



Designation: E2991/E2991M – 17

Standard Test Method for Evaluating Response Robot Mobility: Traverse Gravel Terrain¹

This standard is issued under the fixed designation E2991/E2991M; 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

The robotics community needs ways to measure whether a particular robot is capable of performing specific missions in unstructured and often hazardous environments. These missions decompose into elemental robot tasks represented individually as standard test methods and practices. The associated test apparatuses and performance metrics provide a tangible language to communicate varying mission requirements. They also enable repeatable testing to establish the reliability of essential robot capabilities.

The ASTM International Standards Committee on Homeland Security Applications (E54) specifies standard test methods and practices for evaluating such robot capabilities. These standards facilitate comparisons across diverse models or multiple configurations of a single model. They support robot researchers, manufacturers, and user organizations in different ways. Researchers use the standards to understand mission requirements, encourage innovation, and demonstrate break-through capabilities. Manufacturers use the standards to evaluate design decisions, integrate emerging technologies, and harden developed systems. User organizations leverage the resulting robot capabilities data to guide purchasing decisions, align deployment objectives, and focus training with standard measures of operator proficiency. Associated usage guides describe how such standards can be applied to support these various objectives.

The overall suite of standards addresses critical subsystems of remotely operated response robots, including maneuvering, mobility, dexterity, sensing, energy, communications, durability, proficiency, autonomy, logistics, safety, and terminology. This test method addresses the robotic mobility on gravel terrain.

1. Scope

1.1 The purpose of this test method is to specify the apparatuses, procedures, and performance metrics necessary to quantitatively measure a teleoperated ground robot's capability of traversing gravel terrain. The primary performance metric for this test method shall be a robot's possession of such a capability with a specified statistical significance level.

1.2 Average rate of advance over the specified terrain shall be the secondary performance metric for this test method. The measure shall be calculated only when a robot under test has completed a statistically-significant number of repetitions.

1.3 This test method can also be used to measure the operator proficiency in performing the specified task. The

corresponding performance metric may be the number of completed task repetitions per minute over an assigned time period ranging from 10 to 30 minutes.

1.4 This test method is a part of the mobility suite of ground response robot test methods, but this test method is stand-alone and complete. This test method applies to ground systems operated remotely from a standoff distance appropriate for the intended mission. The system includes a remote operator in control of all functionality and any assistive features or autonomous behaviors that improve the effectiveness or efficiency of the overall system.

1.5 The apparatus, specified in Section 6, can only test a limited range of a robot's capabilities. When the robot has been tested through the limit or limits of the apparatus, a note shall be associated with the results indicating that the robot's actual capability may be outside of the limit or limits imposed by the test apparatus. For example, the size of the gravel terrain test apparatus could possibly affect the acceleration of the robot under test and, in turn, the resulting average rate of advance.

¹ This test method is under the jurisdiction of ASTM Committee E54 on Homeland Security Applications and is the direct responsibility of Subcommittee E54.09 on Response Robots.

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1.6 *Performing Location*—This test method may be performed anywhere the specified apparatuses and environmental conditions can be implemented.

1.7 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard. Both units are referenced to facilitate acquisition of materials internationally and minimize fabrication costs.

1.8 *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.*

1.9 *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

C33/C33M Specification for Concrete Aggregates

D5821 Test Method for Determining the Percentage of Fractured Particles in Coarse Aggregate

E2521 Terminology for Evaluating Response Robot Capabilities

E2592 Practice for Evaluating Response Robot Capabilities: Logistics: Packaging for Urban Search and Rescue Task Force Equipment Caches

E2803 Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Obstacles: Inclined Planes

3. Terminology

3.1 Definitions:

3.1.1 The following terms are used in this test method and are defined in Terminology **E2521**: abstain, administrator or test administrator, emergency response robot or response robot, fault condition, operator, operator station, remote control, repetition, robot, teleoperation, test event or event, test form, test sponsor, test suite, testing target or target, testing task or task, and trial or test trial.

3.1.2 The following terms are used in this test method and are defined in *ALFUS Framework Volume I*:³ autonomous, autonomy, level of autonomy, operator control unit (OCU), and semi-autonomous.

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 NIST Special Publication 1011-I-2.0 *Autonomy Levels for Unmanned Systems (ALFUS) Framework Volume I: Terminology*, Version 2.0. Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, <http://www.nist.gov>.

