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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Standard Test Method for Exoskeleton Use: Beams[1]

This standard is issued under the fixed designation F3583; 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) safety (see 1.4) or performance, or both, when traversing beams.

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.

1.1.3 Environments in these typical sectors often pose constraints to exoskeleton user movement to various degrees. Being able to traverse beams, as intended by the user or test requestor, while using an exoskeleton, is essential for exoskeleton deployment for a variety of tasks (for example, ascending/descending stairs, ramps, hills). This test method specifies test setup, procedure, and recording to standardize this beams task for testing exoskeleton user movement.

1.1.4 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, hurdles, stairs, beams, 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.

1.1.5 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 beams 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.

1.1.6 The test methods quantify elemental exoskeleton use capabilities necessary for sector applications listed in 1.1.2 and perhaps others. 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 beam traversing and the test requestor intends to use the exoskeleton to perform a beam test (for example, for research, development of beam-capable use by a manufacturer, beam 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 in the field where the specified apparatus and environmental conditions are implemented.

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 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] 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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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

[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.

3. Terminology

3.1 General terminology for ASTM F48 standards is listed in Terminology F3323. Terminology specific to this standard is 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 *beam, n*—a narrow horizontal bar, on or raised off the floor, on or over which a user traverses.

3.2.3 *platform, n*—a raised level surface, wider than a beam, on which a user can stand.

3.2.3.1 *Discussion*—The platform may be attached to a beam(s) as used in this test method.

3.2.4 *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 traverses beam(s), is defined as the exoskeleton-user performing a beam traversal test, including a number of repetitions as set by the test requestor. Guidance on number of repetitions for the test is shown in Appendix X1. An in-situ beam (for example, a log) or a beam and platform (for example, a construction beam to a landing) can be used for this test method. For ideal test replication, standard beam apparatuses, which include: (a) a beam or (b) a beam and platform(s), can be used for this test method. See Fig. 1 for an illustration.

4.2 The test is described as follows:

4.2.1 This test can be used to assess aerobic function, endurance, beam traversal capability and speed, balance, or other parameters, or combinations thereof, as required by the test requestor.

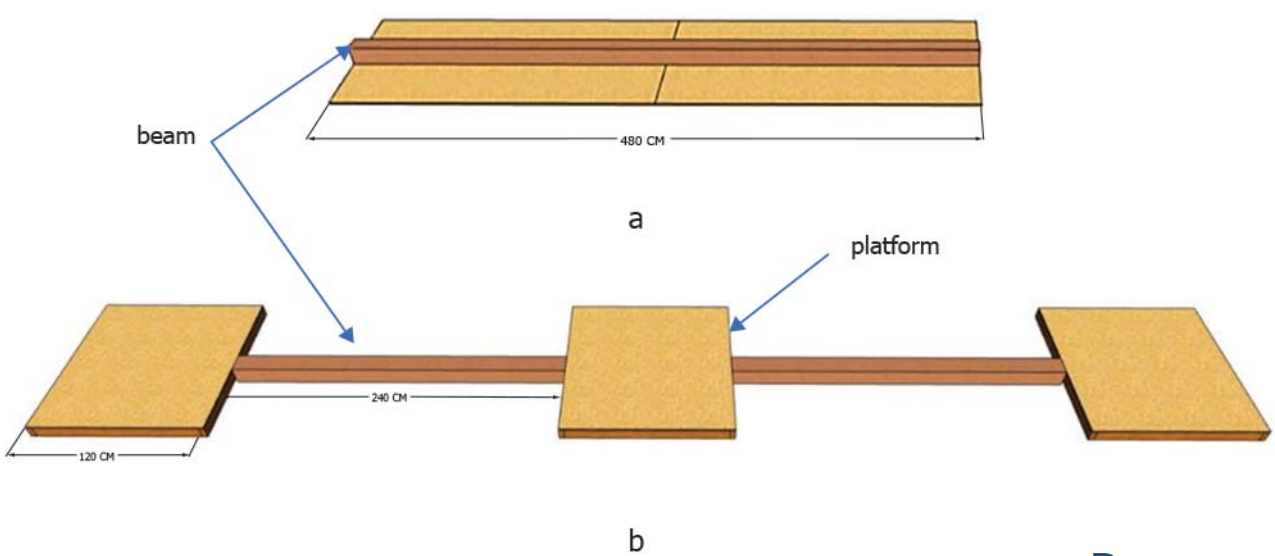

FIG. 1 Graphic of: (a) Beam Apparatus and (b) Beam-and-Platform Apparatus

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

4.2.2.1 Number of beams traversed,

4.2.2.2 Change(s) in user (for example, heart rate, fatigue, stability, toe drag, missed steps, near falls/falls) by a specified amount,

