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.

Designation: F3582 – 22

Standard Test Method for Exoskeleton Use: Gaps[1]

This standard is issued under the fixed designation F3582; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 *Purpose:*

1.1.1 The purpose of this test method, as a part of a suite of exoskeleton use test methods, is to quantitatively evaluate an exoskeleton's (see Terminology F3323) performance or safety, or both, of usage by the exoskeleton user (see 1.4) for gaps.

1.1.2 Exoskeletons shall possess a certain set of allowable exoskeleton user movement capabilities, including user-motion adaptability, to suit operations such as: industrial/occupational, military, response, medical, or recreational. Environments in these typical sectors often pose constraints to exoskeleton user movement to various degrees. Being able to step over gaps, as intended by the user or test requestor, while using an exoskeleton is essential for exoskeleton deployment for a variety of tasks. This test method specifies test setup, procedure, and recording to standardize this gaps task for testing exoskeleton user movement.

1.1.3 Exoskeletons need to function as intended, regardless of types of tasks and terrain complexities (for example, carpet, metal, masonry, rock, wood). Required movement capabilities may include, for example: walking, running, crawling, climbing; traversing gaps, stairs, slopes, various types of floor surfaces or terrains, or confined spaces, or combinations thereof. Standard test methods are required to evaluate whether or not exoskeletons meet these requirements.

1.1.4 ASTM Subcommittee F48.03 develops and maintains international standards for task performance and environmental considerations that include but are not limited to, standards for safety, quality, and efficiency. This subcommittee aims to develop standards for any exoskeleton application as exemplified as in 1.1.2. The F48.03 test suite consists of a set of test methods for evaluating exoskeleton capability requirements. This gaps test method is a part of the test suite. The setup, procedure, and apparatuses associated with the test methods challenge specific exoskeleton capabilities in repeatable ways to facilitate comparison of different exoskeleton models or exoskeleton capabilities to tasks. Not all exoskeletons may have the capabilities needed to use this test method.

1.1.5 This test method tests for generic gaps-traversal exoskeleton capability, with straight paths and no test course curves, obstacles, or other complexities not described herein (see 4.6). This test method is considered the basis for exoskeleton gaps capability testing.

1.1.6 The test methods quantify elemental exoskeleton use capabilities necessary for sector applications listed in 1.1.2 and perhaps other applications. As such, users of this standard should use either the entire suite or a subset based on their particular requirements. Users are also allowed to weight particular test methods or particular metrics within a test method differently based on their specific requirements. The testing results should collectively represent an exoskeleton's overall safety or performance, or both, as required for the task. These performance data can be used: to guide procurement specifications, for acceptance testing, and for training to use exoskeletons intended for specified applications.

NOTE 1—Additional test methods within the suite are anticipated to be developed to address additional exoskeleton capability requirements, including newly identified requirements and even for new application domains.

1.2 *Exoskeleton*—The exoskeleton shall be used as intended by the manufacturer to perform the test described in this test method. If the exoskeleton is not designed for gaps traversing and the test requestor intends to use the exoskeleton to perform a gaps test (for example, for research, development of gaps-capable use by a manufacturer, gaps training as in military applications), appropriate manufacturer approvals should be sought prior to performing the test method.

1.3 *Performing Location*—This test method shall be performed in a testing laboratory or at a site that represents the place where the exoskeleton will be used.

1.4 *Units*—The values stated in SI units are to be regarded as the standard. The values given in parentheses are not precise mathematical conversions to inch-pound units. They are close approximate equivalents for the purpose of specifying material dimensions or quantities that are readily available to avoid excessive fabrication costs of test apparatuses while maintaining repeatability and reproducibility of the test method results. These values given in parentheses are provided for information only and are not considered standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the*

[1] This test method is under the jurisdiction of ASTM Committee F48 on Exoskeletons and Exosuits and is the direct responsibility of Subcommittee F48.03 on Task Performance and Environmental Considerations.

