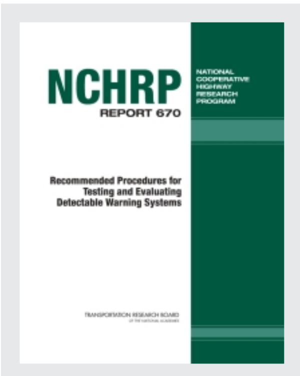


Recommended Procedures for Testing and Evaluating Detectable Warning Systems

DETAILS

105 pages | | PAPERBACK
ISBN 978-0-309-15506-9 | DOI 10.17226/22937

AUTHORS

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 670

Recommended Procedures for Testing and Evaluating Detectable Warning Systems

Thomas J. Rowe
Kimberly Steiner
John Lawler
Jonah Kurth
WISS, JANNEY, ELSTNER ASSOCIATES, INC.
Northbrook, IL

Subscriber Categories
Pedestrians and Bicyclists • Safety and Human Factors

Research sponsored by the American Association of State Highway and Transportation Officials in cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2010
www.TRB.org

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Academies was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NCHRP REPORT 670

Project 4-33
ISSN 0077-5614
ISBN 978-0-309-15506-9
Library of Congress Control Number 2010936777

NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program, conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council.

The members of the technical panel selected to monitor this project and to review this report were chosen for their special competencies and with regard for appropriate balance. The report was reviewed by the technical panel and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the Governing Board of the National Research Council.

The opinions and conclusions expressed or implied in this report are those of the researchers who performed the research and are not necessarily those of the Transportation Research Board, the National Research Council, or the program sponsors.

The Transportation Research Board of the National Academies, the National Research Council, and the sponsors of the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of the report.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet at:

http://www.national-academies.org/trb/bookstore

Printed in the United States of America

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, on its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is one of six major divisions of the National Research Council. The mission of the Transportation Research Board is to provide leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied activities annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation. **www.TRB.org**

www.national-academies.org

COOPERATIVE RESEARCH PROGRAMS

CRP STAFF FOR NCHRP REPORT 670

Christopher W. Jenks, *Director, Cooperative Research Programs*
Crawford F. Jencks, *Deputy Director, Cooperative Research Programs*
Amir N. Hanna, *Senior Program Officer*
Eileen P. Delaney, *Director of Publications*
Natalie Barnes, *Editor*

NCHRP PROJECT 4-33 PANEL
Field of Materials and Construction—Area of General Materials

Peter Kemp, *Wisconsin DOT, Madison, WI* (Chair)
Norie Calvert, *Maryland State Highway Administration, Baltimore, MD*
Dennis Cannon, *Synergy, LLC, Washington, DC (formerly United States Access Board)*
Kenneth R. Cooper, *Kenneth Cooper Engineering, PLLC, Hendersonville, NC (formerly Arizona DOT)*
Cindy Estakhri, *Texas A&M University, College Station, TX*
Peter B. Krause, *Texas DOT, Austin, TX*
Henry W. Lacinak, *AASHTO, Baton Rouge, LA (formerly Louisiana DOTD)*
Christopher M. Newman, *FHWA Liaison*
Richard Pain, *TRB Liaison*

AUTHOR ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 4-33 by Wiss, Janney, Elstner Associates, Inc. (WJE). Mr. Thomas J. Rowe, P.E., Senior Consultant, was the Principal Investigator. The authors of this report are Kimberly Steiner, Senior Associate; Dr. John Lawler, Senior Associate; and Jonah Kurth, Associate II, of WJE. The authors thank James Connolly, John Fraczek, and Paul Krauss of WJE for their helpful input.

FOREWORD

By Amir N. Hanna
Staff Officer
Transportation Research Board

This report presents a set of recommended test methods for evaluating durability of detectable warning systems. These methods address exposure regimes, test procedures, and evaluation criteria to help select detectable warning systems that provide long-term performance and durability while meeting the requirements of the Americans with Disabilities Act Accessibility Guidelines (ADAAG). The test methods are presented in AASHTO format to facilitate consideration and incorporation into the *AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing.* The material contained in the report should be of immediate interest to state materials engineers and those concerned with the different aspects of the ADAAG.

Since 2001, the Americans with Disabilities Act Accessibility Guidelines (ADAAG) have required placement of detectable warnings on curb ramps, which remove a tactile cue otherwise provided by curb faces, and at other areas where pedestrian ways blend with vehicular ways. The ADAAG defines a detectable warning as "a standardized surface feature built in or applied to walking surfaces or other elements to warn visually impaired people of hazards on a circulation path." The ADAAG further provides geometric requirements for truncated domes and stipulates a visual contrast with adjacent walking surfaces. To accommodate these requirements, detectable warning surfaces (e.g., plastics, ceramics, brick and concrete pavers, and metal) have been developed. These systems are expected to provide long-term performance and durability by maintaining geometric characteristics, frictional properties, and other functional requirements over the expected service life. These performance considerations are influenced by material properties and conditions of use, including climate (e.g., temperature ranges, sun exposure, and snowfall), maintenance practices (e.g., snow removal, use of deicing chemicals, and sweeping), type and condition of underlying surface (e.g., underlying material types, texture, and distress), construction methods (e.g., surface preparation and use of adhesives), and other factors.

The ADAAG and recent research focused on detectability; limited attention was given to material requirements that influence long-term performance and durability or the test procedures needed for evaluating detectable warning systems. Thus research was needed to (1) identify the long-term performance and durability requirements and related properties of detectable warning systems, (2) recommend test methods for evaluating detectable warnings, and (3) develop guidance on the use of these methods for selecting detectable warning systems that will provide long-term performance and durability for different conditions while meeting the requirements of the ADAAG.

Under NCHRP Project 4-33, "Procedures for Testing and Evaluating Detectable Warning Systems," Wiss, Janney, Elstner Associates, Inc. of Northbrook, Illinois, worked with the objectives of recommending test methods for evaluating performance and durability aspects of detectable warning systems and providing guidance on the use of these methods for selecting detectable warning systems for specific conditions of use. The research focused on material requirements and did not deal with detectability or geometric compliance requirements.

The research included a review of the existing information relevant to detectable warning system designs, materials, durability, and testing. As part of this review, information on commonly used products, deterioration mechanisms, and performance was obtained through a survey of state and municipal departments of transportation. The important properties for functional performance of detectable warning systems are color contrast, slip resistance, mechanical integrity, and dimensional stability. Degradation mechanisms that affect these aspects of functional performance are freezing and thawing, abrasion, ultraviolet radiation, moisture, extreme temperatures, as well as physical stresses caused by impact, snow removal, and foot and vehicular traffic.

The research also included an extensive laboratory testing program to evaluate the effects of specific exposure regimes on detectable warning systems and to develop test methods for evaluating durability of these systems. These exposure regimes covered a range of freeze-thaw, high temperature thermal cycling, ultraviolet exposure, and abrasion exposure. The evaluations included visual and microscopic examination, color measurement, dome shape and geometry measurement, slip resistance, coating and single dome bond, resistance to impact from falling objects, wear resistance, and resistance to impact from simulated snowplow operations. These exposures were combined and performed cyclically to better simulate the effects of in-service exposure. Test results provided the basis for the recommended set of thirteen tests.

The research also provided guidance on the use and interpretation of the test results to help select those systems that will provide long-term performance and durability when used under specific environmental conditions.

The appendix contained in the research agency's final report provides further elaboration on the work performed in this project. This appendix titled "Research Leading to the Development of Methodology for Durability Assessment of Detectable Warning Systems" is not published herein; but is available on the *NCHRP Report 670* summary web page at http://www.trb.org/Main/Blurbs/163989.aspx.

CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

SUMMARY

Recommended Procedures for Testing and Evaluating Detectable Warning Systems

The Americans with Disabilities Act mandates the use of tactile detectable warning systems at curb ramps to warn the blind and visually impaired of the transition to a vehicular way. The Americans with Disabilities Act Accessibility Guidelines outlines geometric, dome shape and visual contrast guidelines for detectable warning systems, which are generally adopted into federal, state and local requirements. Detectable warning systems meeting these requirements are currently available in a broad range of materials and designs, and the anticipated long-term performance of these systems varies widely. Little information is available regarding the long-term durability of many detectable warning systems currently on the market. The durability of these systems is an important part of their performance. To date, various materials test and field trial evaluation programs have been conducted, but the information that is available varies considerably in relevance and often does not permit objective comparisons. However, state and municipal agencies must make decisions about which available products should be used on the projects they supervise. To provide a universally applicable basis for evaluating detectable warning systems and provide a foundation for comparison and decision-making, NCHRP Project 4-33, "Recommended Procedures for Testing and Evaluating Detectable Warning Systems," was initiated. The goals of this project were the development of standard testing methodologies and guidance for assessing durability test results for a given set of environmental conditions. Testing of detectable warning system products for comparative purposes was not within the scope of this project. This work has consisted of a review of the available literature and a survey of state department of transportation (DOT) professionals, the development of testing methods and an overall testing protocol.

As a basis for the protocol and test method development, a review of the existing information regarding detectable warning system designs, materials, durability and testing was performed. The collective experience of state and municipal DOTs was surveyed, and important deterioration mechanisms of detectable warning systems as well as commonly used product types were identified. The important properties for the functional performance of detectable warning systems are color contrast, slip resistance, mechanical integrity, and dimensional stability. The most significant degradation mechanisms that may affect functional performance are freezing and thawing, abrasion, ultraviolet radiation, moisture, and extreme temperatures, as well as physical stresses caused by impact, snow removal and traffic.

The ability of detectable warning systems to resist these deterioration mechanisms has been considered during the development of the proposed testing protocol, which consists of subjecting systems to specific exposure regimes and evaluating the response to these regimes with a series of evaluation tests. Exposure regimes simulate the effects of outdoor in-service exposure, while the evaluation tests are used to assess durability and performance of the detectable warning systems. Since the durability of detectable warning systems is tied

to the interaction between the system and the concrete substrate to which the system is attached or anchored, the protocol is executed with the detectable warning systems installed in concrete slabs. The exposure regimes include freeze/thaw, high temperature thermal cycling, ultraviolet exposure, and abrasion exposure. The evaluation tests include visual and microscopic evaluation, color measurement, dome shape and geometry measurement, slip resistance, coating and single dome bond, resistance to impact from falling tup, wear resistance, and resistance to impact from simulated snowplow blade.

The exposure regimes are combined and performed cyclically to better simulate the effects of outdoor exposure. Environmental exposure leads to progressive deterioration; the effects of one type of exposure will build upon the effects of other types of exposure to produce overall greater deterioration than expected from each type of exposure alone. To address the wide variety of environmental conditions found throughout the United States, two exposure categories ("hot" and "cold"), based on climatic conditions, have been developed. Each exposure category consists of a set of cycled exposure regimes intended to simulate the types of exposure deterioration mechanisms observed by transportation professionals.

Non-destructive evaluation tests (visual and microscopic evaluation, color measurement, dome shape and geometry measurement, and slip resistance) are performed on specimens before exposure as well as after the exposure regimes. Destructive evaluation tests (coating and single dome bond, resistance to impact from falling tup, wear resistance, and resistance to impact from simulated snowplow blade) are conducted after completion of the exposure regimes. These test results can then be interpreted based on a level expected to produce acceptable performance and the perceived importance of the property being measured by the test. Both these interpretations and the test results themselves can then be used to make comparisons between products.

Thirteen draft methods covering the exposure regimes, evaluation tests, and an overall test protocol have been developed as part of this project. Additionally, guidance on the use of the methods and on interpretation of the results for determining which of the many available material systems will be durable for a given set of environmental conditions has been provided.

CHAPTER 1

Background

Detectable warning systems are installed at curbs throughout the United States in response to requirements of the Americans with Disabilities Act (ADA). Detectable warning surfaces warn visually impaired persons that they are approaching a street or crosswalk. Increasing wheelchair accessibility by replacing curbs with ramps at crosswalks has had the unintended effect of eliminating the tactile cue (curb) that visually impaired persons relied upon to detect the end of the sidewalk. To address this problem, the ADA has required that detectable warning systems that are also suitable for wheelchair and foot traffic be placed at curb ramps.

The ADA Accessibility Guidelines (ADAAG) specify a tactile detectable warning system in the form of truncated domes with base diameter of 0.9–1.4 inches (23–36 mm), top diameter of 50–65% of the base diameter, nominal 0.2-inch (5.1 mm) height, 1.6–2.4-inch (41–61 mm) center-to-center spacing, and a nominal base-to-base spacing of 0.65 inch (17 mm). The detectable warning system is required to have a visual contrast with adjoining surfaces (US Access Board, 2005). Contrasting colors (light on dark or dark on light) provide a visual clue to visually impaired persons, while the tactile surface of truncated domes provides a warning to blind persons using a cane for navigational aid, as well as a warning that can be felt underfoot.

Detectable warning systems are commercially available in a wide variety of materials and are anchored to the sidewalk by several different attachment mechanisms. Some products are intended to be used only in new construction, while others are intended to be used to retrofit existing sidewalk surfaces. The materials used in detectable warning systems include flexible polymer mats, metal, precast concrete and brick pavers, stamped concrete, rigid fiber-reinforced polymer composite panels, and others. Products for use in new construction are generally intended by the manufacturer to be embedded in freshly placed (plastic) concrete and may have a supplementary anchorage system, although they may alternatively be set in a sand bed or affixed with thin-set mortar. Retrofit products are usually adhered to the concrete surface with an adhesive and may also include supplementary mechanical anchorage. The exact shape and texture of the truncated domes varies from product to product.

There is no description in the ADAAG recommending material type or identifying durability requirements for detectable warning systems. To fill this need, National Cooperative Highway Research Program (NCHRP) Project 4-33, "Recommended Procedures for Testing and Evaluating Detectable Warning Systems," was initiated, and the goals of this project were the development of testing methodologies and guidance for determining which of the many materials systems available may be durable for a given set of environmental conditions. The findings of this project will assist state and municipal Departments of Transportation (DOTs) by providing laboratory testing methods than can be used to generate objective data to aid in the selection of durable detectable warning systems. The many variations of materials, textures and attachment mechanisms, as well as the different environmental and traffic conditions throughout the United States make evaluating durability of detectable warning systems challenging.

Detectable Warning Systems Performance and Deterioration Mechanisms

Prior to identifying tests suitable for evaluating durability of detectable warning systems, the desirable properties for these systems were identified. These are the properties that allow the detectable warning systems to perform their warning function and to serve as a safe travel surface for pedestrians and people in wheelchairs. These properties are required in the initial system and need to be maintained for the detectable warning system to assure functionality. The desirable properties are:

- Color contrast
- Slip resistance

- Mechanical integrity
  - Adhesion/attachment to substrate
  - Material strength
- Dimensional stability of truncated domes

These properties have a direct impact on the performance of a detectable warning system on a sidewalk. A contrasting color guideline is included in the ADAAG, and any fading or other changes in color as a result of exposure can affect functionality. A minimum level of slip resistance is required on all walking surfaces, and changes in slip resistance (coefficient of friction) can lead to an unsafe walking surface. Both the mechanical attachment to the sidewalk and the inherent strength of the detectable warning system to withstand various kinds of in-service loading are important to maintain functionality. A detectable warning system that comes partially debonded from the sidewalk can be a tripping hazard, while a system that becomes completely debonded can lead to both a tripping hazard and the loss of functionality of the system as a detectable warning. Cracking and warping of the detectable warning system can lead to decreased detectability, creation of a tripping hazard, and reduced capability to withstand additional environmental exposure. Finally, changes in the dimensions of the truncated domes may affect detectability. For all these reasons, a system that is not durable cannot be relied on to perform its function over time and is not desirable.

While determining what constitutes detectability and loss in detectability (e.g., how changes in the dimensions of domes affect detectability) is outside the scope of this research, changes in the properties of the detectable warning systems from the original values, or the results of testing performed after laboratory exposure, can be used to assess performance and durability.

Durability testing is needed because environmental exposure may have a deleterious effect on the performance of a detectable warning system. Examples of deteriorated detectable warning systems can be found throughout the United States (Figure 1).

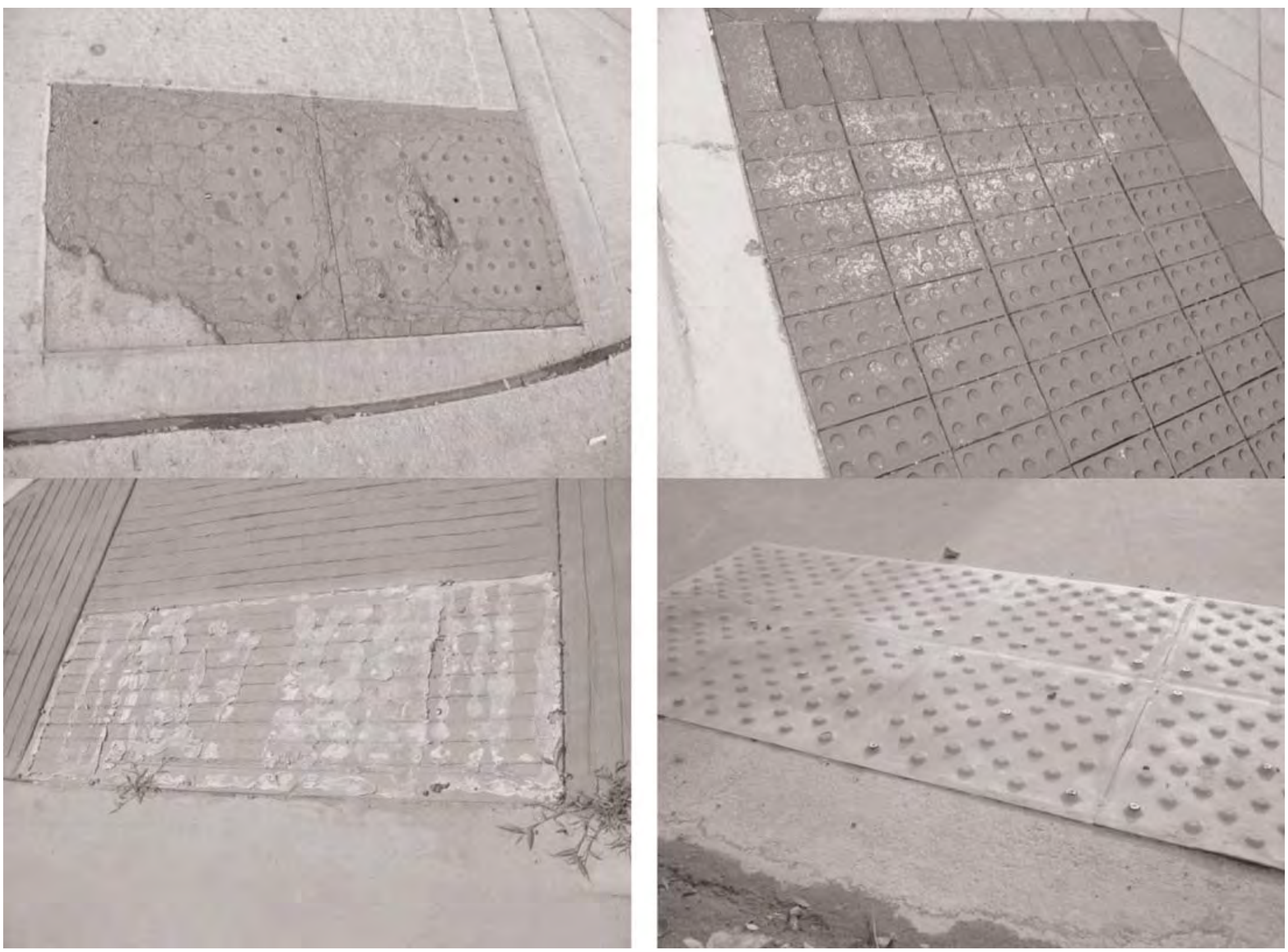


Figure 1. Photographs showing deteriorated detectable warning systems.

The following deterioration mechanisms have been identified as significant:

- Freezing and thawing
- Exposure to ultraviolet radiation
- Snow removal
- Abrasion
- Exposure to moisture
- Thermal cycling and exposure to high temperatures
- Impact
- Vehicle traffic
- Corrosion
- Exposure to moisture and alkalinity
- Salt scaling and corrosion of metallic systems
- Settling of pavers

Each of these deterioration mechanisms is caused by natural or man-made environmental exposure. In some geographic areas, detectable warning systems may be vulnerable to all of the listed deterioration mechanisms, while in other areas, some mechanisms may be negligible. Further discussion of these deterioration mechanisms is provided in Chapter 2. The ability of detectable warning systems to resist each of these mechanisms has been considered during the development of the evaluation protocol that is the objective of this research project.

Objectives and Scope of Completed Research

The objectives of this research were to (1) recommend test methods for evaluating durability of detectable warning systems and (2) provide guidance on the use of these methods for identifying detectable warning systems likely to be durable in different conditions.

