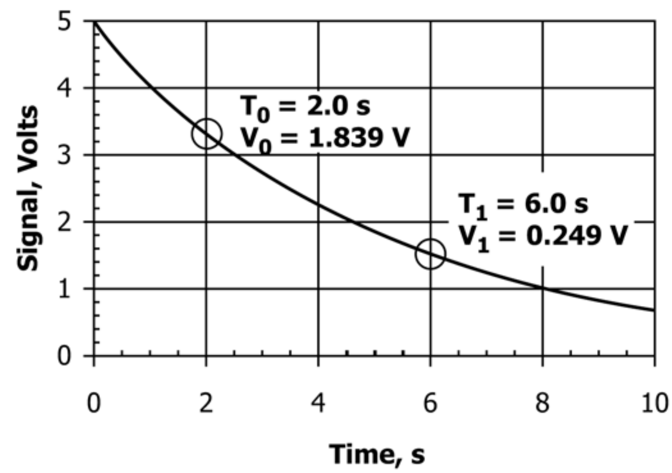


FIG. A1.3 Example Recording from Time Constant Test

A1.4.2.1 The pulse to be generated is a cosine wave of the form:

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

where:

V = the output voltage,
A = the pulse height (amplitude),
t = time, and
T = target pulse width.

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

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

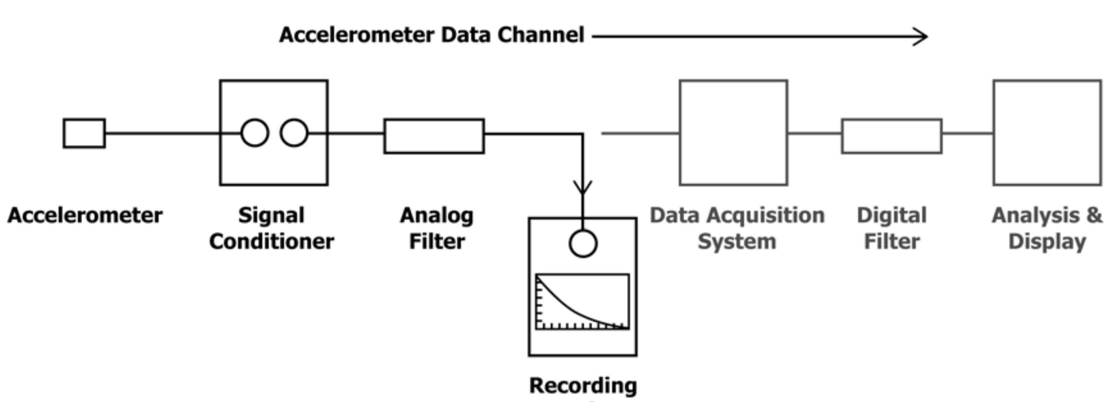


FIG. A1.2 Schematic of the Time Constant Test

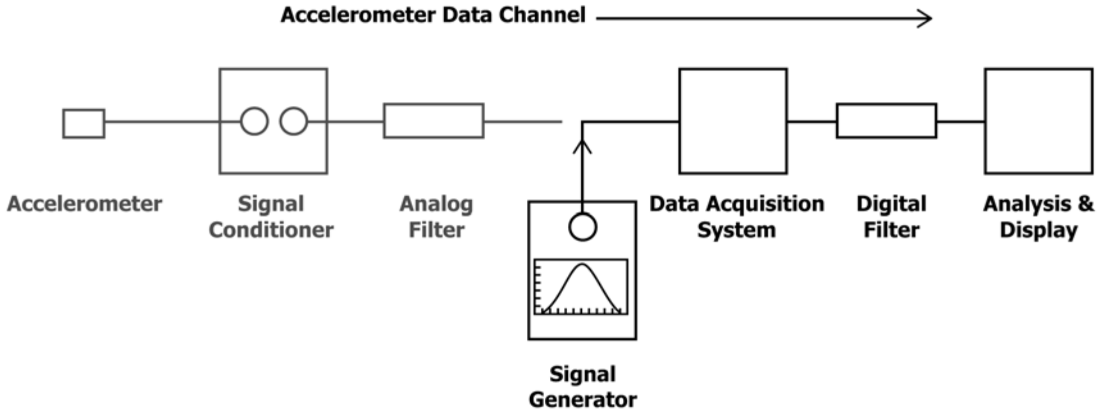


FIG. A1.4 Schematic of the Calculation Verification Test

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 scores to be calculated directly from first principles.

A1.4.2.2 To perform the 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 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.