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responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.

1.6 *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:*[2]

F3323 Terminology for Exoskeletons and Exosuits

F3427 Practice for Documenting Environmental Conditions for Utilization with Exoskeleton Test Methods

F3443 Practice for Load Handling When Using an Exoskeleton

F3444/F3444M Practice for Training Exoskeleton Users

F3474 Practice for Establishing Exoskeleton Functional Ergonomic Parameters and Test Metrics

F3517 Practice for Movement Tests When Using an Exoskeleton

F3523 Test Method for Exoskeleton Use: Confined Space: Horizontal Movement

F3527 Guide for Assessing Risks Related to Implementation of Exoskeletons in Task-Specific Environments

F3528 Test Method for Exoskeleton Use: Gait

F3613 Practice for Recording the Exoskeleton Fit to the User

F3614 Practice for Recording the Exoskeleton User Information

2.2 *ISO Standards:*[3]

ISO 13482 Robots and robotic devices — Safety requirements for personal care robots

3. Terminology

3.1 General terminology for ASTM F48 standards is listed in Terminology F3323. Terminology specific to this standard are shown in this section.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *apparatus, n*—a structure, object, test component, or artifact thereof, found or placed in an environment and used for a test.

3.2.2 *gap, n*—break or hole in the ground surface.

3.2.3 *test suite, n*—designed collection of test methods that are used, collectively, to evaluate an exoskeleton's safety and/or performance.

4. Summary of Test Method

4.1 The task for this test method, exoskeleton-user traversing gap(s), is defined as the exoskeleton-user performing gap(s) traversal test including a number of repetitions as set by the test requestor. A test includes at least 5 repetitions to traverse one or more gaps that have preset, as per the test requestor, horizontal breaks or holes in the ground surface. See Fig. 1 for an illustration. Further, the test requestor can specify the statistical reliability and confidence levels of such a capability and, thus, dictate the number of successful task performance repetitions that are required. The tests are described as follows:

4.1.1 *Gaps Platform*—A raised, level surface on which the user steps across a set gap between gap platforms and onto another gap platform.

NOTE 2—The gap platform can be, for example, a path where a gap is within the path.

4.2 The test is described as follows:

4.2.1 This test can be used to assess aerobic function, endurance, gap traversal speed, or balance, or combinations thereof.

4.2.2 The test metrics can include, for example, the following:

4.2.2.1 Number of gaps traversed;

4.2.2.2 Distance (see Fig. 2 for gap axes labeling) of gaps traversed;

4.2.2.3 Change(s) in user (for example, heart rate, fatigue, stability, balance, toe drag, stumbles, near falls/falls) by a specified amount; and

4.2.2.4 Upon traversing the gap(s), the ability to turn around on the floor or gap platform and traverse the gap(s) in the opposite direction.

4.3 For all tests, the specified START point to the END point, and TURN point shall be defined by the test requestor prior to the test. This test method can be combined with other test methods, for example, Test Method F3528. The required apparatuses are described in Section 6.

4.4 For any gap test, return from the end marker past the start marker may commence as part of the test or the user may begin each repetition from the start-to-end markers as set by the test requestor.

4.5 The gap test can include one or more gaps, gap-to-gap spacing, and gap distances as requested by the test requestor.

NOTE 3—For the following procedures, the standard gap apparatus is described. The test requestor may instead use the actual gap(s) in situ to the application.

4.6 A full gap test is defined as: the user begins by standing behind a start location, *(1)* walks across the platform to the opposite side, *(2)* traverses the gap(s), *(3)* walks across the platform past the end marker, *(4)* the user turns around 180°, and *(5)* repeats steps 1, 2, and 3, and past the start marker.