4.2.2.3 Upon traversing a beam, the ability to turn around on a platform or floor and traverse a beam, and

4.2.2.4 The ability to transition from a platform or floor to a beam.

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 5.

4.4 A full beam or beam-and-platform test is defined as: the user begins by standing behind a start marker, walks to the beam apparatus, traverses the beam or beams and platforms past the end marker, turns around 180°, repeats the traversal of beam or beams and platforms, and walks past the start marker. A phased test includes portions of the full test as follows:

Phased Beam Test

4.4.1 *Phase 1*—The user stands behind a start marker and walks to the beam apparatus.

4.4.2 *Phase 2*—The user traverses the beam until reaching the opposite end of the beam.

4.4.3 *Phase 3*—The user steps off the beam and walks past the end marker.

4.4.4 *Phase 4*—The user turns around 180°.

4.4.5 *Phase 5*—The user repeats Phase 1, although beginning behind the end marker.

4.4.6 *Phase 6*—The user repeats Phase 2.

4.4.7 *Phase 7*—The user repeats Phase 3, although walks past the start marker.

Phased Beam-and-Platform Test

4.4.8 *Phase 1*—The user stands behind a start marker on a platform and steps onto the beam apparatus.

4.4.9 *Phase 2*—The user traverses the beam, middle platform, and second beam until reaching the opposite end of the beam.

4.4.10 *Phase 3*—The user steps off the beam and walks past the end marker on the platform.

4.4.11 *Phase 4*—The user turns around 180°.

4.4.12 *Phase 5*—The user repeats Phase 1, although beginning behind the end marker.

4.4.13 *Phase 6*—The user repeats Phase 2.

4.4.14 *Phase 7*—The user repeats Phase 3, although walks past the start marker on the platform.

4.5 The test requestor shall provide to the test supervisor prior to the test, whether a full test or phased test will be considered the 'beams test' and, if a phased test is requested, the phase numbers of the seven phases to be tested.

4.6 The test requestor shall provide to the test supervisor prior to the test, exoskeleton information (for example, age, prior use, etc.), user experience, and practice time length and activity.

4.7 The exoskeleton's capability is defined as the exoskeleton's ability to complete the beams test where the user is capable of performing the task at the associated effective speed, stability, or other associated parameters, or combinations thereof, as required by the test requestor. 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. In such a case, the average effective speed shall be used, instead, as the exoskeleton-user's capability.

4.7.1 Guidance on the number of repetitions for a discrete, binary variable test is provided in Appendix X1 (for example, complete the test vs. failure to complete the test). If choosing the number of repetitions for continuous variable (for example, speed, distance) tests, consideration should include: variability between subjects, user capability to perform the test, etc.

4.8 The durability of the exoskeleton shall be such that it can withstand the beams test requirements without failure, as specified by the manufacturer.

4.9 The user is allowed to practice before the test and if practice occurs, practice time, activity, and other pertinent information shall be documented in the notes section on the test report, as practice can change the user. If practice occurs for one subject, all subjects completing the test shall practice for the same time and activity. She/he is also allowed to abstain from the test before it is started.

4.10 The test requestor has the authority to select the test methods that constitute the test event, to select one or more test site(s) and all test parameters (for example, environmental conditions, apparatus materials if not standard) 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.

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 are uncomfortable with completing the test, 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]

NOTE 2—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, or combinations thereof, for the test when applicable.

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

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4.12 The test requestor has the authority to select the parameters that may affect the user for the beams 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. As such, variations to this test method are also described in this standard, including:

4.12.1 Traverse beams while carrying a load(s), and

4.12.2 Environmental conditions including, for example, ground surfaces that are 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 Beams and beams with platforms can vary greatly in, for example: length, width, height, quantity, geometry, surface coatings, and for a variety of industries. Fig. 2 shows examples of various beams and beams with platforms.