The completed research consists of a set of draft testing methods suitable for evaluating durability of detectable warning systems. The methods have been developed with the goal of developing tests and evaluation criteria that are independent of the type of system; the methods are applicable to any type of detectable warning system.

This project was focused on the development of these test methods, rather than the evaluation of detectable warning systems. While commercially available products were used in the test method development, no comparisons of durability between products were made.

Organization of Project Documents

This report is organized into the main project report and two supplementary documents:

1. The main report provides introduction and background to the durability of detectable warnings, discusses the research approach, presents the findings and applications, and gives conclusions and recommendations for future work.
2. The attachment consists of the test protocol separated into a master test method, describing the overall testing protocol, and individual test methods, describing each test in detail. These methods are presented in AASHTO Standard Method of Test format and were written in a form suitable for review and possible adoption by AASHTO.
3. The appendix (available on the *NCHRP Report 670* summary web page: www.trb.org/Main/Blurbs/163989.aspx) consists of narrative documents describing the process by which each test method was developed, as well as reviewing the specific need answered by each method and the objectives during the development process. A section providing guidance on the interpretation of the test results is also provided.

CHAPTER 2

Research Approach

Summary of Tasks

The research approach consisted of two distinct phases. Phase I consisted of a review of available literature and information available from transportation agencies, the definition of long-term performance and durability requirements, the identification of properties that influence long-term durability, the identification of test methods currently used to evaluate these properties (if available), and the design of a test protocol for evaluating durability of detectable warnings. Phase II consisted of development and refinement of the test methods, development of guidance on the use of these test methods, preparation of these test methods in a format suitable for consideration and adoption by AASHTO, and preparation of this final report.

Phase I Approach

The efforts of Phase I focused on collecting and reviewing relevant information that formed the basis for this protocol development. The first part of the Phase I effort consisted of reviewing the available literature regarding the durability of detectable warning systems and reviewing the available literature and manufacturers' product data for test methods used on detectable warning systems and materials. This included a survey of local and state DOTs seeking information related to experiences with detectable warning systems and perceived deterioration mechanisms.

The Transportation Research Information Service (TRIS), National Technical Information Service (NTIS) and the Research in Progress site at the Transportation Research Board website have been extensively searched. In addition, an independent search for additional publications related to durability studies was conducted. Most of the pertinent information identified and reviewed is in the form of reports by state DOTs, as well as two published reports synthesizing earlier work and providing additional information on durability concerns collected from state and municipal DOTs.

To gather additional experiences and identify concerns of transportation professionals about long-term performance and durability requirements, a questionnaire prepared by the research team was submitted to state and municipal DOT representatives. The questionnaire requested information about the respondent's perceptions, problems, and experiences with the durability of detectable warning systems. In addition to direct submission to representatives of the 50 states, the questionnaire was submitted directly to approximately 30 other contacts and was posted on the FHWA's Highway Community Exchange Detectable Warning Discussion site, found at http://knowledge.fhwa.dot.gov/cops/hcx.nsf/home?openform&Group=Detectable%20Warnings.

From this information and the experience of the research team, the mechanisms of deterioration of detectable warning systems were determined, the suitability of standard test methods was evaluated and a test protocol for evaluating durability of detectable warnings was designed.

Phase II Approach

The objective of this phase was to develop and refine the proposed testing protocol consisting of individual exposure and evaluation tests suitable for evaluating durability of detectable warning systems.

The testing protocol has been developed with the following objectives in mind:

- The protocol evaluates detectable warning systems that have been attached to concrete slabs to test the durability of the installed system, while considering the interaction of the detectable warning system with a concrete substrate.
- A cyclic exposure protocol has been proposed to test the interaction of various exposure regimes. The exposures will by cycled to evaluate the interaction.
- The protocol is not product-specific; all tests are applicable to all types of detectable warning system materials and attachments.

The durability of detectable warning systems is inextricably tied to the interaction between the system and the concrete sidewalk to which it is applied or anchored, the exposures and evaluation tests were conducted on detectable warning systems installed in concrete slabs to appropriately simulate the field response under the applied exposure conditions.

The test protocol consists of exposing systems to specific physical and environmental regimes and evaluating responses to these regimes with a series of performance evaluation tests. Exposure regimes will simulate the effects of outdoor exposure, while the evaluation tests are used to assess durability and performance of the detectable warning systems. Exposure regimes include freeze/thaw, high temperature thermal cycling, ultraviolet light exposure, and abrasion exposure. Evaluation tests include: visual and microscopic evaluation, color measurement, dome shape and geometry measurement, slip resistance, coating and single dome bond, resistance to impact from falling tup, wear resistance, and resistance to impact from simulated snowplow blade.

The exposure regimes are intended to be combined and performed cyclically to simulate the effects of outdoor exposure, where exposure-related deterioration mechanisms act simultaneously. Environmental exposure leads to progressive deterioration; the effects of one type of exposure will build upon the effects of other types of exposure to produce overall greater deterioration than expected from simple additive effects. Two exposure categories ("hot" and "cold"), based on climatic conditions, have been developed. Schematics of the two exposure categories showing the cyclic exposure are provided in Figures 2 and 3.

Evaluation tests are laboratory procedures that test a specific property or quality of the detectable warning system. These tests may be performed on specimens before exposure and will be performed after exposure. The results of the tests conducted after exposure may be compared to the results from the as-fabricated specimens to determine durability of the product. These test results may also be compared to a set of minimum standards (which may be set by individual DOTs or by future legislation) to determine suitability of the product.

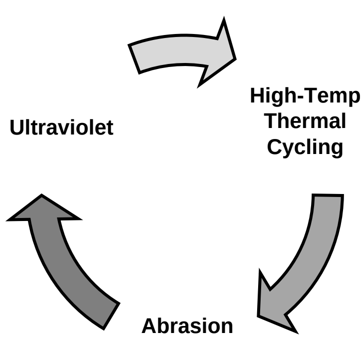


Figure 2. Cycle of exposure regimes for the hot exposure category.

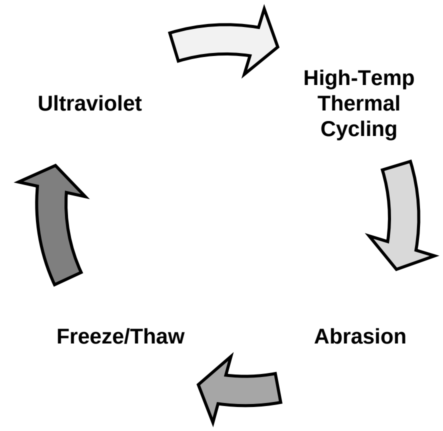


Figure 3. Cycle of exposure regimes for the cold exposure category.

Test Method Development

The literature review and survey of state and municipal agencies identified specific needs relative to the development of a procedure for evaluating durability of detectable warning systems. Each individual exposure and evaluation test method has been developed with the following objectives in mind. The standardized test methods need to be repeatable so that the data obtained can be compared with the results of other tests run according to the same method. The methods have been written to be implemented in any laboratory that has or can fabricate the basic facilities and equipment required. Where possible, existing standard test methods were used or adapted; however, most methods developed for this program could not adequately draw on an existing method. For each newly developed test, the equipment is defined in sufficient detail so that it could be obtained or fabricated. Finally, the test methods were developed with a goal of being representative of field exposure. Studies of field exposure were not included in this project, although the experience of the research team and the literature review and results of the survey provided insight as to the degradation mechanisms and lifetimes of some detectable warning systems.

The test protocol consists of a governing master test method that details the preparation of concrete slabs and attachment of the detectable warning systems and references the exposure methods designed to expose specimens to specific deterioration mechanisms and evaluation test methods for evaluating specific properties of the detectable warning systems before or after exposure. The applicable physical phenomena likely to cause deterioration of detectable warning systems are represented by four exposures and nine evaluation methods. Equipment to perform these methods was designed, built, and used to conduct these tests on samples representing the range of detectable warning systems that are currently commercially available. Based on the experience gained during this effort, the testing procedures were refined.

Sample Selection

Based on the literature review and survey of transportation professionals, commonly available detectable warning systems were classified into types by their material (metallic, flexible polymer, rigid polymer, etc.) and the attachment mechanism. Two attachment mechanisms predominate: cast-in-place, where the detectable warning system is cast into freshly placed plastic concrete, and surface applied, where the detectable warning system is applied to fully cured concrete. Cast-in-place systems are often used in new construction, while surface-applied systems are often used for retrofitting existing walkways.

Table 1. Specimen types selected for use in test method development.

Material Type	Installation Method
Rigid polymer composite panel	Cast-in-place
Rigid polymer composite panel	Surface-applied
Flexible polymer panel	Surface-applied
Metal panel	Cast-in-place
Polymer concrete panel	Cast-in-place
Single domes	Surface-applied
Precast concrete paver	Paver--thin set mortar

The seven specimen types selected for use in the test method development phase are provided in Table 1.

Specimens were obtained from suppliers that were selected, in part, to represent commonly used brands based on the literature review and survey, although the brands represented are not necessarily the most commonly used.

CHAPTER 3

Findings and Applications

Findings of Literature Review

A literature search was conducted to locate published information on durability studies of detectable warning systems, including tests performed and results obtained. The literature generally took one of the following forms: syntheses and summaries, reports of field trials, reports of property-specific laboratory or field tests, and laboratory testing protocols.

Syntheses and Summaries

Detectable Warnings: Synthesis of U.S. and International Practice (Bentzen et al., 2000) discusses, in part, local perceptions of durability of detectable warning systems. The authors conducted interviews with persons responsible for detectable warning system installation. Detectable warning systems were generally installed in the late 1990s and had often three or fewer years of service life at the time the interviews took place. While some of the particular products discussed are no longer on the market, the material and installation types represent products that are currently available and continue to be used. The report outlines several types of degradation, probable causes of degradation (as reported by the interviewees), and the geographic location of the detectable warning system. Several locations, both in the southern and northern regions of the U.S., reported color fading. Peeling of adhesive-applied systems was listed as a problem at multiple locations. Cracking was reported to be a problem in several areas and was felt to be related to freezing and thawing, snow removal, or the use of vehicles or carts over the detectable warning systems.

NCHRP Project 20-7 (Estakhri and Smith, 2005) provided a synthesis of information from publicly available sources and interviews with Alaska DOT and New York DOT that are not available in other published sources. The report discusses material selection and durability concerns, among other topics. The most prominent degradation mechanisms outlined in the report are chipping of domes, removal of surface-applied systems, loosening of anchors, cracking and color fading. The report relates the deterioration mechanisms to both geographic location of the installation and the type of material.

Reports of Field Trials

Most of the reports reviewed by the research team involved field trials and assessments of various proprietary detectable warning systems performed by DOTs. These reports include general comments on the observed durability of the installed systems, and sometimes opinions were provided regarding the mechanisms of deterioration that caused degradation. However, the specific mechanisms or events that lead to the noted deterioration were not normally quantitatively documented. Most studies involved periodic inspection of the detectable warning systems, and the events that led to specific types of degradation were not witnessed. While care was often taken to place detectable warning systems of different types in equivalent locations, the specific conditions for each detectable warning system were not identical. For example, snow removal methods (a significant source of degradation) often varied based on location.

A summary of the durability findings of these DOT reports, along with information presented in Bentzen et al. (2000) and Estakhri and Smith (2005), is presented in Table 2.

Reports of Property-Specific Laboratory or Field Tests

Many reports related deterioration to snow removal. Studies by New Hampshire (Boisvert, 2003) and Illinois (IDOT, 2005) specifically studied the effect of snow removal operations on detectable warning systems by purposefully running a snowplow over detectable warning systems in particular locations. The effect of the plowing on these locations was documented. In addition to the information provided in the published reports, communication with personnel from Wisconsin DOT

Table 2. Summary of findings from published field trials.

Study Location	System Types	Type of Degradation	Listed Source of Degradation
New Hampshire (Boisvert, 2003)	Surface-applied single domes, stamped concrete, polymer concrete, rigid polymer composite panel, flexible polymer mat, brick paver, precast concrete paver	Damaged or missing domes	Snow removal (study specially tested snow removal durability)
Wisconsin (Kemp, 2003)	Rigid polymer composite panel (cast-in-place and surface-applied), precast concrete paver, stamped concrete, flexible polymer mat, surface-applied single domes	Coating abrasion, damaged domes, debonding, inconsistent dome shape (stamped concrete)	Snow removal
Vermont (Kaplan, 2004; Kaplan, 2006)	Surface-applied single domes, flexible polymer mat, polymer concrete, rigid polymer composite panel, metal panel, stone paver	Debonding of mats and single domes, dome damage, dome removal, removal of non-slip texture, color fading, bleeding of rust from cast iron panel, coating abrasion	Snow removal, sun exposure
Montana (Abernathy 2003; Abernathy, 2004a; Abernathy, 2004b; Abernathy, 2005)	Flexible polymer mat, rigid polymer composite panel, surface single applied domes	Dome wear, debonding of mats and single domes, coating loss, tearing of mats, loss of anchor pins, color fading	Snow removal, sun exposure, freeze/thaw
Oregon (Kirk, 2004)	Surface single applied domes, flexible polymer mat	Dome damage, color fading	Not specified
Illinois (IDOT, 2006)	Rigid polymer composite (cast-in-place and surface-applied), metal panel, stone paver, precast concrete pavers	Chipping of domes, removal of domes	Snow removal (study focused on snow removal durability)
Massachusetts Bay Transportation Authority (Ketola and Chia, 1994)	Flexible polymer mat, ceramic tiles, polymer concrete, rigid polymer composite (surface-applied)	Color fading, cracking, debonding, chipping, dome damage, pitting	Snow removal, foot traffic, freeze/thaw, dirt accumulation
Austin, Texas (Bentzen et al., 2000)	Brick pavers	Paver damage	Truck traffic
Claremont, California (Bentzen et al., 2000)	Flexible polymer mat	-- (newly installed system)	-- (no data available)
Metropolitan Atlanta Rapid Transit Authority (Bentzen et al., 2000)	Rigid polymer composite panel	Chipping, cracking, loss of anchors	Steel wheeled carts
Roseville, California (Bentzen et al., 2000)	Rigid polymer composite panel	Color fading	Not specified
Metro North Railroad (Bentzen et al., 2000)	Rigid polymer composite panel	Cracking, color fading, platform deterioration	Freeze/thaw, snow removal, equipment, ultraviolet exposure
Bay Area Rapid Transit (Bentzen et al., 2000)	Flexible polymer mat, rigid polymer composite panel	Delamination of mats, color fading	Weathering, platform vibration, cleaning equipment
Baltimore County, Maryland (Bentzen et al., 2000)	Brick paver	Dome wear	Not specified

Table 2. (Continued).

Study Location	System Types	Type of Degradation	Listed Source of Degradation
Cleveland, Ohio (Bentzen et al., 2000)	Brick paver	Loose pavers	Truck traffic
Harrisburg, Pennsylvania (Bentzen et al., 2000)	Stamped concrete (fabricated off-site into pavers)	Wear, settling, cracking, broken domes	Truck traffic, other
Alaska (Estakhri and Smith, 2005)	Precast concrete paver, rigid polymer composite panel, surface-applied single domes, flexible polymer mat	Dome damage, delamination of mats, adhesive deterioration	Snow removal, weathering, extreme cold temperatures
New York (Estakhri and Smith, 2005)	Rigid polymer composite (cast-in-place), precast concrete paver, polymer concrete, brick paver, flexible polymer mat	Delamination of mat, dome wear, dome removal	Snow removal and other

(WisDOT) indicated that the State of Wisconsin has developed a snowplow test in which a detectable warning panel is placed in a plywood jig and passed over 50 times with a truck-mounted plow. Only products that pass this test (based on visual evaluation) are approved by WisDOT.

Two published studies involved lab testing, in addition to field trials. The first study focused on detectable warning systems for mass transit systems, rather than for sidewalk usage (Ketola and Chia, 1994). The tests conducted were water soaking, bond strength, abrasion resistance, simulated cleaning, coefficient of friction, and impact resistance. The results of the testing and rationale for selecting certain tests were not discussed in detail in the publication. The second study was carried out by the State of Wisconsin, in conjunction with Minnesota DOT, and consisted of ultraviolet/condensation weathering tests (Kemp, 2003). The degree of color fading was measured instrumentally after the testing.

Laboratory Testing Protocol

The working notes from California's Evaluation of Detectable Warnings Advisory Committee (EDWAC) are another significant source of information relevant to this project. This committee was set up under the California Division of the State Architect and was tasked with overseeing the development of a set of tests aimed at assessing durability of detectable warning systems. The California State Assembly charged the Division of the State Architect with developing a test methodology to demonstrate that shape, colorfastness, confirmation, sound-on-cane acoustic quality, resilience, and attachment will not degrade by more than 10% of the approved design characteristics over five years. While EDWAC and members of the public have identified other parameters that affect durability, the focus of the work has been on those criteria specifically outlined in the legislation. Meeting minutes and draft test standards are publicly available and were consulted by the research team. The most recent draft, published in February 2006, includes the testing methods and describes conditioning regimes for outdoor and indoor use (EDWAC, 2006). The outdoor testing regime consists of ultraviolet, chemical, abrasion, elevated temperature, and optional freeze/thaw and optional salt spray exposures. The indoor testing regime consists of ultraviolet, chemical and abrasion exposures.

Findings of Survey of State and Municipal Departments of Transportation

Twenty-two representatives of state and municipal DOTs responded to a questionnaire requesting input regarding durability of detectable warning systems. The responses from state and municipal DOT representatives are summarized here. The responses came from all over the United States, with twelve responses from locations with cold, snowy winters, six responses from areas with hot summers and little to no snow in the winters, three responses from mainly temperate regions, and a response from the State of Utah, which experiences both significant snow in the winter in some regions and very hot summers in others. While the responses were grouped as above, it is recognized that the climatic conditions often vary throughout a state, and many states may contain both hot and cold weather regions.

The respondents were questioned on their perception of the most critical deterioration mechanisms. As summarized in Table 3, snow removal, ultraviolet/sun exposure, freezing and thawing, and abrasion from foot traffic were identified as the four most critical deterioration mechanisms. Unsurprisingly, the fourteen respondents who consider snow removal a key deterioration mechanism are from states where cold weather is common, such as Ohio, Illinois, and New York, while the respondents who did not consider snow removal an issue come from climates where snow is less common, such as Arizona,

Table 3. Deterioration mechanisms reported as important.

Deterioration Mechanism	Number of Responses*
Snow removal	14
Freeze/thaw	10
UV/Sun exposure	9
Other	9
Abrasion from foot traffic	7
Extreme temperatures	6
Thermal cycling	5
Abrasion from vehicle traffic	3

* out of 22 total responses

Nevada, and Washington. The respondents who list ultraviolet/sun exposure as a key deterioration mechanism are from all over the country, including areas, such as New Jersey, that experience cold winters. The respondents concerned with abrasion from foot traffic are from locations throughout the United States. Some respondents specified "other mechanisms," which varied from problems with water staining and poor adhesion to the walking surface, to cracking from heavy vehicles traveling over the detectable warning system.

The responses to the key deterioration mechanisms vary by geographic location. This highlights the need to have a testing approach that considers more than one exposure category, so an appropriate testing methodology can be chosen for locations where certain deterioration mechanisms may be prevalent. Environmental conditions vary throughout the country, with snow and cold weather common in the northern parts of the country, while high temperatures and high ultraviolet exposure is common in the southern part of the country. While environmental conditions vary, all areas of the country suffer from some common deterioration mechanisms, such as abrasion from foot traffic, and this needs to be considered for all geographic locations.

In addition to requesting information on deterioration mechanisms, the questionnaire also requested responses as to opinions of the most critical material properties that influence durability of detectable warning systems. A summary of the responses is presented in Table 4.

Three-quarters of the respondents selected slip resistance as a critical material property. It is obviously important for a walking surface to maintain slip resistance and not endanger pedestrians. Freeze/thaw resistance was the next most frequently cited material property. While cited as a material property, freeze/thaw resistance is a function of both the material itself and the detectable warning system/sidewalk system. Nine of the thirteen respondents who selected freeze/thaw resistance as an important material property are from "cold" regions.

The questionnaire also requested information on how the respondents select detectable warning systems. A summary of responses is presented in Table 5. Many respondents (12 out of 22) indicated that they choose detectable warning systems based on discussions with suppliers. Fifteen respondents indicated that they reviewed manufacturer's product literature to aid the decision-making process. Most respondents (18 out of 22) use field trials to evaluate various detectable warning systems. Many respondents use more than one method to select detectable warning systems for use in their location. Only four states were found to rely on lab or field tests in addition to field trials: New York, which tests contrast ratio; Georgia, which tests physical dimensions; Wisconsin, which tests snowplow resistance; and Minnesota, which tests ultraviolet/condensation, chemical resistance, wear resistance, freeze/thaw exposure, water absorption, impact resistance, and snowplow exposure.