4.6.1 A phased gap test can include one or more phases of the full gap test as follows, beginning with the user standing behind a start/end location:

4.6.1.1 *Phase 1*—The user stands behind the start line on the platform of the gap apparatus,

4.6.1.2 *Phase 2*—The user traverses the gap,

4.6.1.3 *Phase 2a*—If more platforms and gaps are used, the user traverses multiple gaps,

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

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

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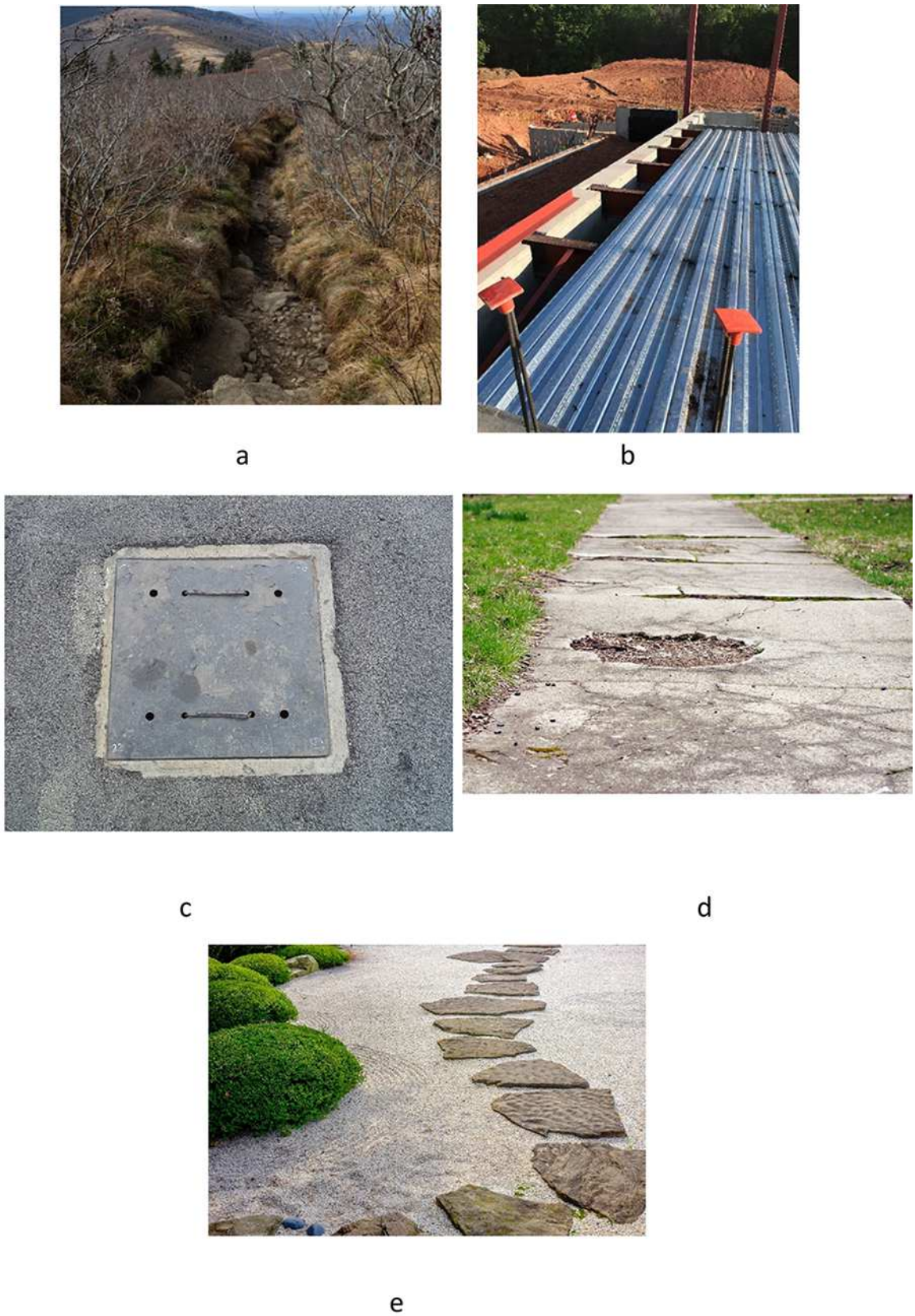