5.2 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 beams are used in many tasks performed and may include, for example, upper, lower, or full body movement in order to complete the task. Dependent upon the task, it may require people to traverse various ground and beam surfaces while wearing an exoskeleton. For example, an exoskeleton may be used to help during construction tasks where workers in exoskeletons traverse beams or beams and platforms with and without carrying loads, indoors or outdoors, as part of their daily activities. The testing results of exoskeletons shall describe, in a statistically significant way (see guidance in Appendix X1), 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.

5.3 This test method addresses exoskeleton safety and performance requirements expressed by manufacturing, 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. Having available direct information from tested exoskeleton(s) with associated performance data to guide procurement and deployment decisions is essential to exoskeleton purchasers and users.

5.4 The testing results of the candidate exoskeleton(s) shall describe, in a statistically significant way, how reliably the exoskeleton user is able to negotiate beams. The test apparatus described in 6.7 is intended to be a single, standardized beam or beam and platform where repeatable results between exoskeletons, users, and organizations are comparable. The standard test setup and apparatus can also be used to support training and establish proficiency of exoskeleton users, as well as provide manufacturers with information about the usefulness of their exoskeleton(s) for tasks. For guidance on exoskeleton training, see Practice F3444/F3444M.

5.5 Although the test method was developed for the sectors listed in 5.2, 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 apparatus of which will be used, or both, as exemplified in Fig. 2, may be used for this test. In the event that the actual performance space or apparatus, or both, is not available or the test is to be exactly replicated by others, or both, test setup and a standard beams test apparatus is also described in this section.

6.2 *Optional Equipment:*

6.2.1 *Safety Equipment,* for example: belay; gait belt; personal protective equipment, such as: knee pads, helmet, gloves; user health monitoring, such as: pulse oximeter, oxygen source, Borg Breathlessness Scale, sphygmomanometer, inertial measurement units, joint angle and speed measurement equipment; and other safety equipment, such as: telephone, automated electronic defibrillator that can be at the ready as needed.

6.2.2 *User Measurement Devices,* for example: walkway or force plates for traversing beams analysis; step force/contact measurement/detection devices, user tracking system; heart rate, pulse, oxygen monitors, inertial measurement units, joint angle and speed measurement equipment.

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

6.3 The test course shall include START and END markings near the beam apparatus.

6.4 Turnaround 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.

6.5 The use of exercise equipment is not recommended to replace the beam or beam-and-platform apparatus for this test method as users are unable to pace themselves on such equipment. Exercise equipment test results, therefore, are not interchangeable with beam apparatus tests.

6.6 *Required Apparatus:*

6.6.1 1 m or greater straight, unimpeded path to the beam or beam-and-platform apparatus,

6.6.2 Beam or beam-and-platform apparatus,

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

NOTE 3—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 (bright colored), and

6.6.6 Test report (see Section 10).

6.7 *Standard Beams or Beams-and-Platform Test Apparatus (if used):*

6.7.1 A standard beams or beams and platforms test apparatus is suggested for use to provide maximum repeatability in

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FIG. 2 Example Beams: (a) Steel Construction Beams; (b) Steel Construction Beam to a Platform; (c) Log Construction Beam; (d) Playground Log Beam; (e) Log Beam across Water; and (f) Balance Beam used for Gymnastics

test result comparison between testing organizations, users, or exoskeletons, or combinations thereof. The standard beams and beams-and-platforms test apparatus' are shown in Fig. 3 and Fig. 4, respectively, and are designed based on [illegible] under