Four locations (Nevada, Florida, New York, and Cincinnati, Ohio) reported that they require test data to be submitted by the material supplier prior to approval of a product. The data required varies based on department and on the types of materials systems approved. Nevada has specifications for the compressive strength of precast pavers and coefficient of friction and several proposed specifications for polymeric materials, which are not on the approved list but are under consideration, which would include tests for artificial weathering, chemical resistance, water absorption, tensile strength, compressive strength, color, impact resistance, and salt fog resistance. Florida DOT requires manufacturers to provide data on coefficient of friction, wear resistance, water absorption, bond strength and artificial weathering. New York DOT requires manufacturers to submit certified test data and has different requirements for cast-in-place units and surface-applied units. For cast-in-place units, data on compressive strength and freeze/thaw testing must be supplied. For surface-applied units, test data on wear resistance, coefficient of friction and bond strength must be supplied. The City of Cincinnati

Table 4. Material properties reported as critical.

Material Property	Number of Responses*
Slip resistance	16
Freeze/thaw resistance	13
Compressive strength	11
Flexural strength	11
Fade resistance	10
Chemical resistance (deicers, cleaning chemicals)	7

* out of 22 total responses

Table 5. Methods of selection used by agencies.

Method of Selecting Detectable Warning Systems	Number of Responses*
Field trials	18
Product literature	15
Discussions with suppliers	12
Lab tests	3

* out of 22 total responses

has requirements for brick pavers including water absorption, freeze/thaw resistance and general conformance to ASTM C 902 *Standard Specification for Pedestrian and Light Traffic Paving Brick Class SX, Type I.*

Discussion of Findings of Literature Review and Survey

The findings of the literature review and survey were summarized in terms of the deterioration mechanism judged significant to the durability of detectable warning systems and in terms of the range of detectable warning system products that the test protocol may be used to evaluate.

Deterioration Mechanisms

Several deterioration mechanisms were reported in the literature review and in the survey:

- Freezing and thawing
- Snow removal
- Exposure to ultraviolet radiation
- Abrasion
- Impact
- Exposure to extreme temperatures
- Thermal cycling
- Exposure to moisture
- Exposure to chemicals (including deicers)
- Vehicle traffic
- Settling and displacement of pavers

Displacement of pavers can be primarily an installation or a water drainage issue and will not be considered for the purposes of this study. The others are a result of environmental exposure and have been considered during development of the exposure regimes and evaluation tests.

Detectable Warning System Products

The literature review and survey identified many materials and system types. Table 6 lists the products currently approved or preferred by the survey respondents.

In addition to these products, the research team conducted a review of the products currently marketed as detectable warning systems. An Internet survey of the products currently on the market provided useful information on the types of systems

Table 6. Approved or preferred products listed by survey respondents.

Location	Approved or Preferred Products
Vineland, New Jersey	Metal panels
Princeton, New Jersey	Metal panels, rigid polymer composite panels (surface-applied)
Arkansas	Rigid polymer composite panels (cast-in-place)
Texas	Rigid polymer composite panels (cast-in-place and surface-applied), flexible polymer mat, brick pavers, precast concrete pavers, metal panels
Montana	Metal panels
Illinois	No specific products
South Dakota	Precast concrete pavers
Colorado	Precast concrete pavers, brick pavers
Arizona	Rigid polymer composite panels, ceramic panels, steel panels, stone pavers, polymer concrete panels, single anchored domes, precast concrete pavers
Nevada	Precast concrete pavers, brick pavers
Florida	Rigid polymer composite panels, flexible polymer mats, precast concrete pavers, brick pavers, metal panels
Oregon	Rigid polymer composite panels, single surface-applied domes, flexible polymer mat, ceramic panel, polymer concrete, precast concrete pavers
Wyoming	Metal panels, ceramic panels, precast concrete pavers, rigid polymer composite panels
Cincinnati, Ohio	Brick pavers, rigid polymer composite panels, metal panels, surface-applied single domes
Bellevue, Washington	Rigid polymer composite panels, flexible polymer mats
Georgia	Metal panels, rigid polymer composite panels (surface-applied and cast-in-place), flexible polymer mat
Utah	Precast concrete pavers
West Virginia	No response
Delaware	Metal panels, pavers
Rhode Island	No response
New York	Rigid polymer composite panels (surface-applied and cast-in-place), flexible polymer mat, single surface-applied domes, stamped concrete, brick pavers, precast concrete pavers, polymer concrete, metal panels
Minnesota	Metal panels, polymer concrete

(methods of attachment) as well as the types of materials used in detectable warning systems.

Methods of Attachment

Detectable warning systems can be broken down into the following system types by the method of attachment to the sidewalk:

- Prefabricated panels that are cast into plastic concrete (cast-in-place)
- Surface-applied systems, consisting of:
  - Rigid panels that are attached to cured concrete by an adhesive system and sometimes supplemental anchors
  - Flexible panels that are attached to cured concrete by an adhesive system and sometimes supplemental anchors
  - Single domes that are attached to cured concrete, with a coating applied over the domes and concrete. Domes are attached with adhesive, cast directly onto the concrete, or attached with mechanical anchors.
- Pavers that are supported on a sand setting bed, bituminous setting bed, or thin set mortar
- Domes formed by imprinting plastic concrete (stamped concrete)

Systems that are cast-in-place or stamped can only be applied to new sidewalk construction; if a retrofit of an existing sidewalk is desired, the old concrete must be removed and replaced with new concrete. Systems that are surface applied can be applied to existing concrete with a varying amount of surface preparation required, according to the manufacturer's installation instructions. The use of precast pavers may require replacing the sidewalk concrete, or may be retrofit, depending on the geometry of the previous installation (for example, non-truncated dome pavers may be replaced with truncated dome pavers).

Material Types Reported

A significant variation in the types of materials from which detectable warning systems are fabricated exists. The main material types can be grouped into the following categories:

- Stamped concrete (standard sidewalk concrete with a formed truncated dome surface). The concrete may be integrally colored, or a colored coating may be applied to the surface.
- Flexible polymer mats. These mats are applied to the concrete surface with adhesive and may be integrally colored, or a colored coating may be applied to the surface.
- Surface-applied domes with a polymeric-based coating on the surface. A number of materials are used for the domes, including rubber, polymer, ceramic and aluminum.
- Metallic systems. These systems are cast-in-place or surface applied, consist of stainless steel or cast iron and may be coated or left bare to form a natural patina in the case of cast iron.
- Rigid polymer composite panels. These materials consist of rigid polymer matrices with fiberglass or other reinforcement. These systems may be cast-in-place or surface applied and are integrally colored.
- Polymer concrete. These systems consist of sand in a polymer matrix, may be surface applied or cast-in-place and are integrally colored.
- Pavers. This general type encompasses precast concrete pavers, brick pavers and stone (granite) pavers. These systems may be attached with a setting bed, bituminous setting bed, or thin set mortar. Pavers are generally integrally colored.
- Ceramic panels. These systems consist of ceramic panels that are adhered to fresh concrete with setting pins. Only one product remains on the market.

Summary of Proposed Test Methods

To support the development of the test protocol, the proposed test methods were conducted on samples representing a range of detectable warning systems. The testing procedures were refined based on the experience gained during this effort. The refined test methods were then presented as recommended methods of test and are provided in the attachment to this report. The following discussion outlines the specific need for each test method and its key objectives, and provides a brief summary of the method. Further discussion regarding the development of each test method is given in the appendix.

Durability of Detectable Warning Systems (Master Test Method)

For detectable warning systems to function properly and to serve as a safe walking surface, the following properties are essential: color contrast, slip resistance, mechanical integrity and dimensional stability. Environmental exposures and traffic-related forces may trigger deterioration mechanisms that have a deleterious effect on these properties. These deterioration mechanisms are expected to interact, making long-term in-service behavior difficult to predict. The key objectives in the development of the test protocol for evaluating durability of detectable warning systems were (1) to consider significant deterioration mechanisms, (2) to replicate the potential interaction of deterioration mechanisms, (3) to provide a universally applicable method that could be used to compare currently known product designs regardless of material or anchorage, and (4) to permit flexibility in the interpretation of the test results relative to local requirements and environmental conditions, as well as future findings.

Table 7. Exposure category for each test method.

Test Method	Hot Exposure Category	Cold Exposure Category
Non-destructive Evaluation Test		
Visual and Microscopic Evaluation	Yes	Yes
Dome Shape and Geometry Measurement	Yes	Yes
Color Measurement	Yes	Yes
Slip Resistance	Yes	Yes
Destructive Evaluation Test		
Coating and Single Dome Bond	Yes	Yes
Resistance to Impact from Falling Tup	Yes*	Yes
Wear Resistance	Yes	Yes
Resistance to Impact from Simulated Snowplow Blade	No	Yes
System Bond	Yes**	Yes**
Exposure Regimes		
Freeze/Thaw	No	Yes
High Temperature Thermal Cycling	Yes	Yes
Ultraviolet Light Exposure	Yes	Yes
Abrasion Exposure	Yes	Yes

* Tests performed at room temperature only
** No method finalized

The protocol tests detectable warning systems installed in or applied to concrete slabs. Two types of test methods are used. The first type of method is the evaluation test, which measures a specific property or quality. The evaluation tests are further characterized as non-destructive evaluation tests—which include visual and microscopic evaluation, color measurement, dome shape and geometry measurement and slip resistance—and destructive evaluation tests—which include system bond (no method finalized), coating and single dome bond, resistance to impact from a falling tup, wear resistance and resistance to impact from a falling snowplow blade. The second type of method is the exposure regime, which simulates the effects of in-service exposure but does not include an evaluation phase. The evaluation tests are used to quantify the effects of the exposure regimes. The exposure regimes consist of freeze/thaw, high temperature thermal cycling, ultraviolet light exposure, and abrasion exposure.

The execution of the test protocol requires preparation of two detectable warning system/concrete slab specimens for each product in a manner that replicates the manufacturer's recommended procedures. The non-destructive evaluation tests are then performed on these unexposed samples. (Optionally, the destructive evaluation tests can also be performed on unexposed samples, but this requires additional slab specimens.) The samples are then subjected to four sequential cycles of the exposure regimes, with each cycle consisting of one quarter of the full exposure duration. At the conclusion of each quarterly exposure cycle, all evaluation tests are performed and subsequently used to assess durability and performance of the detectable warning systems.

The specific details of exposure regimes are determined by the exposure category, which is selected by the user based on anticipated environmental conditions where the detectable warning system will be used. Two broad categories, named "hot" and "cold", are identified and are intended to represent the environmental extremes observed in the United States. For the hot exposure category, the duration of the ultraviolet exposure is greater, the maximum temperature defining the high-temperature thermal cycling test is higher, and the freeze/thaw exposure and resistance to impact from simulated snowplow blade evaluation tests are not included. The test methods for each exposure category are given in Table 7. The full exposure durations for each category are outlined in Table 8.

Part 1—Freeze/Thaw Durability

Repeated freezing can cause cracking and degradation of the detectable warning system as water trapped in the system undergoes volumetric expansion. The freeze/thaw durability test method is intended to recreate conditions that might cause freeze/thaw damage and expose the samples to deicing chemicals.

Table 8. Total exposure duration for each exposure category.

Exposure Regime	Hot Exposure Category	Cold Exposure Category
Freeze/Thaw	(None)	60 cycles
High Temperature Thermal Cycling	60 cycles 25-93ºC (77–200°F)	60 cycles 25-77ºC (77–170°F)
Ultraviolet Light Exposure	1500 hrs	1000 hrs
Abrasion Exposure	16 passes	16 passes

The proposed method consists of a freeze/thaw test where the concrete/detectable warning system samples are ponded or submerged in sodium chloride solution and subjected to repeated freezing and thawing cycles. The entire top surface of the specimen is ponded or submersed for the full duration of the test, to allow water to penetrate around any attachments, gaps, joints, or cracks in the detectable warning system/concrete composite system. Water that freezes underneath the detectable warning system may lead to "freeze-jacking," whereby upheaval, cracking or distortion of the detectable warning system occurs as the water volume expands during the freezing process.

During the test, the system is held below freezing until the solution ponded on top of the detectable warning system has frozen completely. The samples are then held at a thawing temperature until the solution has completely thawed. A representative plot of this freeze/thaw cycle is shown in Figure 4. This freeze/thaw cycle is repeated for a total of sixty times, fifteen times for each exposure cycle of in the test protocol. The freeze/thaw resistance test is not intended to be conducted to evaluate performance in the hot exposure category.

Part 2—High Temperature Thermal Cycling

Thermal cycling may cause restraint-related deterioration as a result of differential thermal expansion of the detectable warning system and the concrete sidewalk. High temperatures induced by radiant exposure may also cause degradation and softening of materials or adhesives. The high temperature thermal cycling test is designed to simulate the effects of cyclical variation in temperatures on detectable warning systems fixed to a concrete substrate using a control cycle defined independently of system characteristics.

Detectable warning systems are subjected to thermal cycling between specified temperatures, with the maximum temperature varied based on the exposure conditioning category. Specimens are irradiated with heat lamps to provide surface heating. The exposure is controlled based on insulated black panel thermometers, allowing the irradiation to be controlled independently of the detectable warning system properties. After the heating cycle, the specimens are cooled with flowing water, which produces both a thermal shock as well as exposing the materials to moisture. Photographs of the test apparatus during heating and cooling cycles are shown in Figures 5 and 6, respectively.

The basic test cycle, which is repeated a number of times based on the exposure conditioning category, consists of the following steps:

Ramp—Heat the specimen until an insulated black panel thermometer placed on the surface of the specimen reaches the desired maximum temperature, which is 93°C (200°F) for the hot exposure category and 77°C (170°F)

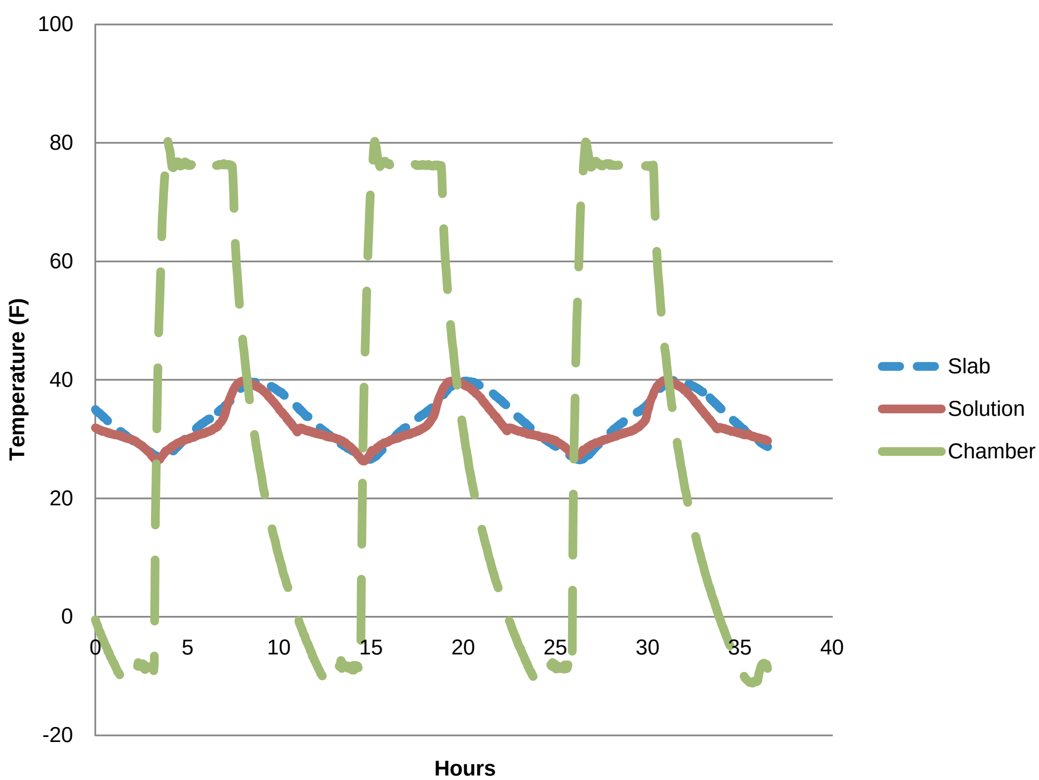


Figure 4. A plot of the freeze/thaw durability test temperatures.

Figure 5. High temperature thermal cycling enclosure and sample under heating (ramp) portion of test cycle.

for the cold exposure category. This heating must be performed within a set time period.

Soak—Maintain the temperature of the insulated black panel thermometer for a set time period.

Cool—Cool the specimen until the central thermocouple embedded in the concrete reaches a baseline temperature of 25°C (77°F). After this temperature is reached, the cycle repeats.

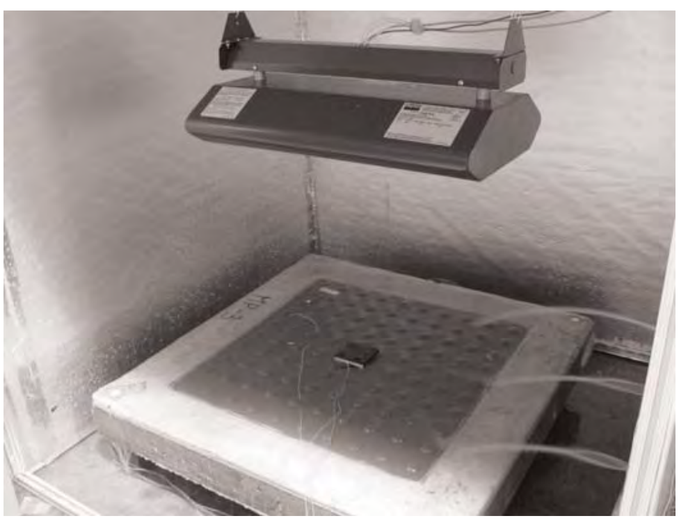


Figure 6. High temperature thermal cycling enclosure and sample under cooling portion of test cycle (note the sheet of water draining to the left on the sample surface).

Part 3—Ultraviolet Light Exposure

Ultraviolet (UV) exposure can cause color fading, surface cracking, or other general material degradation. The objective of the UV light exposure is to simulate exposure to the UV radiation in sunlight.

The UV light exposure is conducted according to ASTM G 151-06 *Standard Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources* and ASTM G 154-06 *Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials*. UV lamps are positioned at a fixed distance above the detectable warning system surface. The lamps are UVA-340 fluorescent lamps that are intended to simulate sun exposure in the UV-A region. These lamps are the same and the distance is similar to a conventional commercially available UV weathering cabinet. The systems are placed in an enclosure to protect worker's eyes from the UV radiation and maintain constant exposure conditions for the specimens. The enclosure used for test development is shown in Figure 7. The duration of irradiation is different for the hot and cold exposure categories. The hot exposure category has a 50% longer duration of UV irradiation than the cold exposure category.

Part 4—Abrasion Exposure

Abrasion from foot traffic or wheeled traffic can reduce overall dome height and alter the surface texture of detectable warning systems. The method discussed in this section is the abrasion exposure and is contrasted with the wear resistance test, which is an evaluation test. The objective of the abrasion exposure is to simulate wear of the dome surface in a progressive and realistic way, so that other wear-triggered exposure-related deterioration mechanisms could manifest.

The proposed test method consists of a laboratory-based exposure test where a fixed weight sled, consisting of aluminum oxide abrasive paper mounted against a sheet of compressible

Figure 7. Interior of the UV light exposure enclosure.

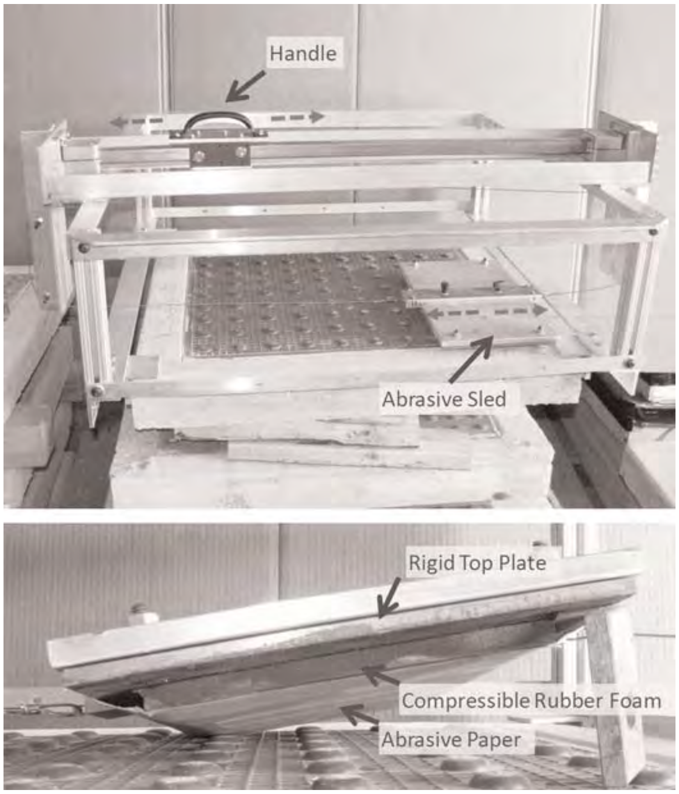


Figure 8. Abrasion exposure setup.

foam attached to a rigid plate, is translated across the surface of the system by a hand-operated dolly and cable system. The foam allows the sandpaper to partially conform to the tops of the domes. The test apparatus is shown in Figure 8. This sled, which is sized to cover half of the nominal 24-inch wide typical detectable warning system, is cycled back and forth over the surface of first one half of a system and then the other half. For informational purposes only, the effect of the abrasive action can be assessed by measuring the height of domes before and after exposure.