FIG. 1 Examples of Gaps to Step Over: (a) Natural Gaps, (b) Slab Forms in Construction, (c) Safety Hole Cover, (d) Sidewalk Cracks, and (e) Stone Path

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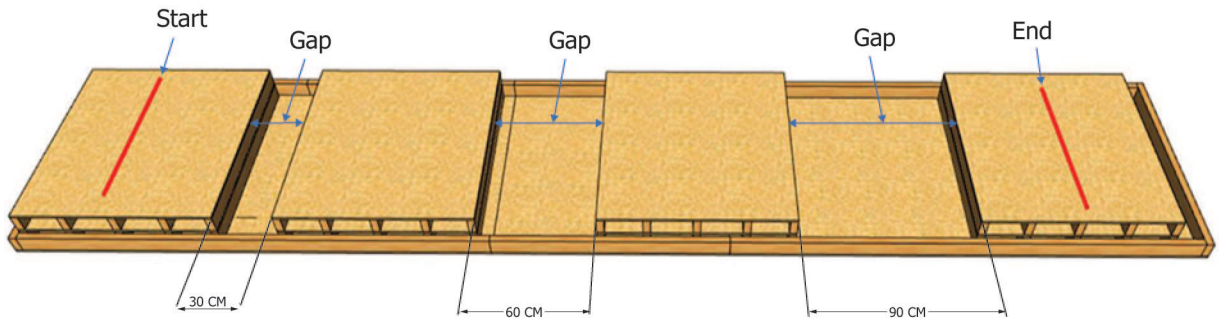

NOTE 1—The test course may include one or more gaps.

FIG. 2 Example of a Gaps Test Course Layout

4.6.1.4 *Phase 3*—The user walks across the end line on the platform,

4.6.1.5 *Phase 4*—The user rotates 180°,

4.6.1.6 *Phase 5*—The user repeats Phase 1 in the opposite direction,

4.6.1.7 *Phase 6*—The user repeats Phase 2 and traverses the same gap again in the opposite direction,

4.6.1.8 *Phase 7*—The user repeats Phase 3, although walks across the start line on the platform.

4.7 The test requestor shall provide to the test supervisor prior to the test, whether a full test or phased test will be considered the 'gaps test' and, if a phased test is requested, the phase numbers of the phased gap test to be performed.

4.8 For all tests, the specified path from the START point to the END point shall be defined by the test requestor prior to the test. The required apparatuses are described in Section 6.

4.9 The exoskeleton's capability is defined as the exoskeleton's ability to complete the gap task where the user is capable of performing the full gap test or phased gap test and, if requested by the test requestor, can perform the task at the desired speed and stability. In such a case, the average speed shall be used as the exoskeleton-user's capability.

4.10 The exoskeleton user is allowed to practice before the test.

4.11 Once the test begins, there shall be no verbal communication between the exoskeleton user and the test supervisor regarding the performance of a test repetition, other than instructions on when to start and notifications of faults, and any safety-related conditions. The user shall have the full responsibility to determine whether and when they have completed a repetition, and notify the test supervisor accordingly. However, it is the test supervisor's authority to judge the completeness of the repetition. Additionally, while it is the user's responsibility to alert the test supervisor of a safety issue they experience, the test supervisor should also alert the user to pause/stop the test if there are observable safety concerns (for example, too many falls, equipment malfunction, heart rate exceeds recommended heart rate for user's age (**1**)).[4]

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

NOTE 4—Practice could help establish the applicability of the exoskeleton for the given test method. It allows the operator to gain familiarity with the standard setup, procedure, apparatus, and environmental conditions. It also helps the test supervisor to establish the initial setup, procedure, including both the user and testing personnel, or apparatus setting for the test, or combinations thereof, when applicable.