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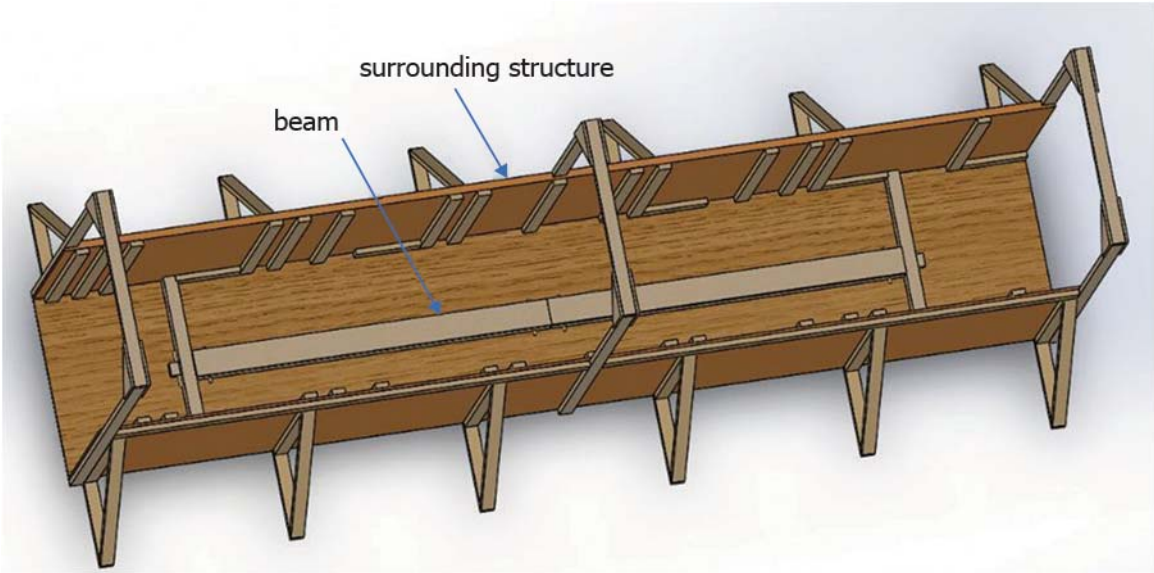

FIG. 3 Beams Test Apparatus

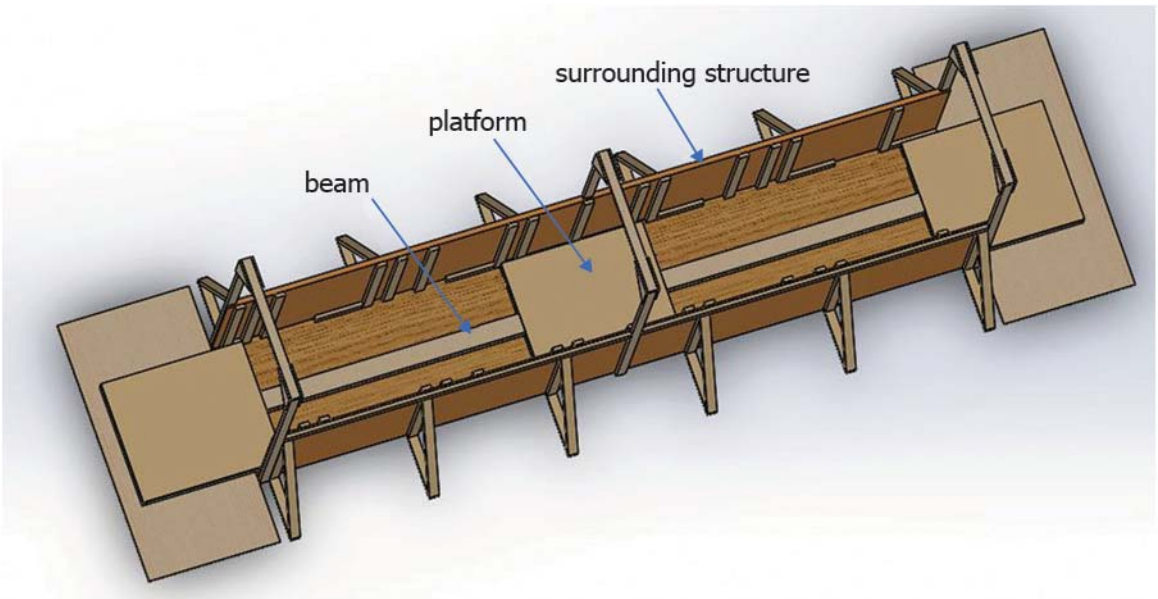

FIG. 4 Beams-and-Platform Test Apparatus

size and materials. The apparatus dimensions are detailed in Appendix X2. The surrounding structure is standardized across other exoskeleton test methods, for example: gait, hurdles, and gaps, and allows standardized test setup, railings, and apparatus support. For the beams test, the surrounding structure may not be necessary to include with the beam or beam-and-platform apparatus.