Part 5—Visual and Microscopic Evaluation

Visual and microscopic evaluation is needed to observe conditions that develop as a result of the exposure cycles that are not readily measured by other techniques, such as cracking or changes in elevation of the detectable warning system in the concrete.

Visual examination is carried out on as-fabricated specimens and consists of examining the specimens for discoloration, cracking, surface distress and other evidence of degradation. Any unusual features prior to exposure, including local discoloration, chips, cracks, and other features are marked on a data sheet. Test specimens are photographed to document conditions. Microscopic evaluation is performed with a portable 10X to 30X magnification field microscope on two spots, approximately one square inch each, on the specimen surface. Microcracking or other forms of surface distress are observed with the field microscope. Similar microscopical examinations are conducted and documented after exposure and are compared to observations made prior to the exposure regime.

Part 6—Color Measurement

Excessive color fading can reduce the color contrast of a dark-on-light system and may lead to non-compliance with adopted specifications. The objective of the color measurement is to provide useful color data for comparison of the detectable warning system surfaces.

The method consists of measuring the color of domes and field areas of a detectable warning system using a colorimeter. The CIELAB system is used to measure color. Measurements are made on ten dome or field areas, and the L^*, a^*, and b^* values are averaged because the surfaces of many detectable warning system products are very rough and, even with an instrument with an integral light source, readings may vary somewhat because of the roughness. Averaging the results of ten readings minimizes the effect of the variability in the readings.

Color difference as a result of exposure is measured as the change in lightness, ΔL^*, the change in redness/greenness, Δa^*, the change in yellowness/blueness, Δb^*, or the overall change in color, ΔE. The overall change in color, ΔE, is suggested as the means for estimating color change, although individual agencies may find differences in one of the other coordinates more useful. For example, if only yellow detectable warning systems are allowed under specification, an agency may find Δb^* more useful, or for agencies that specify any color or range of colors, ΔL^* may provide a measure of fade from dark to light.

Part 7—Dome Shape and Geometry Measurement

Measurement of the shape and dimensions of the truncated domes is required to evaluate compliance with specification requirements. Additionally, shape measurements can be used to quantify damage to domes as a result of exposure or evaluation tests. The shape test method is referenced by a number of the other test methods.

The dome diameter at the base, dome diameter at the top, and inter-dome spacing are measured with calipers. The rounded shape of some domes makes it difficult to identify the dome top and dome base for diameter measurements with precision, because edges may not be clearly delineated. Operator judgment will be relied upon to take measurements at the top and the base. Four domes will be measured and the values averaged. The averaging of multiple readings will

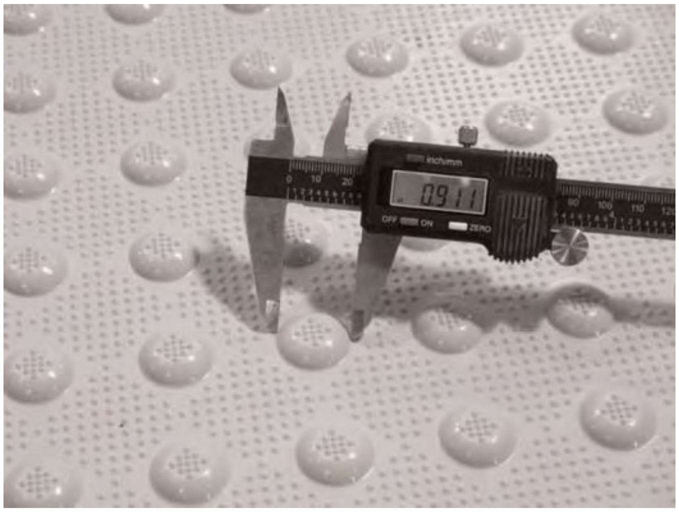


Figure 9. Dome shape and geometry measurement (measuring the dome base diameter).

accommodate slight differences in dome dimensions and operator uncertainty in measurement. Measuring the dome diameter at the base with calipers is shown in Figure 9.

The dome height is measured with a depth gauge mounted to a steel plate that can be placed over the top of four domes. The gauge spindle point rests on the bottom of the field, while the plate rests on the highest feature on the top of the domes. Figure 10 shows the depth gauge on a detectable warning system.

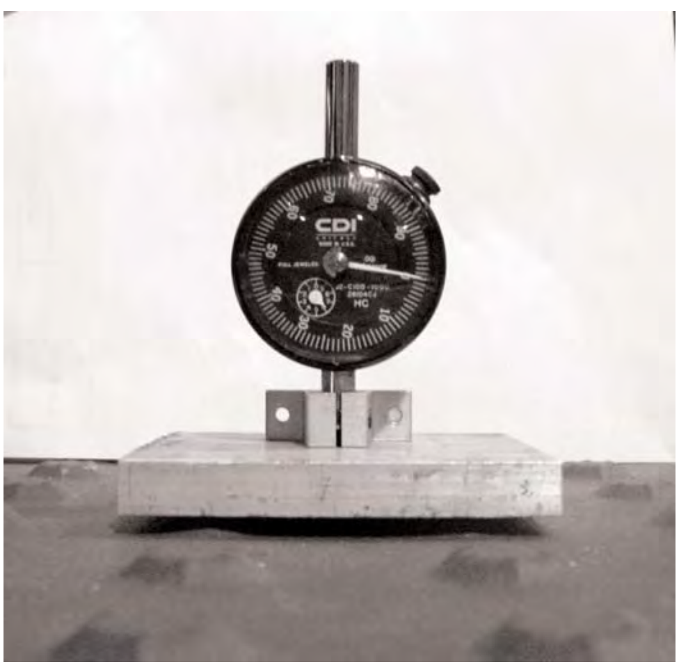


Figure 10. Dome shape and geometry measurement (measuring the dome height).

Part 8—Coating and Single Dome Bond

Detectable warning systems may be coated or consist of an array of individually adhered surface-applied single domes. Coatings may become degraded and surface-applied single domes may lose adhesion caused by several degradation mechanisms. The coating and single dome bond test was developed to measure bond strength of coatings and surface-applied single domes.

The proposed method consists of adhering dollies to the surface of the detectable warning system that are then pulled off in direct tension. A Type V tension tester, described in ASTM D 4541 *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers,* provides a reading of the pull-off force required to overcome the bond of the coating to the system. This force is converted to a pull-off strength based on the area of the dollies or the equivalent diameter of the surface area stressed. Testing is carried out in triplicate on the tops of the domes and also in triplicate on the field between domes, because the adhesion may be different in these areas. Schematics for testing the coating bond on the tops of the domes and on the field and for testing the bond of surface-applied single domes are provided in Figure 11. Tests are carried out at room temperature (approximately 21–27°C [70–80°F]) and also at elevated temperature (60°C [140°F]).

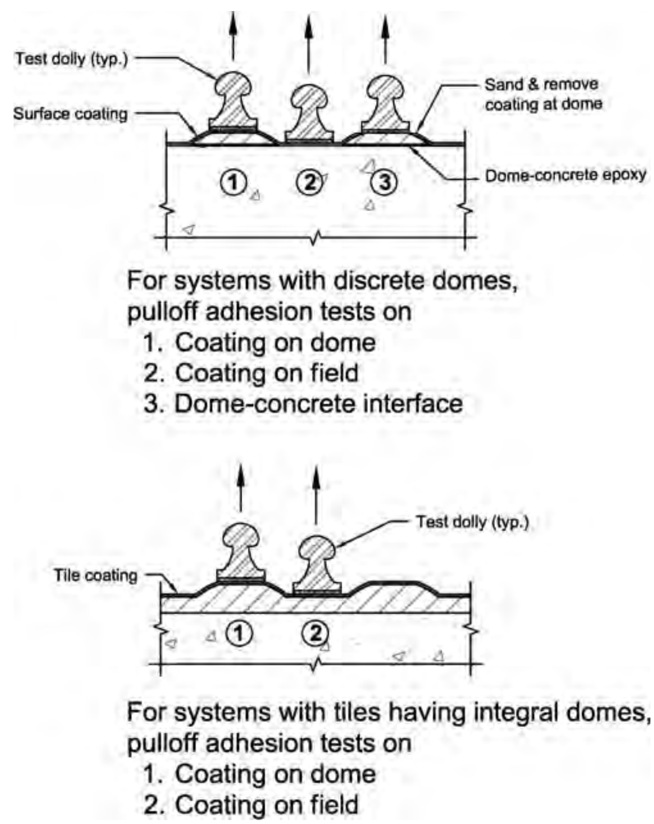


Figure 11. Schematic of coating bond tests.

This test method has been adapted to test the adhesion of surface-applied single domes to the concrete surface. If coating is present on the top of the domes, the domes are tested with the coating in place and with the coating removed with abrasive paper to isolate the dome/substrate interface. Direct tension is applied to the dolly bonded to a single dome until failure.

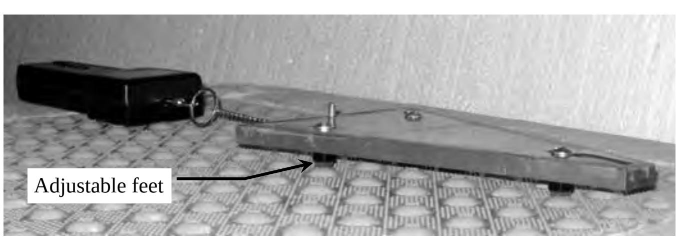
Part 9—Slip Resistance

Slip resistance is an important factor in preventing a pedestrian from falling on a walking surface. The slip resistance test was developed to measure the coefficient of friction on both the field and tops of domes with a test apparatus adjustable to the range of allowed geometries.

Slip resistance is measured in general accordance with ASTM F 609-05 *Standard Test Method for Using a Horizontal Pull Slipmeter (HPS)*. A modified slipmeter is used to measure coefficient of friction on both the tops of the domes and the field. The Neolite rubber feet are adjustable such that all three feet can be placed on dome tops or the field of detectable warning systems of all allowable dome sizes and spacings. Figure 12 shows the slipmeter on a representative detectable warning system.

Each coefficient of friction measurement is obtained by averaging readings performed in four perpendicular directions. Two sets of measurements are taken on both the domes and the field. These eight measurements are reported separately and are averaged to obtain an overall coefficient of friction for the domes and a separate overall coefficient of friction for the field.

a)



b)

Figure 12. Evaluating slip by the slipmeter (note that the adjustable Neolite feet are centered on the tops of the domes).

Part 10—Resistance to Impact from Simulated Snowplow Blade

Snow removal operations are considered to be a significant source of degradation of detectable warning systems in northern states. Snow removal has been reported to chip and remove domes, to remove colored coatings, and to peel and, in some cases, remove surface-applied products. The test for resistance to impact from simulated snowplow blade was developed to produce an accurate representation of the dynamic nature and lateral directionality of the snowplow impact process.

The proposed test method consists of a laboratory-based snow removal resistance test where an impactor (called the "strike plate"), simulating a snowplow blade and mounted on a pendulum, impacts single domes of detectable warning system/concrete composite systems. The pendulum is designed to simulate the movement of a snowplow blade, so that the strike plate impacts the dome moving in the plane parallel to the surface of the detectable warning system. The pendulum shaft is constructed so as to allow upward vertical movement of the impactor, such that the impactor can "bounce" upward and lift over the surface of the tested dome at impact. This type of dynamic movement is consistent with that of actual plows, which continue to move over the system after making initial contact. The pendulum consists of two connected rigid arms: (1) a rotating arm and (2) a rotating-translating arm. The rotating arm is mounted to an axle and the rotating-translating arm is attached to the rotating arm by a connection that allows the rotating-translating arm to move along the axis of the pendulum arms. The test apparatus is shown in Figure 13.

The test is conducted at below-freezing temperatures and a total of three domes on the edge of the samples are impacted during a single test series. The type and extent of damage is ranked from A (least damage) to F (greatest damage) for each of these domes by comparison with standard schematics. The effect of the impact is also documented photographically.

The snow removal resistance test is not intended to be conducted to evaluate performance in the hot exposure category.

Part 11—Resistance to Impact from Falling Tup

Detectable warning systems are subject to impact from a variety of sources that may damage the system surface. The test for resistance to impact from falling tup was adapted from a standard test method for conducting impact testing on detectable warning system/concrete composites.

The proposed test method consists of an impactor that is dropped onto domes of the detectable warning system/concrete

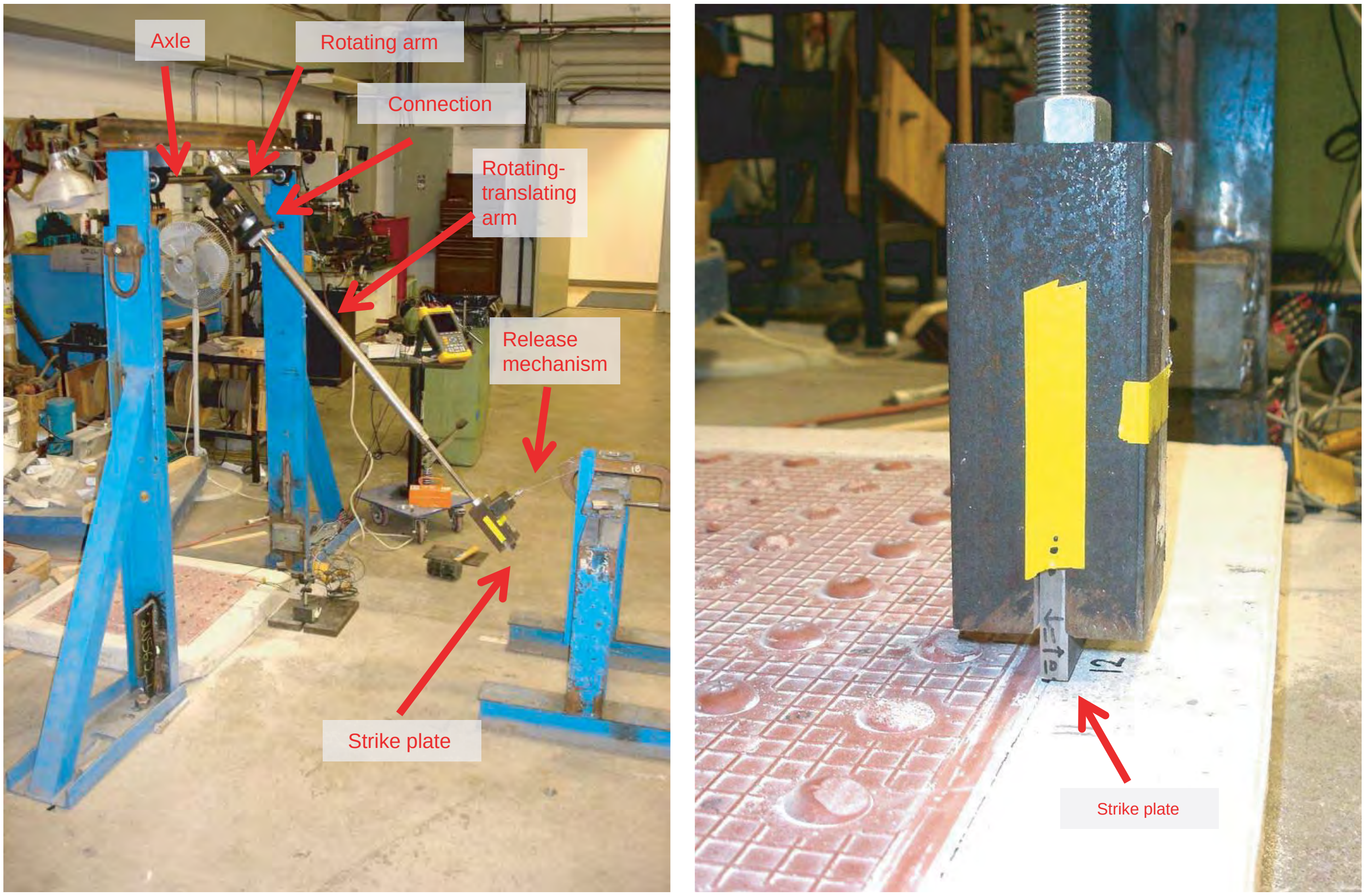


Figure 13. Apparatus to test impact resistance to a simulated snowplow blade.

system. The energy of impact is controlled by a combination of impactor mass and drop height. The tup is a standardized, 25 mm (1-inch) diameter hardened steel hemisphere. Each set of tests consists of impacting three separate domes at each of three impact energies. The test apparatus and a close-up view of the impactor are shown in Figures 14 and 15, respectively.

For the testing according to the cold exposure category, tests are carried out at both room and freezing temperatures. The freezing impact resistance test is not intended to be conducted to evaluate performance in the hot exposure category, although tests at room temperature are still performed.

Part 12—Wear Resistance

As noted in the previous section discussing the abrasion exposure, abrasion is a significant source of degradation of detectable warning systems. The evaluation test, which is discussed in this section, quantifies the resistance of a detectable warning system to abrasion in a rapid, controlled, and consistent manner.

The proposed destructive test method evaluates the surface of a 150 mm (6-inch) diameter specimen cored or otherwise cut from a detectable warning system/slab sample. This surface specimen is held with a fixed weight against an aluminum oxide abrasive sand paper affixed to a standard lapping wheel, which is rotated at a fixed speed for a specific number of revolutions. The specimen is rotated intermittently during the test to ensure even abrasion. The wear resistance of the detectable warning system is assessed by measuring the dome height before and after the test. A photo of the wear resistance test apparatus is shown in Figure 16.

Part 13—System Bond Measurement

System bond describes the adhesion or anchorage of the detectable warning system to the concrete substrate. There are a wide range of methods by which the currently available systems are fixed in place. While a detectable warning system is unlikely to ever experience an upwardly directed vertical load in its service life, measurement of the relative system direct tension bond strength is important for evaluating relative durability of different detectable warning systems. Direct tension bond strength of a system is judged to have direct correlation with the overall structural integrity.

Figure 14. Apparatus to test impact resistance of a falling tup. (The metal guide tube is indicated with an arrow. The casters allow easy positioning of the impactor over the detectable warning system. The mass and tup have been retracted through the guide tube.)

Difficulties in obtaining repeatable results, representative of the full system response, prevented finalization of a method. The data for the bond testing varied significantly between the five different systems included in the development, as well as within a single material when repeated tests were performed. This is partially attributable to the varying methods of anchorages employed by each system. Because of the wide disparity of bond forces results, efforts were made to normalize the strength per anchor or unit length of anchorage. These results were also divergent. More discussion of these difficulties is provided in the appendix. No final method has been proposed.

Guidance on Interpretation of Test Results

Little laboratory testing of detectable warning systems has been carried out in such a way to support objective comparisons or predictions of future performance. Most municipalities that do perform testing use in-situ trial installations that are monitored for one or more years to qualitatively assess durability, but unfortunately without quantifying the exposure conditions. There are no published data available to scientifically correlate performance in laboratory tests to expected field performance and in-service longevity. As laboratory testing becomes more prevalent and methodologies more consistent, the results of these tests can be used to compare laboratory performance with reported performance in field installations. At this time, without the necessary correlation to field performance, the results of the laboratory tests cannot be used to

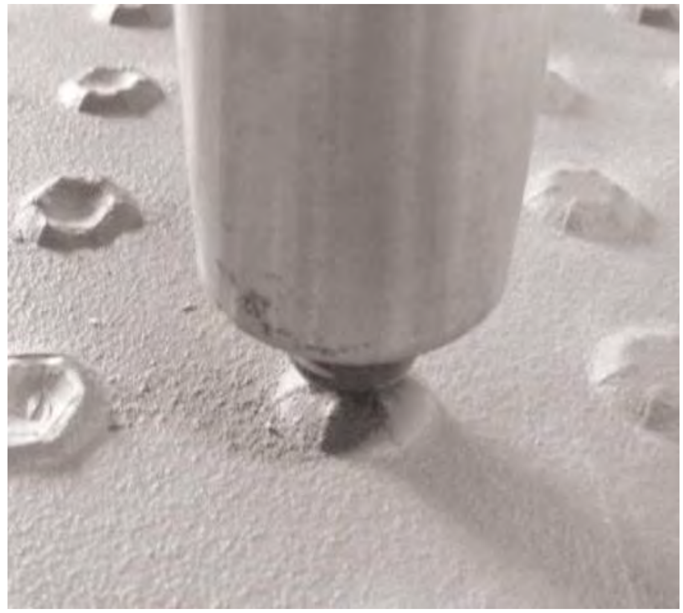


Figure 15. View of the falling tup for the resistance to impact test.