4.12 The test requestor has the authority to select the parameters that may affect the user for the gaps task. The test requestor also has the authority to select test methods that constitute the test event, to select one or more test site(s) at which the test methods are implemented, to determine the corresponding statistical reliability and confidence levels of the results for each of the test methods, and to establish the participation rules, including the testing schedules and the test environmental conditions. Also, the test requestor has the authority to add variations to this test method, including:

4.12.1 Gap test while carrying a load(s);

4.12.2 Variations in gap traversal (for example, traverse with only the left foot first, jump over the gap); and

4.12.3 Environmental conditions including, for example, ground surfaces that are level or undulating, hard or soft, dry or wet; temperatures and humidity levels that are normal or extreme; precipitation that is no, low, or high.

5. Significance and Use

5.1 Exoskeletons are being used in the industrial/occupational, military, response, medical, and recreational sectors to enhance safety and effectiveness of the user to perform tasks. Traversing gaps is a component of many tasks that someone would do with an exoskeleton. For example, an exoskeleton may be used to help a worker in building construction where gaps in ground surfaces are prevalent. In the military, and other similar environments, soldiers using exoskeletons may traverse gaps along paths carrying loads. Fig. 1 shows examples of gaps typically found in various environments in which persons using exoskeletons may be required to step over gaps. The testing results of exoskeletons shall describe, in a statistically significant way, how reliably the exoskeleton is able to support tasks within the specified types of environments, confinements, and terrains, and thus provide sufficiently high levels of confidence to determine the applicability of the exoskeleton to a given task.

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5.2 This test method addresses exoskeleton safety and performance requirements expressed by manufacturing, medical, emergency responders, military, or other organizations requesting this test. The safety and performance data captured within this test method are indicative of the test exoskeleton's and the exoskeleton user's capabilities. The safety and performance data from these tests are essential to guiding the procurement and deployment decisions of exoskeleton purchasers and users.

5.3 The standard test setup and apparatus (see Section 6) is specified to be easily fabricated. This facilitates evaluation and replication of gap tests by exoskeleton sectors. The standard test setup and apparatus can also be used to support training (see Practice F3444/F3444M) and to establish proficiency of exoskeleton users, as well as provide manufacturers with information about the usefulness of their exoskeleton(s) for tasks.

5.4 Although the test method was developed for the sectors listed in 5.1, it may be applicable to other operational domains.

6. Test Course and Apparatus

6.1 The actual performance space where the exoskeleton is to be used or in-situ (that is, typically found in the environment, such as ground surface cracks/crevices, trees, loads, natural markings) apparatus of which will be used, or both, as exemplified in Fig. 1, may be used for this test. In the event that the actual performance space or the in-situ apparatus, or both, is not available or the test is to be exactly replicated by others, or both, test setups and the standard apparatus, as described in the following subsections, shall be used. Refer to Fig. 2 for test course layouts and Appendix X2 for apparatus details.

6.2 *Optional Equipment:*

6.2.1 *Safety equipment,* for example: heart rate monitor, pulse oximeter, oxygen administration kit, sphygmomanometer, inertial measurement units, joint angle and speed measurement equipment, telephone, automated electronic defibrillator, or Borg Breathlessness Scale that can be at the ready as needed.

6.2.2 *User measurement devices,* for example: walkway (that is, pressure mats) or force plates for human gaps analysis; user tracking system; heart rate, pulse, oxygen monitors, inertial measurement units, or joint angle and speed measurement equipment.

6.2.3 *Loads,* for example: tools, crates, or bags (refer to Practice F3443).