4. Summary of Test Method

4.1 A robot under test traverses from one end of the gravel terrain to the other and back while alternating left and right turns around the pylons to complete a figure-8 path. The robot is credited with a fixed forward distance for each completed figure-8 path repetition.

5. Significance and Use

5.1 Traversing on terrains with small aggregate (such as Number 8 or smaller gravel, per Specification **C33/C33M**) could pose problems for ground robots because the aggregate may become incrementally packed into the locomotion subsystems (such as driving sprockets, belts, chains, tire treads, or track pads) leading to jamming, slippage, or other failures, and thus adversely affecting a robot's mobility. This test method addresses aforementioned issues of mobility.

NOTE 1—Larger-sized gravel might not be as easily packed into robotic locomotion subsystems but might present different types of mobility challenges such as angular, rough, sharp, or broken aggregate pieces interfering with wheels, tracks, or other types of locomotion mechanisms. These issues are out of the scope of this test method.

5.1.1 Small gravel based terrains are non-rigid in nature and could cause a robot to turn-in-place or dig-in when the robot is negotiating a tight turn. Certain robotic locomotion mechanisms might be designed for other mobility purposes and might not create sufficient traction against the specified gravel terrain. As such, extensive testing within this type of terrain may expose robot design or reliability issues and lead to field maintenance or repair.

5.1.2 The gravel traverse capabilities could be affected by additional factors such as the weight and its distribution, ground contact areas, and control schemes for the robot. As such, extensive testing within this type of terrain may also lead to innovations in robot design.

5.2 Key features of response robots are that they are remotely operated from safe standoff distances, deployable at operational tempos, capable of operating in complex environments, sufficiently hardened against harsh environments, reliable and field serviceable, durable or cost-effectively disposable, and equipped with operational safeguards. As such, a major advantage of using robots in response operations is to enhance the safety and effectiveness of responders or soldiers.

5.3 This test method aligns user expectations with actual capabilities to understand the inherent capability trade-offs in deployable systems at any given cost. For example, a design issue of the number of batteries to be packed on a robot could affect desired weight, endurance, or cost. Appropriate levels of understanding can help ensure that requirement specifications are articulated within the limit of current capabilities.

5.4 This test method provides a tangible representation of essential robot capabilities with quantifiable measures of performance. When considered with other related test methods in the suite, it facilitates communication among communities of robot users and manufacturers. As such, this test method can be used to:



5.4.1 Inspire technical innovation and guide manufacturers toward implementing combinations of capabilities necessary to perform essential mission tasks.

5.4.2 Measure and compare essential robot capabilities. This test method can establish the reliability of the system to perform specified tasks, highlight break-through capabilities, and encourage hardening of developmental systems.

5.4.3 Inform purchasing decisions, conduct acceptance testing, and align deployment objectives with statistically significant robot capabilities data captured through repeated testing and comparison of quantitative results.

5.4.4 Focus operator training and measure proficiency as a repeatable practice task that exercises actuators, sensors, and operator interfaces. The test method can be embedded into training scenarios to capture and compare quantitative scores even within uncontrolled environmental variables. This can help develop, maintain, measure, and track very perishable skills over time and enable comparisons across squads, regions, or national averages.

5.5 Although this test method was developed for response robots, it may be applicable to other domains. Different user communities can set their own thresholds of acceptable performance within the test method for various mission requirements.

5.6 It is recommended that users of this test method consider their particular robot requirements when interpreting the test results. The capability evaluated in this test method alone shall be interpreted according to the scope of this test method and shall not be considered as an overall indication of the capability of the robot's mobility system nor of the entire robotic system. A single test method only captures the specified single aspect of a robot's capabilities. A more complete characterization of a robot's capabilities requires test results from a wider set of test methods.

6. Apparatus

6.1 The test apparatus is a fixed-size gravel terrain through which the robot has to traverse (see Figs. 1 and 2 for illustrations).

6.1.1 The terrain size may be scaled to provide for various levels of mobility constraints for robots under test depending on testing requirements. Three typical terrain sizes are nominally 3.6 m [12 ft] long by 1.2 m [4 ft] wide, 7.2 m [24 ft] long by 2.4 m [8 ft] wide, and 14.4 m [48 ft] long by 4.8 m [16 ft] wide, respectively. A test sponsor is authorized to specify other test apparatus sizes to suit particular deployment requirements.