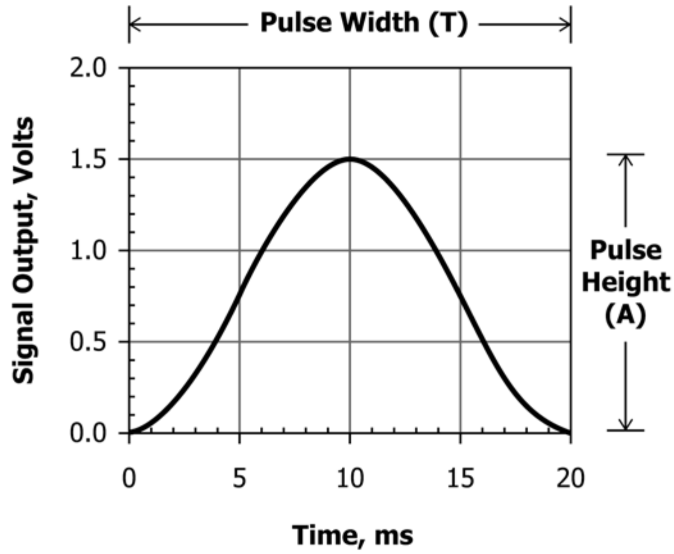


FIG. A1.5 Example of a Synthesized Impact Waveform

TABLE A1.2 Input Waveform Characteristics and Target Scores

Waveform		Target Scores		
Pulse Width (ms)	Reference *g*-max	*g*-max (g)	HIC	HIC Interval (ms)
10.0	100	100	302.9	5.08
10.0	150	150	834.8	5.08
10.0	200	200	1 713.7	5.08
20.0	100	100	605.9	10.15
20.0	150	150	1 669.6	10.15
20.0	200	200	3 427.4	10.15

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.[6,7] 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 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.

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.

[6] National Highway Traffic Safety Administration (NHTSA), Department of Transportation., 1997, FMVSS201, Head Impact Protection, 49 CFR 571.201.

[7] 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.

At 38 %, the risk of a moderate injury at this HIC level 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 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 in the 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 specified by this specification produces HIC scores that are somewhat higher than those generated by a cadaver or a headform with lifelike properties.[8] HIC scores determined in accordance with this specification will overestimate the probability and severity of head injury if they are interpreted 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 absence of specific data for the head injury tolerance of children falling from playground equipment and by the fact that the limiting HIC score of 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 probability of experiencing a 1000 HIC impact with no injury is very low (less than 1 %).

[8] 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.

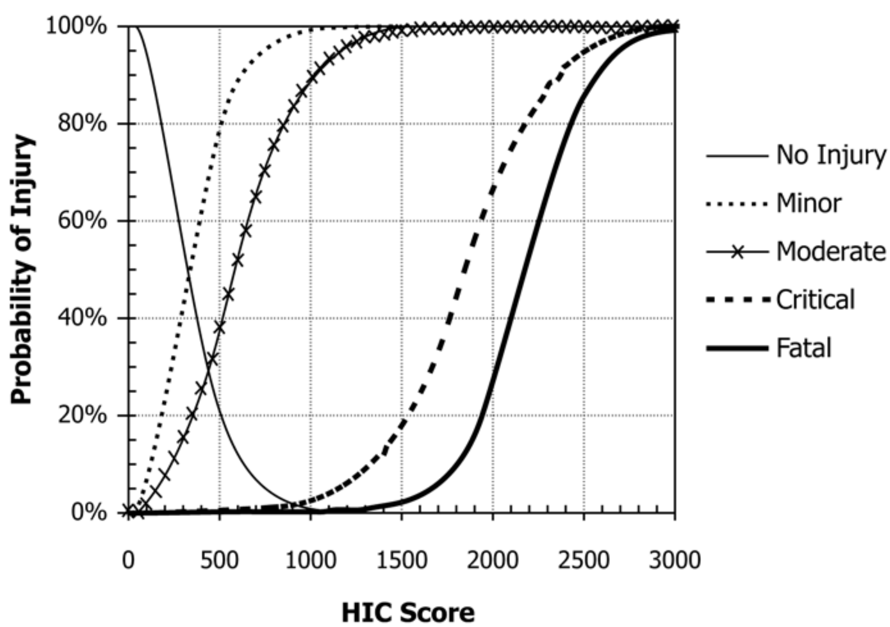
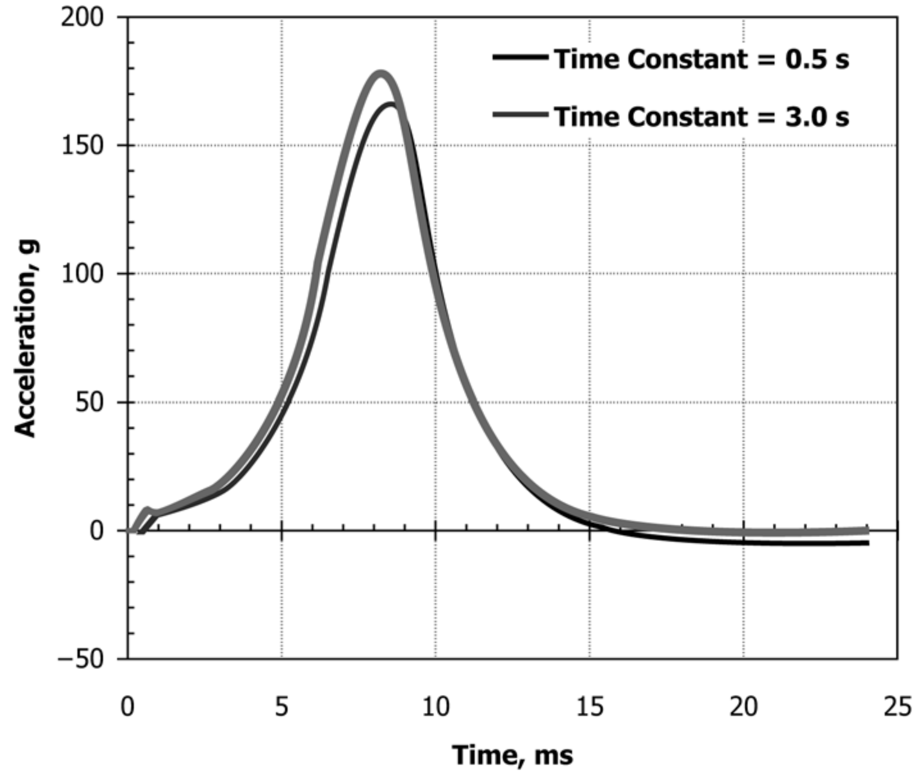