6.3 The test course shall include START markings near the gap apparatus.

6.4 For a phased gap test, the following additional parameters shall be set prior to the test:

6.4.1 If there is no Phase 1, the location where the user begins the test to traverse a gap(s),

6.4.2 *Phase 4*—The location, if needed, where the user turns around 180°,

6.5 Turn-around space for the user to reverse direction shall be provided according to the apparatus being used. A starting and ending line, which marks the START and END of the test repetition, should be marked on the floor using brightly colored tape. As described in 4.6, the start and end marker may be at the same location.

6.6 *Required Apparatus:*

6.6.1 1 m or greater straight, unimpeded path to the gap apparatus,

6.6.2 *Gap Apparatus* (see Fig. 2, Fig. 3, and Appendix X2 for details)—One or more gaps,

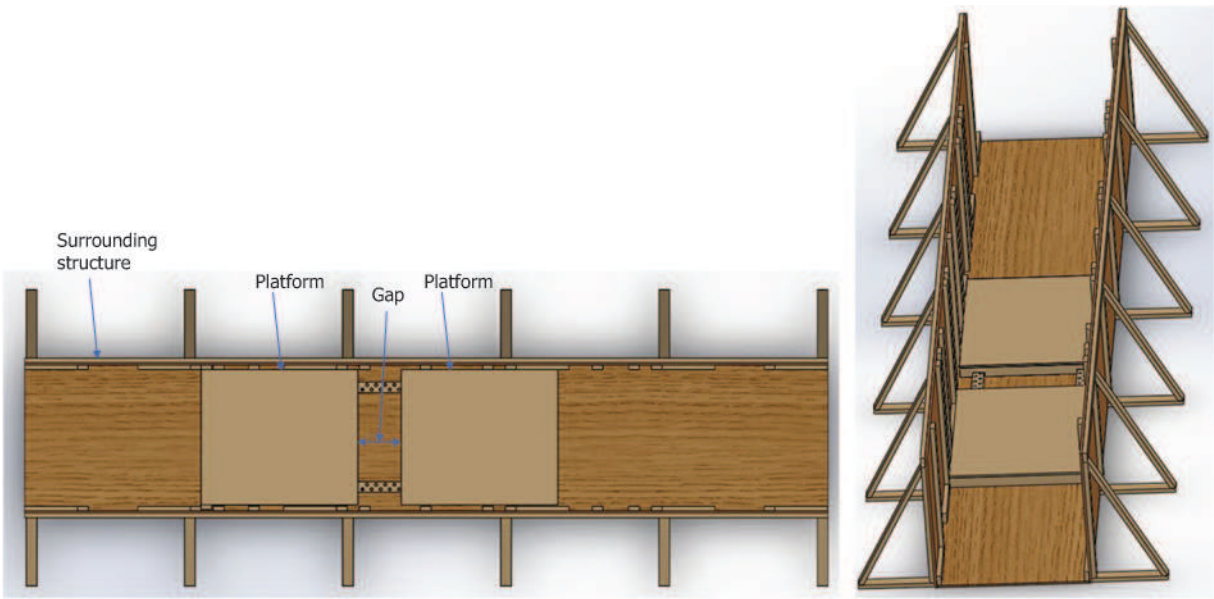

FIG. 3 Gap Test Apparatus: (a) Top View, (b) End View showing One Gap between Platforms

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6.6.3 *Timer* (for example, stopwatch) with at least 0.1 s calibrated time resolution,

NOTE 5—Other time-synchronized tools are: clock synchronized to WWVB radio or computer-based timing synchronized to network time protocol.

6.6.4 *Repetition Counter,*

6.6.5 *Tape or Similar Marking* (preferably bright colored), and

6.6.6 *Test Report* (see Section 10).

7. Hazards

7.1 Hazards for gaps tests when using exoskeletons can be as follows: slips, trips, falls, fatigue, and collisions dependent upon the exoskeleton, the test environment, and the apparatus (for example, surrounding structure (see Fig. 3)). Refer to the References section in order to characterize biomechanical stressors.