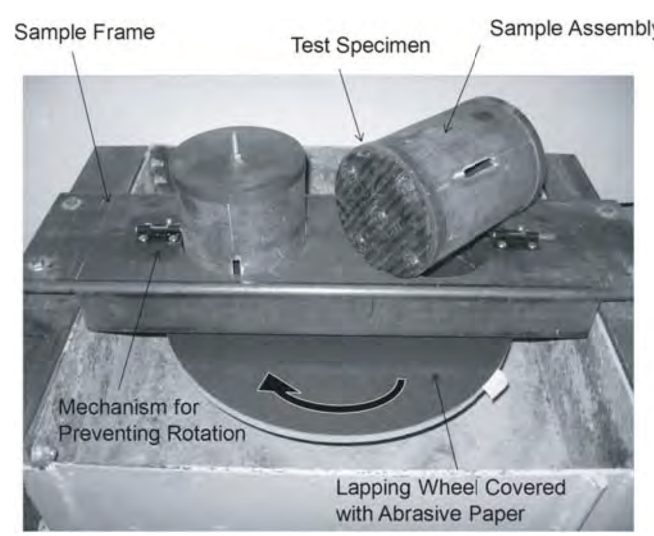


Figure 16. Wear resistance sample frame assembly.

confidently predict a specific service life under particular site conditions.

Variability in field installation, field service conditions and interaction of the effects of environmental exposure creates additional challenges in predicting service life of detectable warning systems. Inconsistencies in the installation process, such as poor consolidation of the concrete below a cast-in-place system or air bubbles under a surface-applied system, can be expected to affect durability in an unpredictable manner. Because there is likely to be an interaction between exposure-related deterioration mechanisms, an attempt was made to include reasonable severity levels in the exposure protocol. However, the interaction between these effects is not fully understood. This protocol includes both hot and cold categories to address variable climate conditions. However, the environmental climates across the United States vary widely making complete representation by only two exposure categories impossible. Other exposure conditions, such as the degree of foot traffic or amount of small vehicle traffic (such as carts), will vary depending on the location of the detectable warning system.

The ability of the protocols proposed herein to simulate actual exposure conditions is uncertain, and future work is needed to provide a better understanding of the relationship between laboratory testing and field performance. Nevertheless, this protocol was developed to provide a basis for comparing performance in a uniform test program, and some guidance has been provided in the appendix to support the interpretation of the results of testing relative to in-service performance.

Combining Test Results

Products tested using this protocol can be compared to one another on a test-by-test basis, but it is clearly desirable to determine a ranking for comparing the overall performance of the systems. If only one test was performed, the performance of the systems could be compared based on the measured value of that test for each system. However, since multiple evaluation tests are included in this protocol, a method of combining the responses (test results) from the different tests is needed. The best choice for a given installation must be based on weighting the importance of the various durability-related properties and the anticipated performance, as well as consideration of aesthetics, initial cost, ease and quality of installation, maintenance requirements, replacement cost, and other factors. This testing protocol focused on an assessment of the durability of the systems; therefore, a method for developing a combined rating of durability is proposed. Many options for performing such a combination are possible, but the procedure presented here is intended to allow the user great flexibility in interpretation of the protocol test results and in the assignment of the importance of the test response to overall performance so that local specifications, conditions, and preferences may be addressed.

Ratings

Many of the tests performed during this program were developed to simulate the unique conditions that are important to the durability of detectable warning systems. No industry-accepted or proven guidance has been developed for the interpretation of test results and prediction of in-service performance. Accordingly, the research team has applied engineering judgment in evaluating the absolute and relative test data and developed a system for assigning a rating for each evaluation test result based on whether that response is expected to meet a criterion of "acceptable performance." For the purposes of this project, "acceptable performance" refers to serviceable, functional and durable use within the environment represented by the selected exposure category for approximately five years or more. It is emphasized that the research team's conclusions are an estimate based on results of the test methods that are newly developed and this protocol has not been compared to a systematic study of the performance of detectable warnings in service.

The performance of each product may be rated in each of the evaluation tests included in this program. The system proposed to characterize the performance is based on ratings of 0 to 4. The assigned performance level of each of the ratings is:

- 4 for a product that is likely to significantly exceed acceptable performance
- 3 for a product that is likely to slightly exceed acceptable performance
- 2 for a product that is likely to produce acceptable performance
- 1 for a product that is likely to produce slightly less than acceptable performance
- 0 for a product that is not likely to produce acceptable performance.

Correlation tables providing guidance for applying ratings for each evaluation test result have been provided with the discussion given in the appendix. It is anticipated that the correlations between test results and ratings may need revision in the future as experience with the protocol and field performance grows. Agencies specifying these tests may consider developing correlation tables to adapt the interpretation of test responses to reflect their own specific needs.

Two evaluation test methods that are not easily interpreted and assigned numerical ratings are the visual and microscopic evaluation and the dome shape and geometry measurement. The visual and microscopic evaluation is subjective and may identify too wide a range of possible features or defects for a correlation table to be developed. For this reason, anticipated performance ratings are not assigned using the same incremental scale. Rather, the evaluation is set up as a pass/fail result, with the test result being assigned either a 2 (likely to produce acceptable performance) or a 0 (not likely to produce acceptable performance). The dome shape and geometry measurement has also been set up as a pass/fail test. The dome shape is specified by each agency, and geometries within the specified range are considered a 2 (likely to produce acceptable performance), while geometries outside the specified range are considered a 0 (not likely to produce acceptable performance). The dome shapes and geometries have been specified by experts on detectability, but no guidance on how changes (small or large) to the shape may affect detectability has been provided. Determination of detectability is outside the scope of this project, so no guidance on interpretation of dome shape and geometry after exposure has been developed.

Importance Multipliers

While individual tests have been performed to evaluate a number of durability-related properties, the importance of each test result to the expected overall system performance varies. To assist in the interpretation of the test results, a relative importance factor for estimating the performance of the detectable warning systems may be assigned to each test method. Selection of an appropriate importance factor for each test result requires some level of subjective judgment from the user. This judgment should consider (1) the test method and its accuracy at simulating the anticipated deterioration mechanism and at predicting performance and (2) the significance of tested property relative to the anticipated service environment. The importance can be judged to be low, medium, or high and these qualitative assignments have been quantified as importance multipliers equal to 1, 2, and 3, respectively. If a particular test is considered to be not applicable for a given agency, its test results can be left out of the analysis.

Combination

The method proposed for generating an overall rating is based on a well-established experimental methodology (Derringer and Suich, 1980). Mathematically, the overall rating is calculated as the geometric mean of the individual ratings for each of the tests. In general, for n test methods, the overall rating is the n^{th} root of the product of the ratings in each of those tests. For example, suppose that the ratings for three different (but equally important) tests are represented by r_1, r_2, and r_3. The overall rating (R) is then determined according to $R = \sqrt[3]{r_1 \times r_2 \times r_3}$. Since the individual ratings range between 0 and 4, the overall ratings also range between 0 and 4.

The main reason for using a geometric mean instead of the more routine arithmetic mean (or average) is that if a system scores a 0 in any single test, which means that performance is likely to be unacceptable in that category, the overall rating is also 0. An unacceptable rating for any test implies that the product is unsuitable for use. This would not be the case if the arithmetic mean was used. In developing the rating correlation tables, it is important to consider this consequence of using the geometric mean; a 0 should be assigned only to test responses judged to be sufficiently far below desired performance that, on their own, they eliminate the tested product from further consideration.

The importance of each test result may be considered in the calculation of the overall rating by including the result of that test in the calculation once, twice or three times if that method's importance was judged to be low, medium or high, respectively, by assigning an importance multiplier of 1, 2, or 3.

Example

An example of an overall rating calculation for five hypothetical products is shown in Table 9. The exposure category

Table 9. Overall rating for five hypothetical products.

Test	Multiplier (Importance factor)	Product A	Product B	Product C	Product D	Product E
Visual and Microscopic Evaluation	2 (M)	2	2	2	2	2
Color Measurement	1 (L)	1	2	2	1	3
Dome Shape and Geometry Measurement	2 (M)	2	3	2	2	2
Coating and Single Dome Bond	2 (M)	2	1	2	2	2
Slip Resistance	3 (H)	2	3	2	1	0
Resistance to Impact from Simulated Snowplow Blade	3 (H)	2	3	2	2	2
Resistance to Impact from Falling Tup	3 (H)	4	2	1	1	2
Wear Resistance	3 (H)	2	2	2	1	4
Overall Rating (Weighted geometric mean)		2.15	2.21	1.79	1.39	0.00

and importance factors have been selected to represent an urban, high-traffic setting in an environment where freezing and thawing is expected.

While Table 9 shows a hypothetical set of results, the following discussion provides an example of how such results might be interpreted. For this example, both Products A and B are shown with similar overall ratings, and the difference in the overall rating between the two should not be considered significant. Differentiation of the performance between the two should be made based on the importance of individual tested properties, such as resistance to impact from falling tup. In contrast, the difference in overall rating assigned to Products C and D compared to Products A and B are large enough that their performance would be anticipated to noticeably lag that of Products A and B. Finally, while Product E appears to have performed well enough in most tests to achieve a rating of 2 or higher, a rating of 0 in slip resistance would produce an overall rating of 0. Such a rating would be representative of very poor performance and might indicate a tile that was too slippery to support pedestrian traffic. Obviously, such a situation must be avoided, and an overall rating of 0 is appropriate.

Application of Test Protocol

This test protocol was developed for use in comparing the performance of detectable warning systems. It is clear that each agency will want to consider different environmental and service conditions and will likely have access to only a subset of the products that are available nationwide. However, a primary objective of this development process was a universally applicable set of methods that would provide sufficient, objective, and valuable information to allow the test protocol results to be interpreted relative to the needs of each agency.

To allow each agency to consider their own needs, the interpretation of the test results for a given product should be modified to suit the intended application. Note that this should not require modification of the test protocol itself. If the proposed rating and combination system was adopted, the interpretation could be modified by adjusting the ratings assigned to each result and the importance multipliers. The rating schemes were not included in the test methods, but provided separately, to allow individual agencies latitude to adopt ratings suitable for their application and particular needs. Furthermore, it is possible that a different method for combining test results could also be adopted to better suit a given set of circumstances.

It is envisioned that raw test results obtained during testing programs conducted at the direction of material suppliers could be shared among multiple agencies. However, for the test data to have universal application, the test protocols must be strictly reproduced. In this way, all parties concerned will have a clear understanding of how the testing was performed and may form interpretations about how a given product may perform in the field based on their experience with similar products. In addition, data from products from different suppliers or even different generations of the same product can be compared.

Two exposure categories have been developed to represent hot and cold environmental conditions, and these categories have been incorporated into the protocol. While additional exposure categories could be envisioned, for example a category based on traffic levels, the effort involved in executing this test protocol for even one category is significant. The decision to limit this protocol to only two categories was made to keep the effort required to reasonable limits. The rigorousness of the exposure regimes was designed to be more rather than less severe with the idea that if a product performs well in a severe test then it will do well in a milder one. In the application of this test protocol, the agency will need to decide whether the hot or cold category represents conditions in its state or municipality. It is likely that some agencies will need to consider both categories in order for the conditions in their jurisdiction to be comprehensively represented.

While the overall rating scheme has been adopted from a methodology targeted at optimizing performance, specifying agencies would probably prefer to be able to identify multiple products deemed likely to produce acceptable performance. Such products could be identified using this framework by defining a minimum acceptable overall rating that the performance must exceed. The correlation between test results and ratings will likely need to be revisited relative to this objective.

CHAPTER 4

Conclusions and Recommendations

Conclusions

Limited information is available regarding the long-term durability of many detectable warning systems currently on the market. Available information varies considerably in relevance and often does not permit objective comparisons. However, state and municipal agencies must make decisions about which available products should be used on the projects they supervise. To support this decision, laboratory testing methods have been developed to provide objective data that can be used to aid selection of more durable detectable warning systems. Furthermore, some initial guidance in interpreting these results relative to anticipated performance in the field has been provided.

Detectable warning systems are commercially available in a wide variety of materials and are anchored in place by many different attachment mechanisms. In addition, they could be exposed to a wide range of environmental and traffic conditions throughout the United States. During the testing method development, the many variations of materials, textures and attachment mechanisms, as well as the potential variety of exposure conditions, were considered. The test protocol was developed to be capable of providing universally applicable information about the durability of any detectable warning system product. This protocol is also highly adaptable, since great flexibility in the interpretation of the test results is possible.

For detectable warning systems to function and to serve as a safe traffic-bearing surface, the following properties are essential: color contrast, slip resistance, mechanical integrity and dimensional stability. Environmental exposures may have a deleterious effect on these properties, triggering a number of deterioration mechanisms. The developed test protocol considers the following deterioration mechanisms: freezing and thawing, snow removal, exposure to ultraviolet radiation, abrasion, impact, exposure to extreme temperatures, thermal cycling, exposure to moisture, exposure to deicer chemicals, corrosion, exposure to moisture, and salt scaling.

The protocol consists of subjecting systems to exposure regimes and evaluating the response. Exposure regimes simulate the effects of outdoor exposure, while the evaluation tests assess subsequent performance of the detectable warning systems. Exposure regimes include freeze/thaw, high temperature thermal cycling, ultraviolet, and abrasion exposures. Evaluation tests include visual and microscopic evaluation, color measurement, dome shape and geometry measurement, slip resistance, coating and single dome bond, resistance to impact from falling tup, wear resistance, resistance to impact from simulated snowplow blade, and system bond (no method finalized). Since the durability of detectable warning systems is tied to the interaction between the system and the concrete substrate, the protocol is executed with the detectable warning systems installed in concrete slabs.

These methods are provided in the attachment to this report and these draft methods are expected to provide a basis for future standard test methods. In combination with the guidance on interpretation given in the appendix, this protocol provides a framework for obtaining and implementing valuable information about the likely durability of detectable warning systems. The use of this protocol will advance the knowledge about different detectable warning system products and provide guidance for specifying such systems.

Recommendations for Future Research

In addition to the work performed as part of this project to develop a universally applicable and adaptable testing protocol, further research is needed to successfully implement this protocol.

Because individual exposure and evaluation test methods were demonstrated on a selected group of product types, validation of the test method on a broader scale is desirable.

The parameters of the exposure and evaluation tests that determine the severity of these tests, such as the duration of test cycles, were defined based on judgment and experience. An investigation that covers a range of products and the effects of variations in these parameters on performance would provide information for modifying or confirming the suitability of these proposed methods.

Because cyclic exposure protocol may be affected by the order in which the exposures are run, a specific order has been recommended in the draft test method. However, if testing of multiple products is desired, it may be more efficient to set up different exposures for different sets of specimens. Further research to compare the effects of the order of the exposures is recommended.

Because of the wide variation in the detectable warning system attachment configurations, a universally applicable procedure for testing system bond was not singularly identified. However, an evaluation of the system bond performance is important for assessing system durability and indicating structural integrity of the system. Therefore, it is recommended that further research include the development of system bond test.

While this research developed a set of testing methods to address durability of detectable warning systems, such durability requirements are intrinsically tied to the detectability requirements. For example, it is unknown how much color fading or dome shape change may affect detectability. Further studies addressing how changes in detectable warning systems affect detectability may aid in determining appropriate ways to interpret results of certain tests.

Finally, to better interpret the results of the test protocol, knowledge of the correlation between the test results and field performance is necessary. Currently, the test methods can be used to distinguish between performance levels of various products. However, insufficient information is available to define what level of performance could be considered sufficient to meet the design service life objectives for a given installation. Monitoring field installations, in conjunction with laboratory testing, would provide valuable information regarding the long-term durability of the installed systems and support more accurate interpretation of these laboratory test results relative to in-service conditions. These studies would lead to improved guidance regarding the relationship of test results to performance rating.

References

Abernathy, Craig. (2003). *Post-Construction Initial Evaluation Report Detectable Warning Devices (Truncated Domes) for use by the Visually Impaired*. Montana Department of Transportation, 10 pp.

Abernathy, Craig. (2004a). *Post-Winter Evaluation Report Detectable Warning Devices (Truncated Domes) for use by the Visually Impaired.* Montana Department of Transportation, 14 pp.

Abernathy, Craig. (2004b). *Pre-Winter Evaluation Report Detectable Warning Devices (Truncated Domes) for use by the Visually Impaired.* Montana Department of Transportation, 10 pp.

Abernathy, Craig. (2005). *Post-Winter Evaluation Report Detectable Warning Devices (Truncated Domes) for use by the Visually Impaired.* Montana Department of Transportation, 10 pp.

Bentzen, Billie Louise, Janet M. Barlow, and Lee S. Tabor. (2000). *Detectable Warnings: Synthesis of U.S. and International Practice.* U.S. Access Board, Washington, DC, pp. 71–100.

Boisvert, Denis M. (2003). *Durability of Truncated Dome Systems (a.k.a. Detectable Warning Surfaces).* New Hampshire Department of Transportation, 22 pp.

Derringer, G., and R. Suich. (1980). "Simultaneous Optimization of Several Response Variables." *Journal of Quality Technology,* Volume 12, pp. 214–219.

Estakhri, Cindy K. and Roger Smith. (2005). "Detectable Warning Products: Installation, Maintenance, and Durability Concerns." Draft report, NCHRP Project 20-7(177), Texas Transportation Institute, 150 pp.

Evaluation of Detectable Warning Advisory Committee (EDWAC). (February 2006). *Fourth Draft of the Proposed Standard Test Methods for the Evaluation of Detectable Warnings and Directional Surfaces.*

Illinois Department of Transportation. 2006. *Experimental Features Program: Pre-Fabricated Cast-In-Place Truncated Domes Summary Report,* 43 pp.

Kaplan, Jon. (2004). *Report on Durability of Detectable Warning Products in Burlington, Vermont.* Vermont Agency of Transportation, 17 pp.

Kaplan, Jon. (2006). *Report on Spring 2006 Evaluation of Detectable Warning Products Installed 2003–2005.* Vermont Agency of Transportation, 13 pp.

Kemp, Peter. (2003). *Truncated Warning Dome Systems for Handicap Access Ramps.* Wisconsin Department of Transportation, 80 pp.

Ketola, H. Norman and David Chia. (November 1994). *Detectable Warnings: Testing and Performance Evaluation at Transit Systems.* U.S. Department of Transportation Federal Transit Administration Report Number FTIR-ATR-MA-26-0031-94-1.

Kirk, Alan. (2004). *Durability of Truncated Dome Warnings on Existing Curb Ramps.* Oregon Department of Transportation and Federal Highway Administration, 22 pp.

United States Access Board. (July 23, 2004; amended August 5, 2005). *Americans with Disabilities Act and Architectural Barriers Act Accessibility Guidelines,* pp. 233–234.

ATTACHMENT

Recommended Methods of Test for Evaluating Durability of Detectable Warning Systems

CONTENTS

Note: The proposed test methods are the recommendations of NCHRP Project 4-33 staff at Wiss, Janney, Elstner Associates, Inc. The methods have not been approved by NCHRP or any AASHTO committee or formally accepted for AASHTO specification.

Recommended Method of Test for

Durability of Detectable Warning Systems

Designation: Draft T4-33

1. SCOPE

1.1. The use of detectable warning systems at curb cuts and vehicular ways is mandated as part of the Americans with Disabilities Act. These detectable warning systems are subject to a variety of environmental conditions that can lead to material degradation and reduction in performance. In extreme cases, degradation may occur such that the detectable warning systems become a hazard to pedestrians, for example, by becoming a tripping or slip hazard.

1.2. This method provides a protocol for testing the durability of detectable warning systems in a repeatable manner. Laboratory exposures and evaluation tests were developed to simulate the types of damage and degradation anticipated in service. Exposures are conducted cyclically to allow for effects of combined interaction of the simulated environmental exposures. Non-destructive evaluation tests are conducted both before and after exposures to provide comparative values. Destructive evaluation tests are conducted after the exposures.

1.3. The primary objective of this test method is to provide a repeatable set of tests that can be conducted specifically to evaluate durability of detectable warning systems. Each test is suitable for use with any type of detectable warning system, regardless of the material composition or method of attachment. Specimens are attached to concrete slabs to provide a test of the detectable warning system/sidewalk system. Data produced following this method is anticipated to be used for purposes of product comparison.