FIG. X1.1 Probability of Specific Head Injury Level for a Given HIC Score



NOTE 1—Acceleration-time curves from two accelerometers mounted on the same missile during an impact. The accelerometer with the short (0.5 s) time constant overshoots the baseline by more than 5 g after the impact and underestimates the *g*-max score by 11.5 g (6 %), compared to the accelerometer with an appropriate (3 s) time constant.

FIG. X1.2 Effects of Accelerometer Time Constant

X2. EFFECTS OF MEASUREMENT ERRORS

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

X2.1.1 The sensitivity and error estimates were calculated using a model of 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 flag width measurement or the transit time (Δt) causes an error more than 4 % in the critical fall height estimate. In 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 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*:

X2.2.1 Differences in accelerometer time constant of have been identified as a major source of interlaboratory variability.

The time constant determines the low frequency response of the accelerometer to mechanical inputs, with longer time constants indicating better low frequency response. A very short time constant (~0 s) results in ac response and the accelerometer is insensitive to constant or slowly changing inputs. A very long time constant (>10 s) indicates near-DC response and the accelerometer is sensitive to low frequencies, including 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 2 s or greater and appropriate signal conditioning will generally meet this requirement. Typically, accelerometers are manufactured for the purposes of measuring vibration, and have shorter time constants (<1 s) than the minimum required for the impact acceleration measurements required by this specification. Many accelerometers must be modified by the manufacturer in order to be conform to the requirements of this specification. As shown in Fig. X1.1, an accelerometer with a time constant that is too low produces a characteristic signal, tending to "overshoot" the zero baseline after the impact. The lack of appropriate low-frequency response also results in the underestimation of *g*-max and HIC scores.

X2.3 *Interval Between Impacts*—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.

X2.4 *Impact Velocity*—Variations in the impact velocity brought about by changes in drop height or friction in the drop guidance mechanism.

X2.5 *Missiles*—Use of missiles other than those referenced in this specification may cause substantial variations in results. Missile with masses greater than the specified range will result in lower *g*-max and HIC scores.

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		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	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		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	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.

X3. COMPUTER ALGORITHM FOR CALCULATING HIC

X3.1 The following example pseudo-code computes the HIC score of an acceleration pulse to within 0.5 % of theoretical values. For clarity, the program has been written as a 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 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 sample rate of 20 000 Hz.

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. ALGORITHM FOR DIGITAL BUTTERWORTH FILTER

X4.1 This specification specifies the use of a Butterworth Digital Filter for smoothing acceleration data. Also, the response spectrum of modified Channel Frequency Class (CFC) 1000 acceleration data channels is defined in terms of the Butterworth digital response. The CFC 1000 data channel requires a fourth order (4-pole) Butterworth filter with a -3dB corner frequency of 1686.1 Hz. Instead of implementing a fourth order filter, it is recommended that the data be filtered twice, once forwards and once backwards using second order (2-pole) filter twice with a -3dB corner frequency of 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:

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

where:

F_t = filtered acceleration datum at time t,
A_t = input acceleration datum at time t,
Δ = sample interval, and
a_i *and* b_j = filter coefficients