NOTE 6—Although these references address typical risks and mitigation procedures, they may not address safety issues for an exoskeleton user.

7.2 Safety standards providing risks and mitigation procedures for hazards when using an exoskeleton are developed or being developed, including:

7.2.1 ISO 13482, and

7.2.2 Guide F3527.

8. Calibration and Standardization

8.1 The exoskeleton configuration as tested shall be described in detail on the test report, including all subsystems and components and their respective features and functionalities, including version or iteration details as applicable. The configuration shall be subjected to all the appropriate tests within the suite of exoskeleton test methods. Any variation in the configuration shall cause the resulting exoskeleton variant to be retested across all the test suites to provide a consistent and comprehensive representation of the performance. Additional information describing the exoskeleton, exoskeleton user, and the exoskeleton fit to the user should also be documented.

8.2 Once an exoskeleton user begins a test, by starting to execute the task as specified in 4.1, the exoskeleton shall be used to perform the task for the specified number of repetitions through completion without changing the exoskeleton or apparatus.

8.3 A battery may be changed or charged between repetitions provided that other configurations remain unaltered and if allowed by the test requestor. Battery changes/charging shall be noted on the test report. Unless otherwise stated by the requestor, during the test the exoskeleton shall not be allowed to have the energy/power source replenished nor shall the exoskeleton be allowed any human physical intervention, including adjustment, maintenance, or repair. Any such actions shall be considered a fault condition and the test should be restarted from the beginning.

8.4 The metric for this test method is the complete and successful gaps test for the specified number of continuous repetitions where a completed test is set by the test requestor. In addition, the elapsed time for the user to successfully complete the gaps test is a performance measurement reflecting the exoskeleton's capability and efficiency, and the user's skill level. Therefore, this temporal aspect is a part of the test and the results shall be recorded on the test report. The average speed is specified as the sustained speed. Metrics shall also include any test anomalies or occurrences, such as: stumbles, trips, falls, rests, variation in gaps throughout the test or from baseline (that is, called NoEXO when no exoskeleton is used) to exoskeleton test (that is, called EXO when an exoskeleton is used). Test anomalies or occurrences shall be noted on the test report and may also provide additional statistical importance from the test requestor.

8.5 The test requestor has the authority to specify the environmental variables, which may affect the test results. All environmental settings shall be documented using Practice F3427.

8.6 The test requestor has the authority to specify the number of repetitions required for the test. Considerations for user fatigue, abilities, exoskeleton capabilities, and other characteristics that may impact the tests shall be considered. Extending the test should not occur unless under rare circumstances (for example, rehabilitation, mean-time-between-failure tests over many days). Guidance on reliability of test data given the number of repetitions is provided in Appendix X1.

9. Procedure

9.1 A test requestor requests a gaps test, including all test parameters (for example, test apparatus, environment, exoskeleton configuration, etc.) to be recorded and documented.

9.2 For all tests, the environmental conditions of the space where the test will be performed shall be documented using Practice F3427, allowing test repeatability.

9.3 The exoskeleton configuration shall be documented in full detail to ensure that repeatable tests can occur. Upon publication and to ensure standardized documentation, Standard Practice for Recording the Exoskeleton Test Configuration[5] and Practice F3613 shall be used to record the exoskeleton configuration.

9.4 If a load (for example, tool, equipment, artifact load) is to be handled during the test, document the artifact or real load using Practice F3443.

9.5 The test supervisor shall be consistent in their measurement technique. For example, measure all subjects in the same manner (for example, video cameras at the same locations) and measure that the subject has fully crossed a line by consistently measuring when the trailing foot crossed.

9.6 If any movement by the user is requested in addition to this test (for example, move through an area or maze prior to traversing the gaps apparatus), the test administrator should document in detail the movement for repeatable testing (for example, Practice F3517, Test Method F3523, or Test Method F3528, or both).

[5] Standard designation for this practice is to be added after the standard is approved and published.

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