2. REFERENCED DOCUMENTS

2.1. **AASHTO Standards**

2.1.1. Draft T4-33, Part 1 *Recommended Method of Test for Freeze/Thaw Durability of Detectable Warning Systems*

2.1.2. Draft T4-33, Part 2 *Recommended Method of Test for High Temperature Thermal Cycling of Detectable Warning Systems*

2.1.3. Draft T4-33, Part 3 *Recommended Method of Test for Ultraviolet Light Exposure of Detectable Warning Systems*

2.1.4. Draft T4-33, Part 4 *Recommended Method of Test for Abrasion Exposure of Detectable Warning Systems*

2.1.5. Draft T4-33, Part 5 *Recommended Method of Test for Visual and Microscopic Evaluation of Detectable Warning Systems*

2.1.6. Draft T4-33, Part 6 *Recommended Method of Test for Color Measurement of Detectable Warning Systems*

2.1.7. Draft T4-33, Part 7 *Recommended Method of Test for Dome Shape and Geometry Measurement of Detectable Warning Systems*

2.1.8. Draft T4-33, Part 8 *Recommended Method of Test for Coating and Single Dome Bond in Detectable Warning Systems*

2.1.9. Draft T4-33, Part 9 *Recommended Method of Test for Slip Resistance of Detectable Warning Systems*

2.1.10. Draft T4-33, Part 10 *Recommended Method of Test for Resistance to Impact from Simulated Snowplow Blade of Detectable Warning Systems*

2.1.11. Draft T4-33, Part 11 *Recommended Method of Test for Resistance to Impact from Falling Tup of Detectable Warning Systems*

2.1.12. Draft T4-33, Part 12 *Recommended Method of Test for Wear Resistance of Detectable Warning Systems*

2.2. **ASTM Standards**

2.2.1. ASTM C 192 *Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory*

2.2.2. ASTM C 143 *Standard Test Method for Slump of Hydraulic-Cement Concrete*

2.2.3. ASTM C 39 *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimen*

2.2.4. ASTM C 231 *Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method*

3. TERMINOLOGY

3.1. *Cast-in-place*: A detectable warning system that is cast into plastic concrete.

3.2. *Surface applied:* A detectable warning system that is applied to the surface of cured concrete.

3.3. *Exposure regime*: Test subjecting the detectable warning system specimens to simulated environmental exposure, including freeze/thaw, ultraviolet light, abrasion, and high temperature thermal cycling.

3.4. *Evaluation test:* Tests evaluating the performance of the detectable warning systems. These tests include visual and microscopic evaluation, dome shape and geometry measurement, slip resistance, color measurement, resistance to impact from falling tup, resistance to impact from simulated snowplow blade, wear resistance, and coating and single dome bond.

3.5. *Non-destructive evaluation test*: Evaluation tests that do not require any destruction of the sample. These tests are visual and microscopic evaluation, dome shape and geometry measurement, slip resistance, and color measurement.

3.6. *Destructive evaluation test*: Evaluation tests that involve partial destruction of the sample. These tests include resistance to impact from falling tup, resistance to impact from simulated snowplow blade, wear resistance, and coating and single dome bond.

3.7. *Hot exposure category*: A category indicating a set of exposure tests intended to simulate exterior environments with hot summer weather and with little to no freezing weather during the winter.

3.8. *Cold exposure category*: A category indicating a set of exposure tests intended to simulate exterior environments with slightly cooler summer weather and with freezing weather during the winter.

4. SUMMARY OF TEST METHOD

4.1. This method covers specimen fabrication, cyclic exposure, and evaluation testing of detectable warning systems for the purposes of evaluating durability.

4.2. This test method defines two exposure categories for evaluating durability: "hot" for hot weather climates and "cold" for climates where lower maximum temperatures, less ultraviolet exposure and freezing occurs. This test method references three exposure regimes for the hot exposure category and four exposure regimes for the cold exposure category. Seven evaluation test methods are used for the hot exposure category, and eight evaluation test methods are used for the cold exposure category.

4.3. Exposure regimes are conducted cyclically. The specimens are cycled through high temperature thermal cycling, abrasion, freeze/thaw (for the cold exposure category) and ultraviolet light. Each exposure is conducted for one-quarter of the total duration of that particular exposure, and the specimens are rotated through the exposures for a total of four cycles.

4.4. Non-destructive evaluation tests (visual and microscopic evaluation, color measurement, dome shape and geometry measurement, and slip resistance) are conducted both before and after exposure. Destructive evaluation tests (resistance to impact from falling tup, wear resistance, coating and single dome bond [for coated or surface-applied single dome systems] and resistance to impact from simulated snowplow blade [for the cold exposure category only]) are conducted after the exposures.

5. SIGNIFICANCE AND USE

5.1. This method covers specimen fabrication, cyclic exposure, and evaluation testing of detectable warning systems for the purposes of evaluating durability.

5.2. This test method is intended to evaluate durability of detectable warning systems that are attached to concrete slabs.

5.3. This test is intended to provide data that can be used to compare the durability of detectable warning system products.

6. SAFETY HAZARDS

6.1. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

6.2. Review the potential safety hazards associated with all of the referenced methods prior to beginning testing.

7. TEST SPECIMENS

7.1. Test specimens consist of nominally 0.6 m by 0.6 m (2 ft by 2 ft) areas of the detectable warning system applied to concrete slabs following manufacturer's instructions.

7.2. Number of specimens

7.2.1. Two specimens of each type are required for exposure and evaluation testing.

7.2.2. If desired, an additional specimen can be fabricated for additional destructive evaluation testing of the unexposed specimen.

7.3. Detectable warning systems

7.3.1. Sufficient units of the detectable warning system to cover an area of slab nominally 0.6 m by 0.6 m (2 ft by 2 ft).

7.3.1.1. If the smallest available unit of detectable warning system undergoing testing is larger than this, cut the detectable warning system to produce a nominally 0.6 m by 0.6 m (2 ft by 2 ft) sample. Report the fact that the samples were cut as a deviation from the test method during each subsequent test method. Consider the potential effect of this cut on system performance when selecting domes for evaluation tests.

7.3.2. Any required method of attachment, including bolts, anchors, adhesives, or other attachment mechanisms.

7.4. Concrete Slabs

7.4.1. The specimens for use in the method shall be made in accordance with the applicable requirements of ASTM C 192.

7.4.2. Concrete slabs shall measure a minimum of 0.86 m by 0.86 m by 0.1 m high (34 in. by 34 in. by 4 in. high).

7.4.3. Slabs shall be reinforced with a minimum 6x6 - W6xW6 welded wire reinforcing supported on 13 mm (1/2 in.) bolsters.

Note 1: It has been found to be useful to place additional reinforcing bars around the perimeter of the sample. Additional or supplementary reinforcement is optional.

7.4.4. The concrete mix shall meet the following specifications:

7.4.4.1. Contain 359 kg of Type I portland cement per m^3 of concrete (605 lbs. per yd^3).

7.4.4.2. Have a maximum aggregate size of 19 mm (3/4 in.)

7.4.4.3. Have a slump of 100 to 150 mm (4 to 6 in.) when tested according to ASTM C 143.

7.4.4.4. Achieve a minimum compressive strength of 24 MPa (3500 psi) at 14 days when tested according to ASTM C 39.

7.4.4.5. Contain 5 to 8 percent entrained air when tested according to ASTM C 231.

7.4.5. The slabs shall be fabricated so that thermocouples are placed according to Draft T4-33, Part 2 *Recommended Method of Test for High Temperature Thermal Cycling of Detectable Warning Systems*. These thermocouples can be cast into the concrete, or can be installed after curing of the concrete.

Note 2: It has been found useful to cast lifting inserts into the concrete slabs near the edges to facilitate moving the slabs during the testing process.

7.5. For cast-in-place detectable warning systems:

7.5.1. Fill an appropriately sized form with concrete, strike-off the surface, consolidate with a hand vibrator, finish to an even surface with floats, and set the detectable warning system in the concrete according to manufacturer's instructions while the concrete is still plastic.

7.5.2. Center the detectable warning system in the form, leaving a uniform concrete border on all sides of the detectable warning system.

7.5.3. Edge finish around the perimeter of the form.

7.5.4. Do not edge finish around the perimeter of the detectable warning system.

7.5.5. The final finish shall be done with a wooden float, leaving an even surface. Steel trowels shall not be permitted. After the water sheen has disappeared, the surface shall be given a final finish by brushing with a whitewash brush.

7.5.6. Moist cure the concrete according to ASTM C 192 for a minimum of 14 days.

7.5.7. Provide a unique marking to the slab for future identification.

7.6. For surface-applied detectable warning systems:

7.6.1. Fill an appropriately sized form with concrete, strike-off the surface, consolidate with a hand vibrator, and finish to an even surface with floats.

7.6.2. Finish the concrete in the area to receive the detectable warning system as directed by the manufacturer's instructions.

7.6.3. Moist cure the concrete according to ASTM C 192 for a minimum of 14 days.

7.6.4. Apply the detectable warning system to the cured concrete slabs according to the manufacturer's instructions.

7.6.5. Provide a unique marking to the slab for future identification.

Note 3: A permanent ink marker has been found suitable for providing markings on the specimens. It is recommended that both the top surface and side of the detectable warning system specimen be marked.

8. APPARATUS

8.1. The apparatus required for each test is described in the referenced methods.

9. CALIBRATION

9.1. Any calibration required for each test is described in the referenced method.

10. PROCEDURE

10.1. Perform non-destructive evaluation on each of the detectable warning system specimens according to:

10.1.1. Draft T4-33, Part 5 *Recommended Method of Test for Visual and Microscopic Evaluation of Detectable Warning Systems.*

10.1.2. Draft T4-33, Part 6 *Recommended Method of Test for Color Measurement of Detectable Warning Systems.*

10.1.3. Draft T4-33, Part 7 *Recommended Method of Test for Dome Shape and Geometry Measurement of Detectable Warning Systems.*

10.1.4. Draft T4-33, Part 9 *Recommended Method of Test for Slip Resistance of Detectable Warning Systems.*

10.2. Subject two specimens of each type to the exposure regimes.

Table 1. Exposure duration for each exposure category.

Exposure Regime	Hot Exposure Category	Cold Exposure Category
Freeze/Thaw	(None)	60 cycles
High Temperature Thermal Cycling	60 cycles 25–93ºC black panel temp. (77–200°F)	60 cycles 25–77ºC black panel temp. (77–170°F)
Ultraviolet Light Exposure	1500 hrs	1000 hrs
Abrasion Exposure	16 passes	16 passes

10.3. Determine if the samples are to be exposed to the hot exposure category or the cold exposure category.

10.4. For exposures in the hot exposure category:

10.4.1. Subject the specimens to 15 thermal cycles with the maximum temperature defined by an insulated black panel temperature of 93°C (200°F) according to Draft T4-33, Part 2 *Recommended Method of Test for High Temperature Thermal Cycling of Detectable Warning Systems.*

10.4.2. Subject the specimens to four abrasion cycles according to Draft T4-33, Part 4 *Recommended Method of Test for Abrasion Exposure of Detectable Warning Systems.*

10.4.3. Subject the specimens to 375 hours of ultraviolet radiation exposure according to Draft T4-33, Part 3 *Recommended Method of Test for Ultraviolet Light Exposure of Detectable Warning Systems*.

10.4.4. Repeat the series of exposures, in the same order, three additional times for a total of four cycles. This will provide a total of 60 thermal cycles, 16 abrasion cycles, and 1500 hours of ultraviolet radiation.

10.5. For exposures in the cold exposure category:

10.5.1. Subject the specimens to 15 thermal cycles with the maximum temperature defined by an insulated black panel temperature of 77°C (170°F) according to Draft T4-33, Part 2 *Recommended Method of Test for High Temperature Thermal Cycling of Detectable Warning Systems*.

10.5.2. Subject the specimens to four abrasion cycles according to Draft T4-33, Part 4 *Recommended Method of Test for Abrasion Exposure of Detectable Warning Systems*.

10.5.3. Subject the specimens to 15 freeze/thaw cycles according to Draft T4-33, Part 1 *Recommended Method of Test for Freeze/Thaw Durability* of *Detectable Warning Systems*.

10.5.4. Subject the specimens to 250 hours of ultraviolet radiation exposure according to Draft T4-33, Part 3 *Recommended Method of Test for Ultraviolet Light Exposure of Detectable Warning Systems*.

10.5.5. Repeat the series of exposures, in the same order, three additional times for a total of four cycles. This will provide a total of 60 thermal cycles, 16 abrasion cycles, 60 freeze/thaw cycles and 1000 hours of ultraviolet radiation.

10.6. After completion of the cyclic exposures, perform non-destructive evaluation tests on each specimen according to:

10.6.1. Draft T4-33, Part 5 *Recommended Method of Test for Visual and Microscopic Evaluation of Detectable Warning Systems*.

10.6.2. Draft T4-33, Part 6 *Recommended Method of Test for Color Measurement of Detectable Warning Systems*.

10.6.3. Draft T4-33, Part 7 *Recommended Method of Test for Dome Shape and Geometry Measurement of Detectable Warning Systems*.

10.6.4. Draft T4-33, Part 9 *Recommended Method of Test for Slip Resistance of Detectable Warning Systems*.

10.7. After completion of the non-destructive evaluation tests, perform the destructive evaluation tests on either of the exposed detectable warning system specimens. If there are discrepancies in the response of the two samples to the exposure, identify those discrepancies when reporting the results of the evaluation tests. The referenced test methods are:

10.7.1. Draft T4-33, Part 11 *Recommended Method of Test for Resistance to Impact from Falling Tup of Detectable Warning Systems*.

10.7.2. Draft T4-33, Part 12 *Recommended Method of Test for Wear Resistance of Detectable Warning Systems.*

10.7.3. If the specimens were tested according to the cold exposure category, test for snowplow resistance according to: Draft T4-33, Part 10 *Recommended Method of Test for Resistance to Impact from Simulated Snowplow Blade of Detectable Warning Systems.*

10.7.4. If the system is coated or contains surface-applied single domes, perform testing according to Draft T4-33, Part 8 *Recommended Method of Test for Coating and Single Dome Bond in Detectable Warning Systems.*

Note 4: There may be insufficient sample on one specimen to complete all of the destructive tests, and portions of both specimens may be consumed by the destructive testing.

11. REPORT

11.1. The report shall include the following:

11.1.1. Type, manufacturer, and, if known, lot number of the detectable warning system(s) tested.

11.1.2. The exposure category (hot or cold).

11.1.3. The results from each exposure and evaluation test according to the referenced method.

11.1.4. Any deviations from this method.

12. PRECISION

12.1. Data not available at this time.

Recommended Method of Test for

Freeze/Thaw Durability of Detectable Warning Systems

Designation: Draft T4-33, Part 1

1. SCOPE

1.1. This method covers the exposure of detectable warning/concrete systems to repeated cycles of freezing and thawing in the laboratory.

1.2. This exposure is intended to be conducted as part of the test protocol outlined in Draft T4-33, which outlines the exposure and evaluation methods for determination of durability of detectable warning systems.

2. REFERENCED DOCUMENTS

2.1. **AASHTO Standards**

2.1.1. Draft T4-33 *Recommended Method of Test for Durability of Detectable Warning Systems*

3. SUMMARY OF TEST METHOD

3.1. This method exposes detectable warning systems that have been cast into or applied to concrete to repetitive cycles of freezing and thawing temperatures. Freezing and thawing is carried out with the samples fully submerged in a sodium chloride solution.

4. SIGNIFICANCE AND USE

4.1. This test method is intended to aid in the evaluation of freeze/thaw durability of detectable warning systems that are cast into concrete.

4.2. This method is intended to be used as part of the Draft T4-33 to evaluate the durability of detectable warning systems. An evaluation test is not included in this method.

5. SAFETY HAZARDS

5.1. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

6. TEST SPECIMENS

6.1. Test specimens prepared in accordance with Draft T4-33 are required.

7. APPARATUS

7.1. A chamber that is capable of maintaining sufficiently low temperatures to freeze the deicer salt solution.

7.1.1. If a constant-temperature freezer is used, the specimens can be removed and allowed to thaw at room temperature.

7.1.2. A thermal cycling chamber capable of both freezing and thawing the sodium chloride solution may also be used.

7.2. Containers, fabricated out of a corrosion-resistant material, such as plastic or stainless steel, and strong enough to support the specimens submerged in sodium chloride solution. The containers may also be made out of wood with a watertight liner made of rubber or other material.

7.2.1. The containers should be sized to fit the length and width of the specimens with little additional room to reduce the amount of solution that must occupy that space. The depth of the container should be at least 2 cm (0.75 in.) higher than the tops of the domes to accommodate the solution on top of the specimen.

Note 1: For 86 cm by 86 cm by 10 cm (34 in. by 34 in. by 4 in.) specimens, containers with interior dimensions of 90 cm by 90 cm by no less than 12 cm (35.4 in. by 35.4 in. by 4.75 in.) are suitable.

7.2.2. The containers should be fitted with lids of a corrosion-resistant material.

7.3. Thermocouples and a thermocouple logger, if desired, to monitor the temperature of the solution and the samples. While useful for tracking test performance, the use of thermocouples is optional. Note that if used, thermocouples will generally need to be installed in the concrete samples when originally fabricated.

8. REAGENTS

8.1. Deicer salt solution (3% sodium chloride solution)

8.1.1. Reagent water

8.1.2. Sodium chloride, 99% or higher purity

Note 2: If desired, an alternate deicer solution, which will cause scaling on susceptible concrete may be substituted for the 3% sodium chloride solution.

9. PROCEDURE

9.1. The specimens should be placed in the containers with the detectable warning system side up.

9.1.1. If a watertight liner is used, make sure the liner is in place and damage-free prior to inserting the specimen.

9.2. Fill the specimen containers with solution until the level of the liquid is above the tops of the domes. Additional solution may be added, but will increase the freezing and thawing time of the specimens.

Note 3: Check the specimen containers for leaks while adding solution. If leaks are apparent, repair as appropriate.

9.2.1. Place lids on the containers to reduce evaporation of the solution once the solution is at the appropriate level.

Note 4*:* Solution may be added prior to placing the specimens in the freezing chamber, or after the specimens are in the chamber. If adding solution after placing the specimens in the freezing chamber, check for leaks first to avoid having to remove specimens if leaks become apparent upon filling the containers with solution.

9.3. Place the specimens in the freezing chamber, ensuring that enough room is left above the specimen to view and access the solution in order to confirm that freezing and thawing is taking place. Adjust the temperature and duration of the freezing cycle to produce complete freezing of the solution in all specimens. Do not cool the air temperature in the chamber below -23ºC (-10°F).

9.3.1. Ensure the test solution is completely frozen for at least 30 minutes during each freezing cycle. Confirm freezing of solution on all specimens by visually and tactilely monitoring the solution or by remote monitoring of thermocouples placed in the solution.

9.4. Adjust the temperature and duration of the thawing cycle to confirm complete thawing of the solution in all specimens. Do not heat the air temperature in the chamber above 29ºC (85°F).

9.4.1. Ensure the test solution is completely thawed for a minimum of 30 minutes. Confirm thawing of solution on all specimens by visually and tactilely monitoring the solution or by remote monitoring of thermocouples placed in the solution.

9.5. Periodically monitor the solution level and ensure that the tops of the domes remain submerged in 3% sodium chloride solution.

Note 5: If the solution level has decreased, ascertain if the level has dropped because of evaporation or a leak. If the cause of liquid level drop is a leak, fill the specimen containers with 3% sodium chloride solution to cover the tops of the domes. If the cause of the liquid level drop is evaporation, fill the specimen containers with reagent water to cover the tops of the domes.

9.6. The length of a complete freeze-thaw cycle shall be no less than 6 hours.

9.7. Cycle the specimens for the desired number of cycles according to the Draft T4-33.

10. REPORT

10.1. The report shall include the following:

10.1.1. The sample identification assigned according to the Draft T4-33.

10.1.2. Type, manufacturer, and, if known, lot number of the detectable warning system(s) tested.

10.1.3. Air temperatures achieved in the freezing and/or thawing chambers.

10.1.4. The duration of complete freeze and thaw and the method by which freezing and thawing was confirmed.

10.1.5. The number of cycles.

10.1.6. Any deviation from the procedures outlined in this method, such as if an alternative salt was used to produce the solution.

11. PRECISION

11.1. Data not available at this time.

Recommended Method of Test for

High Temperature Thermal Cycling of Detectable Warning Systems

Designation: Draft T4-33, Part 2

1. SCOPE

1.1. This method covers the exposure of detectable warning systems to alternating heating and cooling cycles in the laboratory. Thermal excursions have the potential to induce stresses between the detectable warning system and the substrate, which may have different coefficients of thermal expansion. This thermal cycling may be rapid, such as due to sudden rainfalls, or more gradual due to daily variations in ambient temperature.

1.2. This exposure is intended to be conducted as part of the test protocol outlined in Draft T4-33, which outlines the exposure and evaluation methods for determination of durability of detectable warning systems.