The correct filter coefficients vary with the data sampling rate. Table X4.1 shows coefficients for a sample rate of 20 000 Hz. Fig. 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 pseudocode 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

```
// 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;
```

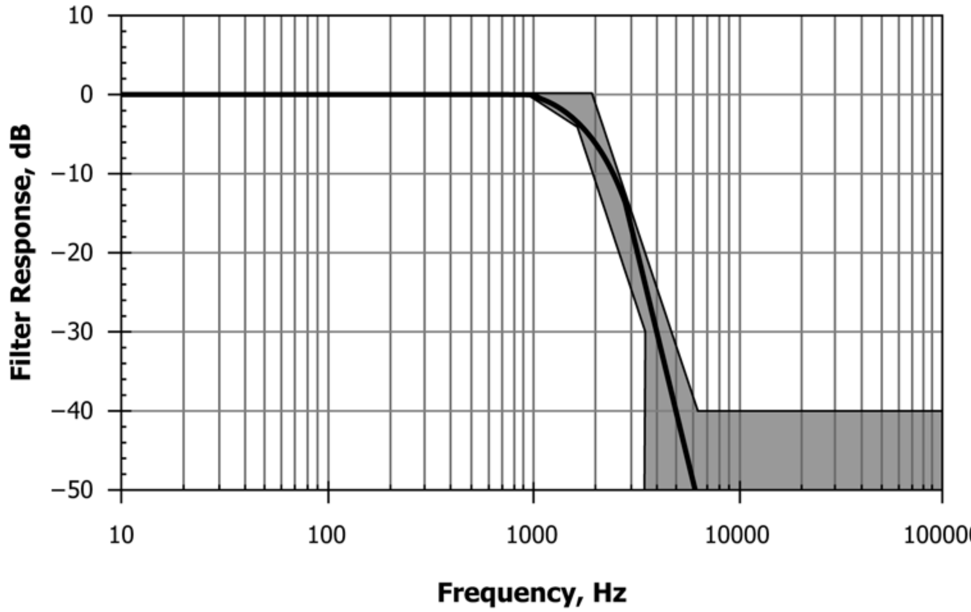


FIG. X4.1 Filter Response Function

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 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.

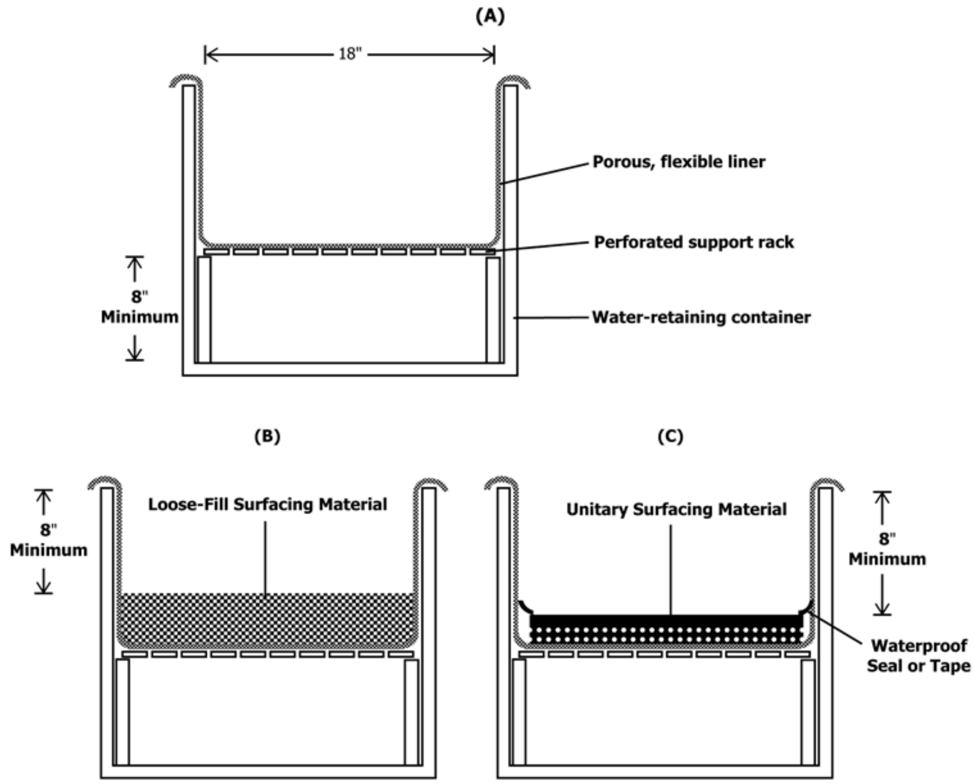


FIG. X5.1 Schematic of Apparatus for Wet/Frozen Conditioning

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.

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