6.7.2 A standard beam or beam-and-platform test apparatus is to be constructed from readily available and nominal 2 by materials made from SPF (spruce, pine, fir) wood, standard and appropriately sized fasteners, and can be weighted using weights, or fixtured to the floor or ground surface to minimize apparatus movement.

6.8 *Alternative Beams Apparatus:*

6.8.1 Any alternative apparatus design, such as for increased loading, raised beams and platforms, increased or decreased sizing, alternative materials (for example, other woods, metals, composites, and combinations thereof), shall be engineered as needed to safely and effectively support the required test.

6.8.2 Smaller turn-around space, located at the start or end locations, is a potential challenge to exoskeletons. Smaller turn-around space(s) shall be engineered as needed to safely and effectively support the required test. If smaller turn-around space is provided in actual apparatus settings (that is, not

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designed and constructed), appropriate safety precautions and test safety shall be used. See also Test Method F3523.

6.8.3 Larger beam, platform, and surrounding structure widths may be required, as with medical applications, where a test technician, safety operator, etc. may walk beside the exoskeleton user. As such, the actual beam apparatus to be used shall accommodate space to allow an exoskeleton user and the test technician, as well as any associated safety, measurement, etc. equipment to perform the test without hindrance due to space limitations. If a larger beam apparatus is to be designed, constructed, and used, the apparatus shall be engineered as needed to safely and effectively support the required test.

6.9 The test course layout for a full test is shown in Fig. 5 and, for consistency throughout this test method, illustrates the use of the standard test apparatus.

7. Hazards

7.1 Hazards for beam tests when using exoskeletons can be as follows: slips, trips, falls, fatigue, and collisions dependent upon the exoskeleton, the test environment (for example, lighting, moisture), and the apparatus (for example, beams). Emergency egress from the area and apparatus should also be considered. Safety equipment should be considered to be used during the test (for example, belay, gait belt). Refer to (**2-4**) in order to characterize biomechanical stressors. Note that 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.

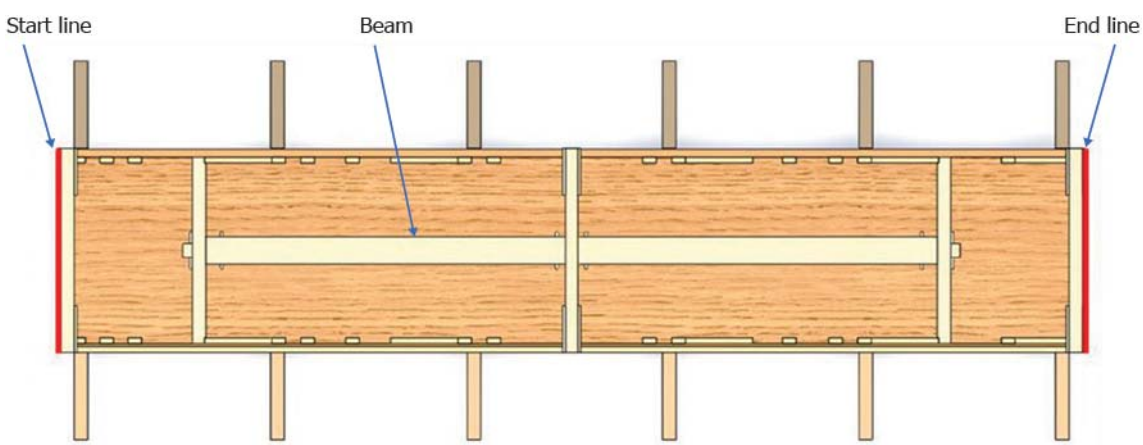
8. Calibration and Standardization

8.1 The exoskeleton configuration as tested shall be described in detail on the test form, 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 test suites, as defined in 3.2.4, as appropriate. 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.

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. 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 beams test, as outlined in this test method, for the specified number of continuous repetitions, as set by the test requestor. In addition, the elapsed time for the user to successfully complete the beams test is a performance proficiency index reflecting the combination of 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 form. Metrics shall also include any test anomalies or occurrences, such as: stumbles, trips, falls, rests, variation in beam-and-platform traversal throughout the test or from baseline (that is, called NoEXO when no exoskeleton used) to exoskeleton test (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 to the test requestor.



(a) Beam Test Layout

FIG. 5 Full Test Layouts (top views)

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