NOTE 2—Test Method E2803 and this test apparatus can be combined to form a gravel test terrain on an incline.

6.1.2 Each of the terrains is fully covered with packed Number 8 aggregate (with nominal size of 2.36 to 9.5 mm, or 0.09 to 0.37 in.), as specified in Specification C33/C33M, for a minimal depth of 15 cm [6 in.], and evenly spread throughout the apparatus floor. The gravel shall be dry, both visibly and to the touch within the entire apparatus, including from the surface through the bottom.

6.1.3 Each terrain is recommended to be fully surrounded by walls that are nominally 1.2 m [4 ft] tall and are typically built out of plywood or oriented strand boards (OSB). Lumber with a nominal cross-section of 5 by 25 cm [2 by 10 in.] could also be used to surround the terrain and help further contain the gravel.

6.1.4 The ends of each of the terrains have end zones that are half as long as the width of the terrain and feature walls completely painted with alternating black-and-white, vertical, and nominally 30 cm [12 in.] wide stripes.

6.1.5 Four pylons define a figure-8 traverse path (see Fig. 2). The two timer pylons are placed at a distance from each other equal to the width of the terrain and centered between the end

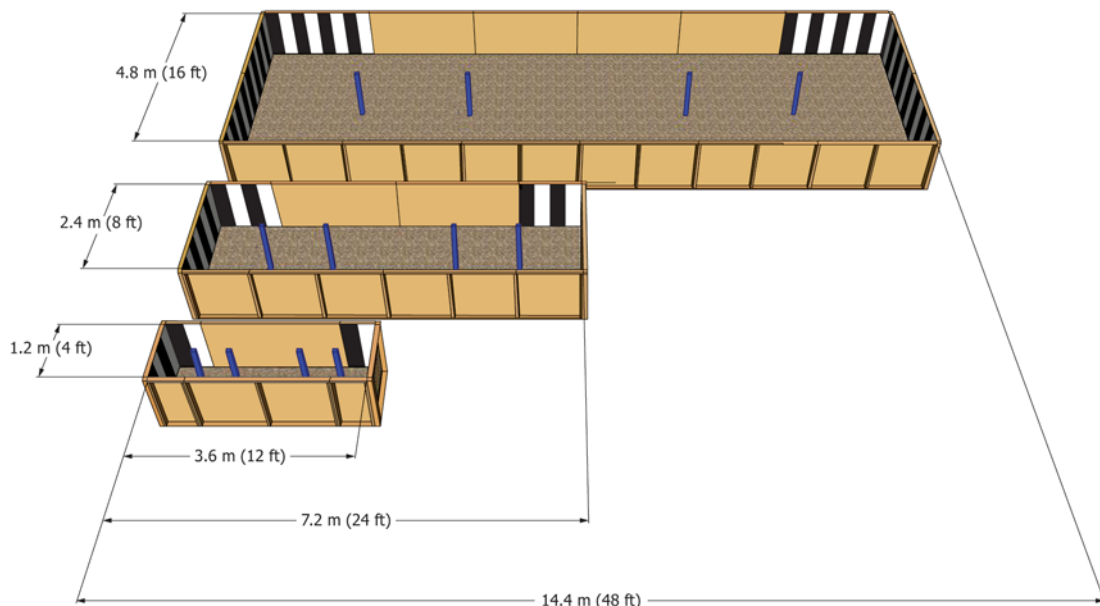