2. REFERENCED DOCUMENTS

2.1. **AASHTO Standards**

2.1.1. Draft T4-33 *Recommended Method of Test for Durability of Detectable Warning Systems*

2.2. **ASTM Standards**

2.2.1. ASTM G 151-06, *Standard Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources.*

3. SUMMARY OF TEST METHOD

3.1. This method exposes detectable warning systems to cyclic ramped heating and sudden cooling to simulate daily thermal variations and rapid cooling events.

4. SIGNIFICANCE AND USE

4.1. This exposure method is intended to produce repetitive elevated temperature excursions followed by rapid water cooling to produce accelerated weathering of detectable warning systems.

4.2. This method is intended to be used as part of the Draft T4-33 to evaluate the durability of detectable warning systems. An evaluation test is not included in this method.

5. SAFETY HAZARDS

5.1. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

6. TEST SPECIMENS

6.1. Test specimens prepared in accordance with Draft T4-33 are required with the modification described below.

6.2. Thermocouples shall be embedded at the following locations in the specimen:

6.2.1. *Near surface (Thermocouples A, B in Figure 1)*

6.2.1.1. For detectable warning systems with a minimum thickness less than 6 mm (¼ in.), embed thermocouples at the middle and corner of the specimen at the interface between the concrete and the detectable warning system. These thermocouples should be installed at the time of system installation or concrete casting.

6.2.1.2. For all other detectable warning systems, install thermocouples at 6 mm (¼ in.) below the field of the detectable warning sample. To install, drill a hole for the thermocouple and adhere it to the specimen with thermally conductive epoxy.

6.2.2. *Interior middle (Thermocouple C in Figure 1):* Install thermocouple 51 mm (2 in.) from the top surface of the concrete in the middle of the specimen, when viewed in plan. For most specimens, this will be in the mid-height of the concrete slab.

7. APPARATUS

7.1. An infrared electric heater shall be used to heat the detectable warning system with a control system capable of performing “ramp” (temperature increase over time) and “soak” (constant temperature over time) steps.

Note 1: 3.2 kW (11,000 Btu/hr) electric infrared heaters with quartz tubes have been used successfully to provide the required amount of heat to the sample surface.

7.2. An enclosure capable of surrounding one detectable warning system test specimen shall be used to control the environment around the test specimen. The enclosure is open on the bottom but enclosed on all other sides. The specimen shall be inclined at a 1:10 slope to allow for water to flow off the surface. The sides of the enclosure shall be constructed with 25 mm (1 in.) thick rigid insulation with foil backing. The insulation shall be oriented with the reflective foil backing toward the interior.

Note 2: An enclosure that is 1.2 m by 1.2 m by 1.2 m (48 in. by 48 in. by 48 in.) has been used successfully to house the detectable warning system, heating, and water distribution/cooling apparatus.

7.3. The specimen shall be cooled by water, applied from one edge in a steady stream at a flow rate of 10 to 20 L/min (3 to 6 gal/min). The water shall uniformly cover the surface and drain off the edge of the specimen without pooling. The temperature of the cooling water shall be 10–20°C (50–68°F).

Note 3: A 19 mm (¾ in.) diameter pipe with 6 mm (¼ in.) diameter holes, spaced at 75 mm (3 in.) on center has been used successfully to provide a uniform application of water.

7.4. Temperature measurements on the surface of the specimen shall be made at two locations using insulated black panel thermometers, constructed according to the requirements in ASTM G 151-06, Annex A2.

Note 4: Measured black panel temperatures are generally expected to be greater than the specimen surface temperature.

Note 5: Photographs of a system consistent with these requirements are given in the appendix of this method.

8. CALIBRATION

8.1. Record the water temperature at the beginning of each set of test cycles and adjust as necessary to meet the requirements of Section 9.2.4.

8.2. Adjust the water pressure so that the water lands on one edge of the specimen and flows across the entire surface. The discharge rate should meet the requirements of Section 7.3 and be such that significant splashing does not occur.

8.3. The uniformity of the infrared radiation on the surface of the specimen shall be measured as follows:

8.3.1. Heat the specimen until the temperature measured by the center black panel thermometer is the maximum cycle temperature and stable temperatures are achieved.

8.3.2. Assure that the steady state reading for the second black panel thermometer on any part of the detectable warning system is no more than 20°C (36°F) less than the center black panel thermometer reading.

8.4. The heat flux at the surface shall be capable of raising the black panel thermometer from ambient temperature to the maximum cycle temperature in less than 15 minutes.

8.5. Adjust the distance from heat source, spacing of heating elements, or number of heating elements in the enclosure to meet the requirements in Section 8.4.

9. PROCEDURE

9.1. Monitoring

9.1.1. Place two insulated black panel thermometers on the specimen at the following locations:
1. At the geometric center of the detectable warning system
2. At the corner of the detectable warning surface, such that the edges of the thermometer are 25 mm (1 in.) from either edge of the detectable warning

9.1.2. Record the maximum and minimum temperature measured by the center and corner black panel thermometers each cycle.

9.1.3. Record the maximum and minimum temperature of all thermocouples each cycle.

9.2. Thermal Cycle

9.2.1. *Initialization*: Apply water to the specimen for 15 minutes prior to the first cycle.

9.2.2. *Ramp*: Discontinue water flow and apply heat to increase the temperature of the center black panel thermometer to the maximum temperature specified in Draft T4-33 in less than 15 minutes.

9.2.3. *Soak*: Maintain the temperature of the center black panel thermometer at the specified temperature ±2°C (± 4°F) for 2 hours.

9.2.4. *Cool*: Apply water to the specimen until the temperature of the “interior middle” thermocouple (Thermocouple C) reaches 25°C (77°F).

9.2.5. One cycle is defined as a completion of the *ramp*, *soak*, and *cool* steps described above. Repeat as required in the Draft T4-33.

Note 6: A schematic of a thermal cycle consistent with these requirements is given in the appendix of this method.

Note 7: As an alternative to controlling the duration of cooling based on continuous monitoring of the temperature at the “interior middle” thermocouple (Thermocouple C), the required duration for the cooling step may be established during the first few cycles at the beginning of testing for a specific detectable warning system and then this duration must be repeated consistently.

10. REPORT

10.1. The report shall include the following:

10.1.1. The sample identification assigned according to the Draft T4-33.

10.1.2. Type, manufacturer, and, if known, lot number of the detectable warning system(s) tested.

10.1.3. The number of cycles performed.

10.1.4. The temperature of the water used for cooling.

10.1.5. The recorded minimum and maximum thermocouple readings for each cycle.

10.1.6. The recorded minimum and maximum black panel thermometer readings for each cycle.

10.1.7. Any deviations from the test procedure outlined herein.

11. PRECISION

11.1. Data not available at this time.

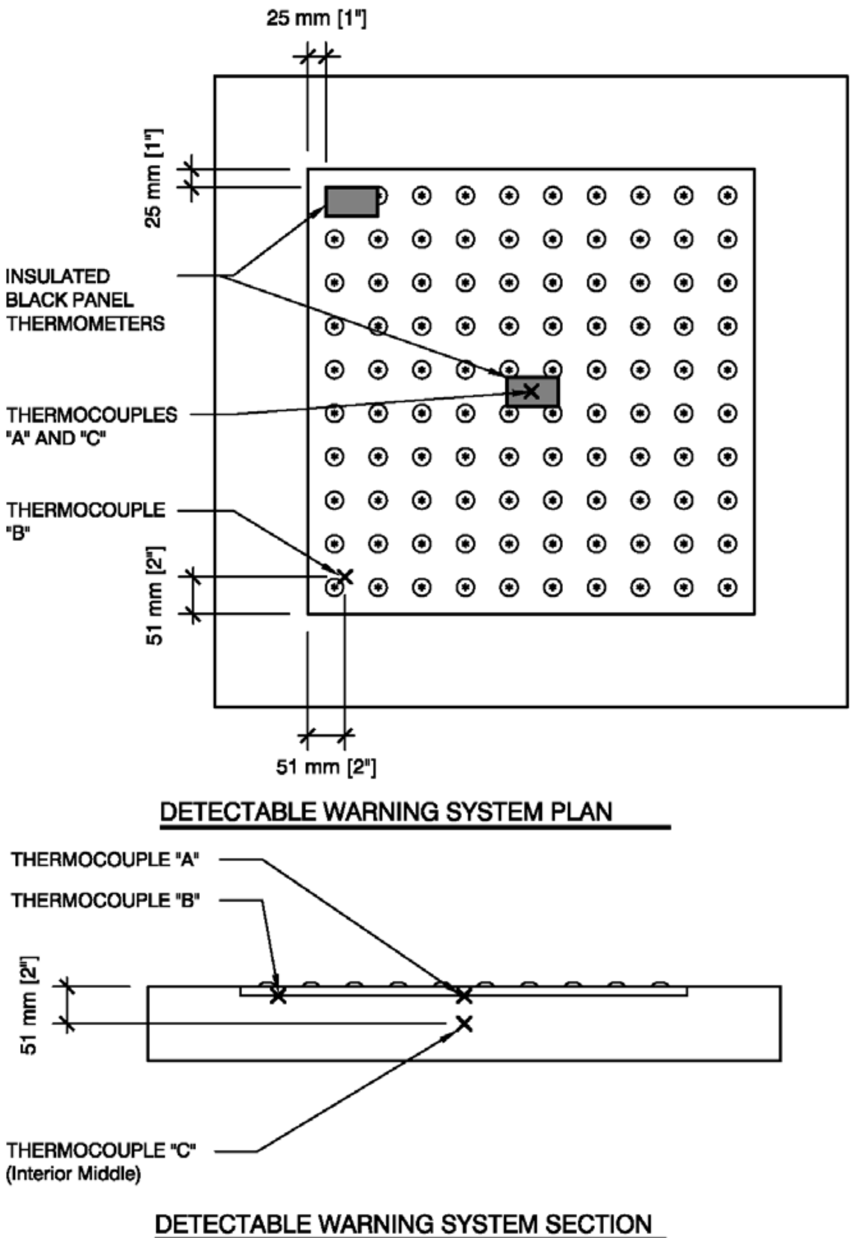


Figure 1. Thermocouple Layout

APPENDIX (Non-mandatory Information)

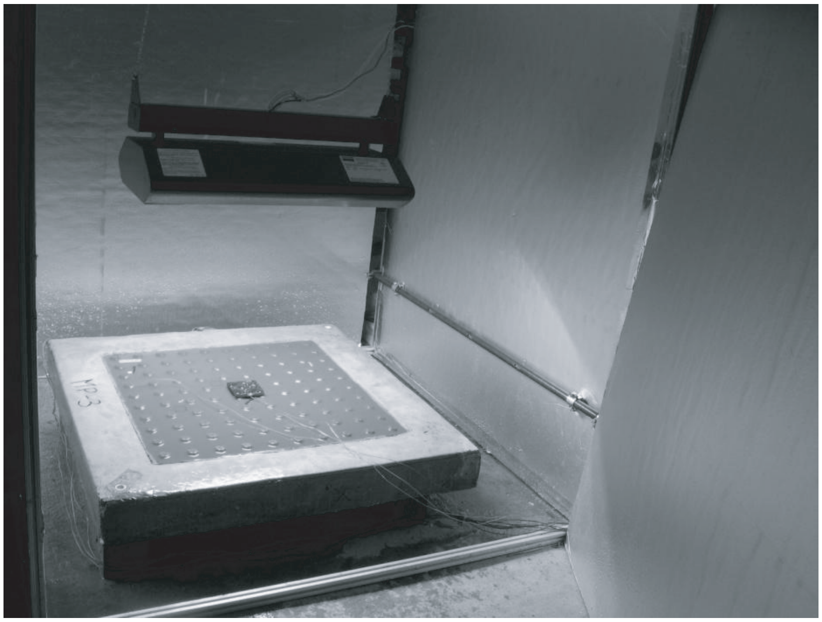


Figure 2. Enclosure and sample under heating (ramp) portion of test cycle.

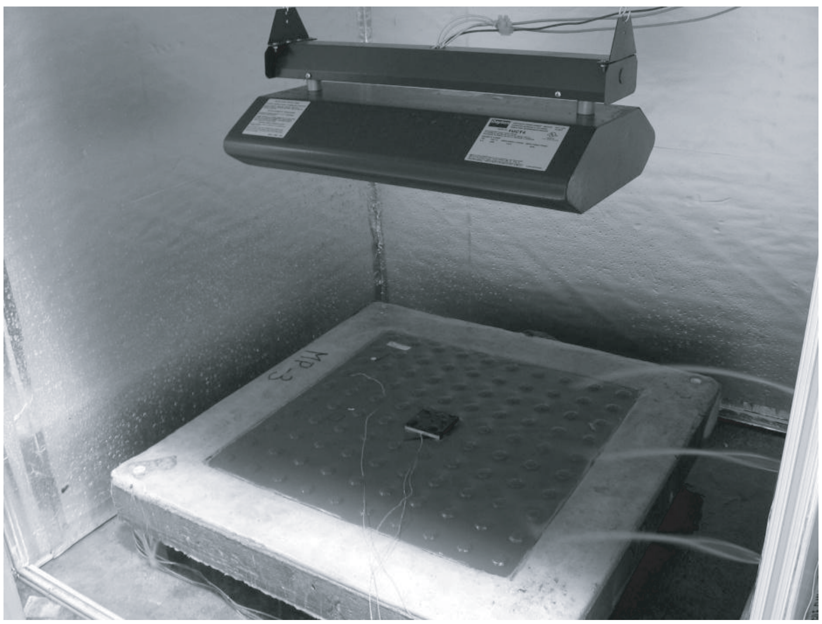


Figure 3. Enclosure and sample under cooling portion of test cycle. Note the sheet of water draining to the left on the sample surface.

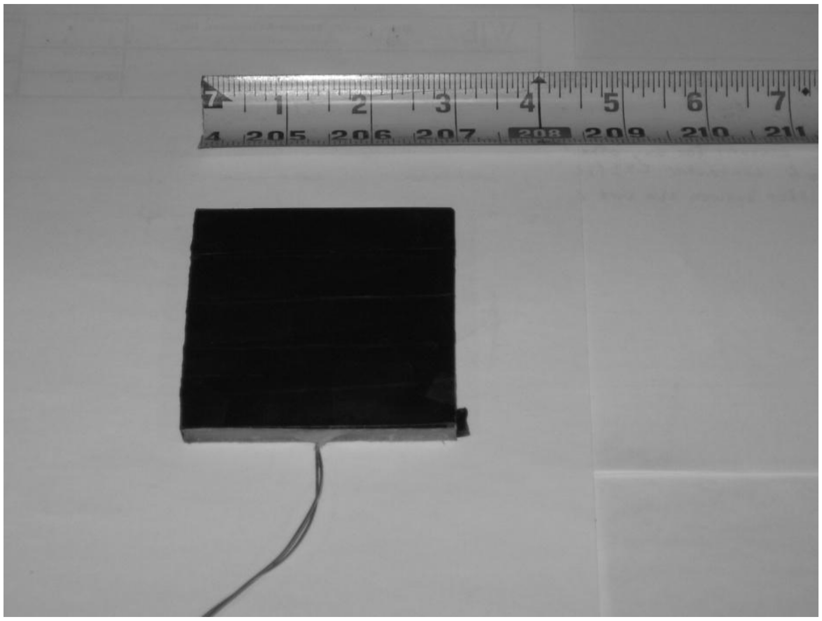


Figure 4. Insulated black panel thermometer used for surface temperature evaluation.

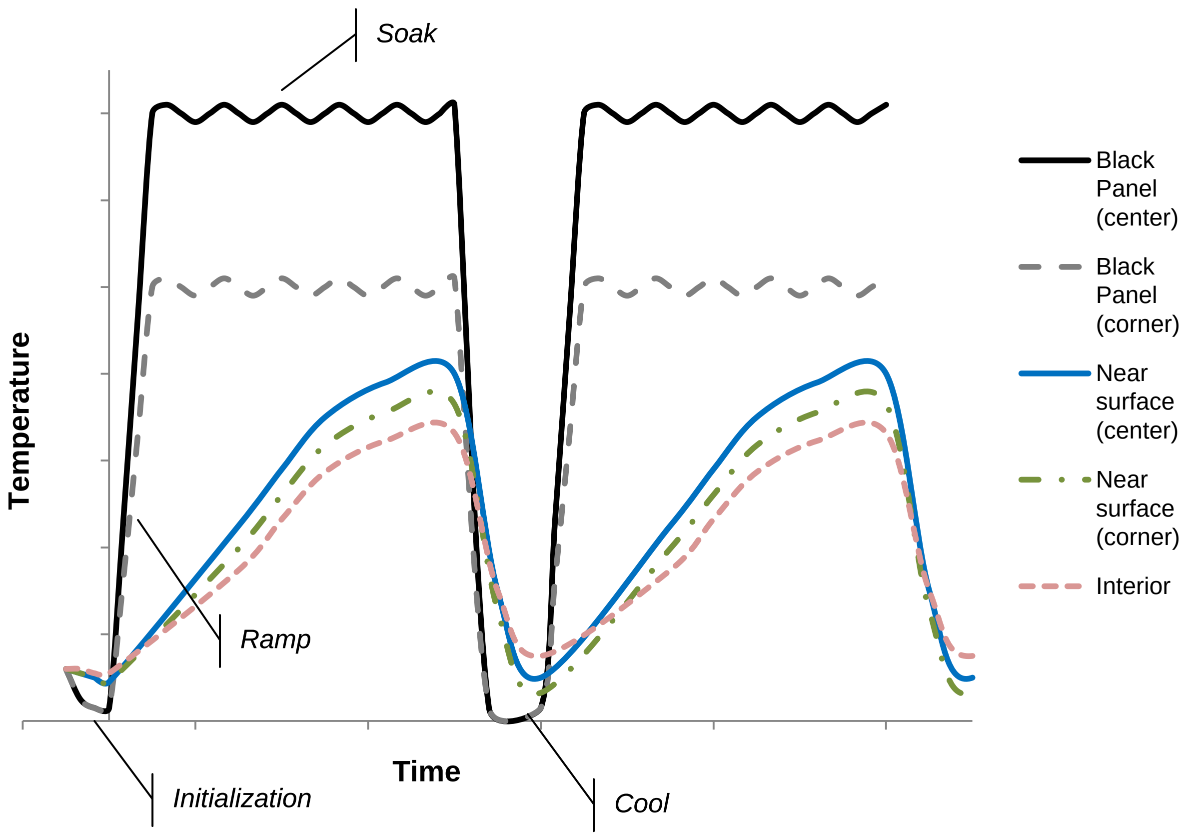


Figure 5. Schematic of Thermal Cycles. Interior is temperature measured by "interior middle" thermocouple.

Recommended Method of Test for

Ultraviolet Light Exposure of Detectable Warning Systems

Designation: Draft T4-33, Part 3

1. SCOPE

1.1. This method covers the exposure of detectable warning systems to ultraviolet light. This exposure has the potential to fade pigments and/or deteriorate the material substrate. Fading or change in color or contrast over time may reduce the Americans with Disabilities Act Accessibility Guidelines–required visual contrast between the system and surrounding concrete.

1.2. This exposure is intended to be conducted as part of the test protocol outlined in Draft T4-33, which outlines the exposure and evaluation methods for determination of durability of detectable warning systems.

2. REFERENCED DOCUMENTS

2.1. **AASHTO Standards**

2.1.1. Draft T4-33 *Recommended Method of Test for Durability of Detectable Warning Systems*

2.2. **ASTM Standards**

2.2.1. ASTM G 151-06, *Standard Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources*

2.2.2. ASTM G 154-06, *Standard Practice for Selecting and Characterizing Weathering Reference Materials Used to Monitor Consistency of Conditions in an Exposure Test*

3. TERMINOLOGY

3.1. *Irradiance:* a measure of power flux. For this method, irradiance is measured over a narrow bandwidth of the peak wavelength for the ultraviolet lights used.

4. SUMMARY OF TEST METHOD

4.1. The ultraviolet (UV) weathering test is a modification of ASTM G 151-06 and ASTM G 154-06. As modified, this test uses a set of ultraviolet lights, analogous to those described in ASTM G 154-06, designed to produce radiation primarily in the UVA part of the solar spectrum.

5. SIGNIFICANCE AND USE

5.1. This exposure method is intended to produce accelerated weathering of detectable warning systems cast into concrete.

5.2. This method is intended to be used as part of the Draft T4-33 to evaluate the durability of detectable warning systems. An evaluation test is not included in this method.

6. SAFETY HAZARDS

6.1. The ultraviolet lights used in this exposure produce wavelengths at intensities that are capable of damaging eye and skin tissue. Adequate protection should be used when lamps are in operation.

6.2. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7. TEST SPECIMENS

7.1. Test specimens prepared in accordance with Draft T4-33 are required.

8. APPARATUS

8.1. Radiometer

8.2. Peak irradiance—The radiometer used shall be capable of measuring electromagnetic radiation at a peak wavelength of 340 nm.