FIG. 1 Confined Area Terrains: Gravel; Three Sizes

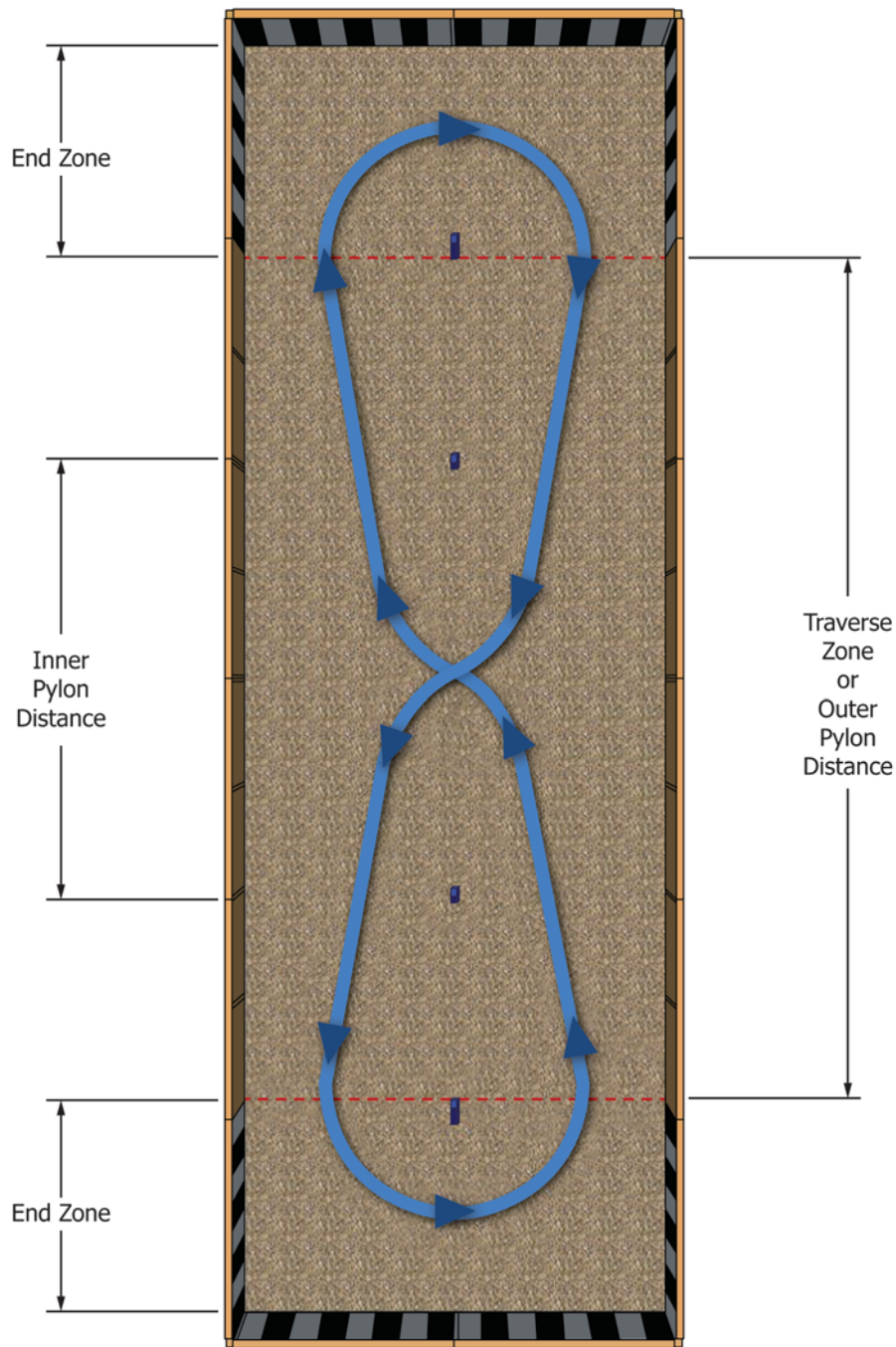


FIG. 2 Confined Area Terrains: Gravel; Figure-8 Path

zones and between the sidewalls. The two outer pylons are placed at the edge of each end zone and centered between the sidewalls. Pylons that are typically used for general traffic guidance and have nominal heights of at least 30 cm [1 ft] and nominal cross-section diameters of at most 30 cm [1 ft] shall be acceptable for use in this test method.

6.2 In terms of lighting, the lit test condition is specified as indoors (with furnished lighting), typically measured at nominally 150 to 300 lux or outdoors (in the daylight), typically measured at up to 1000 lux, nominally. The dark test condition

is specified as nominally 0.1 lux. The dark test condition is not specified to be lower than 0.1 lux because of the implementation cost concerns. 0.1 lux is dark enough to require the robot to have onboard illumination—a test robot capability—in order to perform the task. However, it is recognized that actual operational environments may be darker.

NOTE 3—When this test apparatus is implemented in an International Organization for Standardization (ISO) freight container, the 0.1 lux darkness could be achieved by turning off all the inside lighting sources