8.2.1. Maximum bandwidth—The maximum allowable bandwidth of the detector shall be 10 nm, centered about the peak irradiance.

8.2.2. Range and precision—The detector shall be capable of measuring flux in a range from 0 to 2 $W/m^2/nm$ with a precision of 0.01 $W/m^2/nm$.

8.3. UV Tent

8.3.1. Description—The UV tent is an enclosure that is capable of holding multiple fluorescent ultraviolet light fixtures in a plane at a fixed distance from and parallel to the surface of the detectable warning system. The tent may be constructed such that multiple samples are placed under one enclosure. The enclosure is required to protect personnel from exposure to the ultraviolet radiation.

8.3.2. Irradiance requirements—By adjusting the distance of the sample surface from the lights, the number of fluorescent lights, or the voltage, the peak irradiance at any point on the surface of the detectable warning system shall be 0.6 $W/m^2/nm \pm 0.02$ $W/m^2/nm$.

The minimum irradiance at any point on the detectable warning system shall be no less than 70% of the peak irradiance. If the radiance is between 70% and 90% at any point on the specimen surface, specimens shall be rotated four times per exposure cycle. If the irradiance at all points on the specimen is greater than 90% of the peak irradiance, periodic repositioning is recommended but not required.

8.3.3. Materials—The tent may be made of any material but should have an interior surface that reflects at least 50% of radiation at the peak wavelength.

8.3.4. Temperature—The air temperature at the surface of the specimens shall be measured. Maintain temperatures in the chamber at 30 ± 3ºC (86 ± 5ºF).

8.4. Ultraviolet Light Source

8.4.1. The ultraviolet source used shall be UVA-340 lamps, as described in ASTM G 154-06.

9. CALIBRATION

9.1. Instrumentation

9.1.1. The radiometer used for measurement shall be calibrated and traceable to national standards.

9.1.2. The temperature gauge used for measurement shall be calibrated and traceable to national standards.

9.2. Irradiation

9.2.1. Before each testing cycle, calibrate the irradiance at the level of the testing surface.

9.2.2. Find the peak irradiance and the minimum irradiance in the same area that the detectable warning system will be placed.

9.2.3. Adjust the distance from lights, spacing of lights, or number of lights in the enclosure so that the maximum and minimum irradiance meet the requirements in Section 8.3.2.

10. PROCEDURE

10.1. Monitoring

10.1.1. Place a temperature gauge and radiometer at the same level as the detectable warning system. Do not block any surface of the detectable warning system with the instruments.

10.1.2. During the interval of the exposure, record at least one irradiance and temperature measurement daily. Measurements shall be taken at the same location for comparison purposes. Be sure to record daily temperature and irradiance before the enclosure is opened for any reason.

10.2. Exposure

10.2.1. Place the detectable warning/concrete system sample or samples to be tested underneath the enclosure tent.

10.2.2. Irradiate the specimen continuously for the number of hours specified in Draft T4-33.

11. REPORT

11.1. Report the sample identification assigned according to the Draft T4-33.

11.2. Report type, manufacturer, and, if known, lot number of the detectable warning system(s) tested

11.3. Report the duration of exposure in hours. Do not include time when the UV lamps were off for maintenance or observations.

11.4. Report the daily radiometer and temperature readings for the duration of the exposure.

12. PRECISION

12.1. Data not available at this time.

Recommended Method of Test for

Abrasion Exposure of Detectable Warning Systems

Designation: Draft T4-33, Part 4

1. SCOPE

1.1. This method covers the exposure of detectable warning/concrete systems to repeated cycles of abrasion in the laboratory. Abrasion is expected to occur primarily as a result of pedestrian traffic over the walking surface. Dirt, debris, and sand used to provide traction in an icy environment is anticipated to accelerate the abrasion. Note that this abrasion exposure is distinguished from the procedure outlined in Draft T4-33, Part 12 *Recommended Method of Test for Wear Resistance of Detectable Warning Systems* in that the severity of the abrasion action is reduced and applied to the full surface of the detectable warning system.

1.2. This exposure is intended to be conducted as part of the test protocol outlined in Draft T4-33, which outlines the exposure and evaluation methods for determination of durability of detectable warning systems.

2. REFERENCED DOCUMENTS

2.1. **AASHTO Standards**

2.1.1. Draft T4-33 *Recommended Method of Test for Durability of Detectable Warning Systems*

2.2. **ASTM Standards**

2.2.1. ASTM D 1056 *Standard Specification for Flexible Cellular Materials—Sponge or Expanded Rubber*

3. SUMMARY OF TEST METHOD

3.1. This method describes an exposure regime where the surface of a detectable warning system that has been cast into or applied to concrete is abraded by an abrasive pad mounted on a sled of known weight and resilience. This sled is translated across the surface of the sample multiple times as part of each exposure cycle.

4. SIGNIFICANCE AND USE

4.1. The sled and abrasive have been defined to simulate the wear that may be expected from pedestrian traffic.

4.2. This method is intended to be used as part of the Draft T4-33 to evaluate the durability of detectable warning systems. An evaluation test is not included in this method.

5. SAFETY HAZARDS

5.1. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

6. TEST SPECIMENS

6.1. Two test specimens prepared in accordance with Draft T4-33 are required.

7. APPARATUS

7.1. Abrasive Sled—The abrasive action will be applied to the surface of the detectable warning system by a sled (Figure 1). This sled shall consist of abrasive paper mounted to the bottom of a plate assembly made up of a top plate of rigid material and a securely attached layer of compressible rubber foam. The area of the foam to which the paper will be attached shall be 15.2 x 30.5 ± 0.25 cm [6 x 12 ± 0.1 in.]. The rigid plate shall be 20.3 ± 0.25 cm [8 ± 0.1 in.] in width. The paper shall be wrapped to the top of the rigid plate creating an angle of slope 3/8:1. The total weight of the sled will be 6 ± 0.05 kg [13.2 ± 0.1 lbs.]

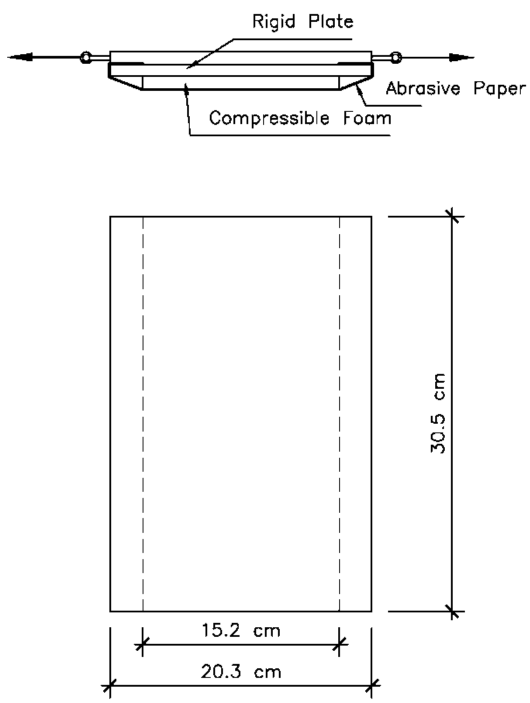


Figure 1. Abrasive Sled

Note 1: Photographs of a system consistent with the requirements of this method are given in the appendix to this method.

7.1.1. The 0.95 cm (3/8 in.) thick, compressible rubber foam layer shall conform with the following specifications: The material shall be closed-cell foam rubber with a durometer of 40 ± 10 OO Shore and density of 0.064–0.128 g/cm^3 [4–8 lbs./cu. ft.] and shall comply with ASTM D 1056 Grade 2A. Firmness expressed by compression-deflection test of 25% deflection shall be 13.8–

34.5 kPa [2–5 psi]. (Blended Neoprene/EPDM/SBR foam has been found to meet these requirements.)

7.1.2. The abrasive paper shall be 120-grit, C weight abrasive paper with a non-loading agent. The paper shall conform with the following specifications: The paper backing shall be abrasive grade and weigh 120 ± 5 g/m^2. The adhesive shall be urea-formaldehyde resin. The total adhesive coat weight (combined make and size coat) shall be 118 ± 5 g/m^2. The abrasive shall be 120-grit FEPA graded coated abrasive grade, low titania, heat treated aluminum oxide. The abrasive coat weight shall be 120 ± 5 g/m^2. A zinc stearate non-loading agent shall be applied at density not to exceed 20 g/m^2.

Note 2: 120-grit Gold Non-Loading C weight abrasive paper available from Johnson Abrasives, Inc., 49 Fitzgerald Drive, Jaffrey, NH 03452, conforms with these requirements.

7.2. A translation mechanism capable of repeatedly moving the sled across the detectable warning system surface shall be used. This system shall apply a force parallel to the detectable warning system surface in such a manner that the movement is continuous and without chatter. The full width of the abrasive surface shall extend past the last row of domes.

Note 3: A test translation mechanism conforming with the requirements of this method is pictured in the appendix. It consists of a frame supporting a hand-activated pulley system that translates the abrasive sled across the sample surface.

8. PROCEDURE

8.1. The full area of the detectable warning surface will be exposed to the abrasion process. One half of the surface will be abraded at a time. Designate the sides as “A” and “B” or similar. Record which side is abraded first during each cycle, and alternate which side is abraded first at the start of the next run.

8.2. Inspect the apparatus for signs of wear or damage. If wear or deformation in the compressible foam is observed, install new foam. Install fresh abrasive paper at the start of each test.

8.3. Measure the height of the domes at four previously selected areas according to the method outlined in Draft T4-33, Part 7 *Recommended Method of Test for Dome Shape and Geometry Measurement of Detectable Warning Systems.* Two of the four measurements should be on each side of the test surface.

8.4. Place the translation mechanism over the detectable warning sample taking care that the sled will cover one half of the tested surface.

8.5. Cycle the specimens for the desired number of cycles according to the Draft T4-33. A single complete cycle will be defined as the distance covered when the sled moves from and back to its starting position.

8.6. Reposition the translation mechanism and repeat the cycling on the second half of the tested surface.

8.7. Repeat the measurement of the height of the selected domes according to the method outlined in Draft T4-33, Part 7 *Recommended Method of Test for Dome Shape and Geometry Measurement of Detectable Warning Systems*.

9. REPORT

9.1. Report the sample identification assigned according to the Draft T4-33.

9.2. Report type, manufacturer, and, if known, lot number of the detectable warning system(s) tested.

9.3. Report the number of cycles.

9.4. Report the change in height of each of the selected domes.

9.5. Report any deviation from the procedures outlined in this method.

10. PRECISION

10.1. Data not available at this time.

APPENDIX (Non-mandatory Information)

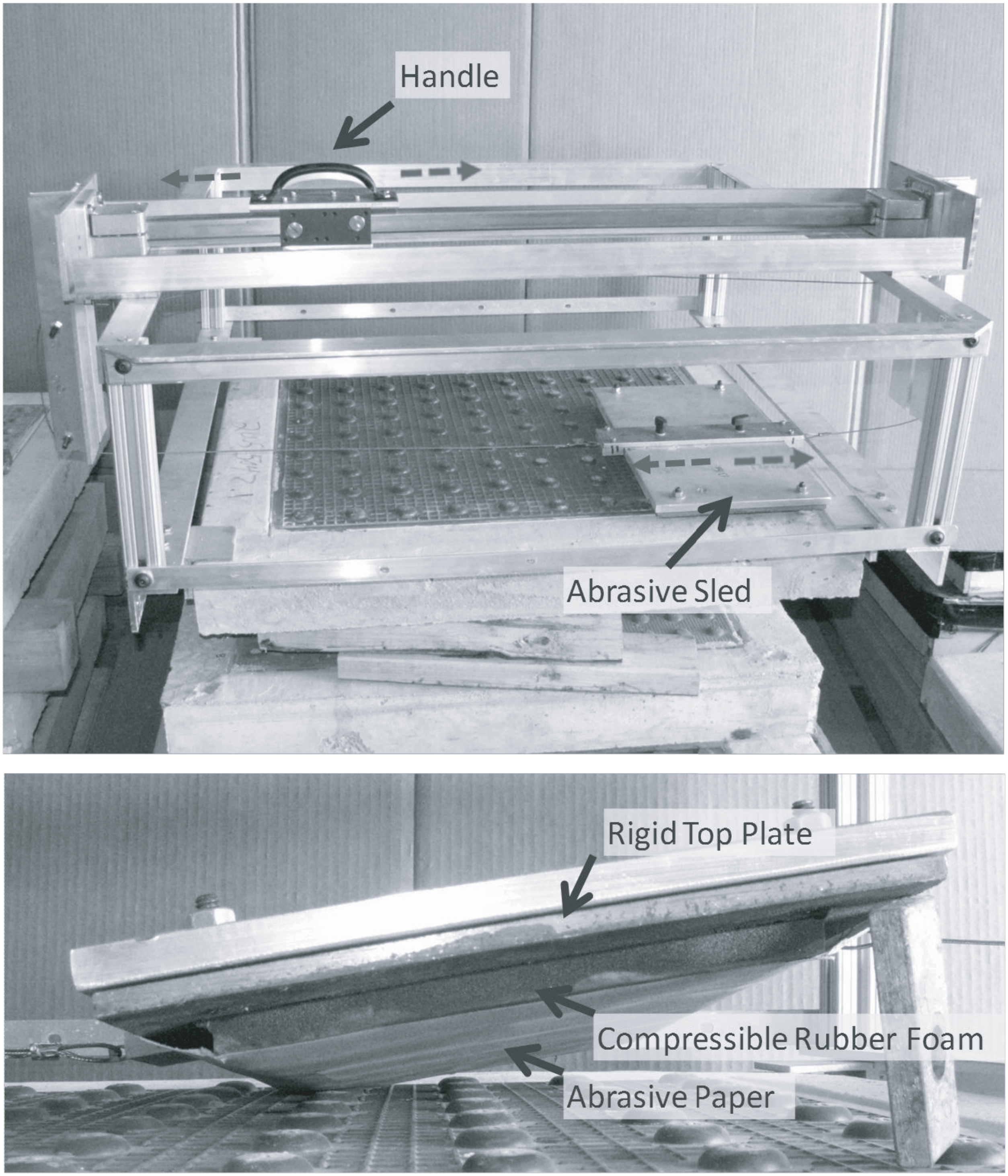


Figure 1-- A frame supporting a hand-activated wire and pulley system that translates the abrasive sled across the sample surface (top) and close-up of side of abrasive sled showing rigid top plate, compressible foam and abrasive paper (bottom).

Recommended Method of Test for

Visual and Microscopic Evaluation of Detectable Warning Systems

Designation: Draft T4-33, Part 5

1. SCOPE

1.1. This test method covers visual and microscopic evaluation of detectable warning systems. Visual and microscopic evaluation provide a method to determine the effects of exposure on detectable warning system specimens that are not readily measured with other standard tests.

1.2. This evaluation test is intended to be conducted as part of the test protocol outlined in Draft T4-33, which outlines the exposure and evaluation methods for determination of durability of detectable warning systems.

2. REFERENCED DOCUMENTS

2.1. **AASHTO Standards**

2.1.1. Draft T4-33 *Recommended Method of Test for Durability of Detectable Warning Systems*

3. TERMINOLOGY

3.1. Dome: The truncated dome on the detectable warning system.

3.2. Field: The space between the domes on the detectable warning system. The field is level with the surrounding concrete.

4. SUMMARY OF TEST METHOD

4.1. This test method describes how to conduct a visual and microscopic evaluation of detectable warning systems in conjunction with exposures described in Draft T4-33.

5. SIGNIFICANCE AND USE

5.1. Visual and microscopic evaluation provides a means to evaluate any degradation of a detectable warning system as a result of laboratory exposures. Visual and microscopic evaluation is intended to be carried out prior to exposure testing and upon completion of the exposure testing, prior to any further evaluation.

5.2. This test method is intended to be used as part of Draft T4-33 to evaluate the durability of detectable warning systems.

6. SAFETY HAZARDS

6.1. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7. TEST SPECIMENS

7.1. Test specimens prepared in accordance with Draft T4-33 are required.

8. APPARATUS

8.1. A hand lens or portable microscope, capable of magnifications of 10X to 30X.

9. PROCEDURE

9.1. Visually examine each specimen for any defects or unusual features, which may include cracks, dents, divots, discolorations, or other features. Also examine the specimens for irregularities in the attachment of the specimen to the concrete, such as debonding or displacement of the detectable warning system. Some features may not be apparent on an unexposed specimen, but may become apparent as a result of the test exposures.

9.1.1. Examine the overall specimen from a sufficient distance to observe the entire specimen at once.

9.1.2. Examine the specimen from a distance of 15 to 45 cm (6 to 18 in.) from several angles to ensure that all features are observed.

9.2. Identify observed features with a contrasting marker and document the locations for future reference.

9.3. Photograph the sample. Take one overall photograph of the sample and the concrete. Additional close-up photographs of any particular features that are observed are recommended.

9.4. Select two areas, approximately 2.5 cm by 2.5 cm (1 in. by 1 in.) in area, for microscopic examination. Examine these areas with a hand lens or microscope, with magnifications 10X to 30X.

9.4.1. If possible, record a micrograph of each area for future reference.

9.4.2. Document the areas examined in the project notes and record any observations.

Note 1: For some materials systems, applying dye or ink to the areas examined, then rapidly removing excess from the surface, is a good way to highlight microcracks and other surface features.

Note 2: If multiple people will be carrying out the visual and microscopic examinations, it is helpful if all observers conduct examinations together on at least one sample and compare their observations to ensure that similar results are produced.

10. REPORT

10.1. Report the following:

10.1.1. Exposure level, if any, prior to the visual and microscopic examination.

10.1.2. Description of features observed visually and location on the specimen.

10.1.3. Description of features observed microscopically and location on the specimen.

10.1.4. Any changes from prior evaluations of the same specimen, if applicable.

11. PRECISION

11.1. Data not available at this time.

APPENDIX (Non-mandatory Information)

Several types of degradation have been observed visually and microscopically as a result of exposure testing of detectable warning systems. The particular type of degradation depends on several factors, including the detectable warning system material, the mechanism of attachment to the concrete, and the geometry of the system. It is anticipated that detectable warning system products may exhibit a variety of or no degradation types and that the type of degradation will depend on the exposure.

The following types of degradation have been observed. This list is intended as an aid to the researcher, and is not comprehensive or representative of any particular detectable warning system.

- Macrocracking (detected visually), often near the edges of specimens or near the domes.
- Microcracking (detected microscopically), on both the domes and the field. These cracks are too short to be detected visually.
- Debonding of the detectable warning system from the concrete.
- Displacement of the detectable warning system relative to the concrete.
- Fracturing or breaking of domes.
- Decrease in dome height (also measured according to Draft T4-33, Part 7 *Recommended Method of Test for Dome Shape and Geometry Measurement of Detectable Warning Systems*).
- Change in surface texture of the field or domes.
- Change in color (also measured according to Draft T4-33, Part 6 *Recommended Method of Test for Color Measurement of Detectable Warning Systems*).

Photographs of some types of degradation are provided in Figures 1 through 7.

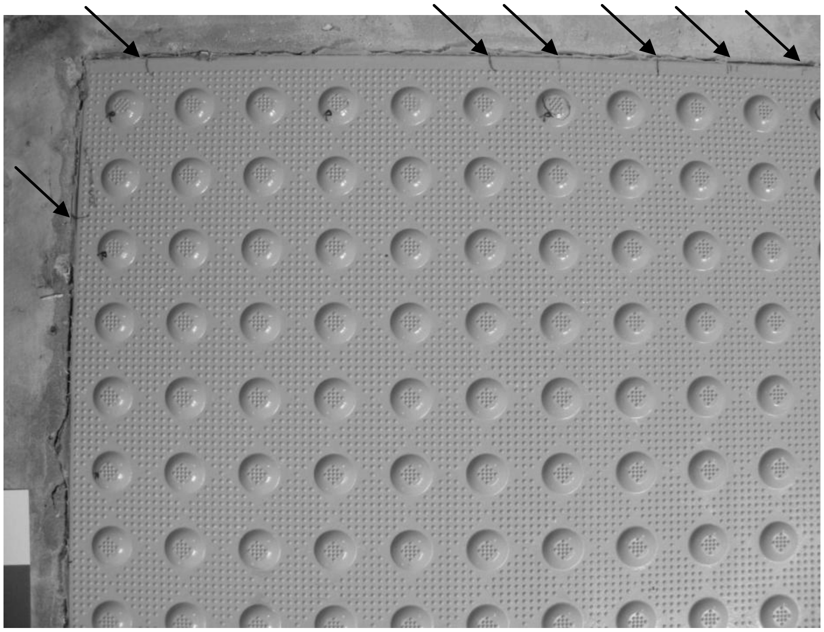


Figure 1 **-** *Macrocracks around the perimeter of a detectable warning system.*

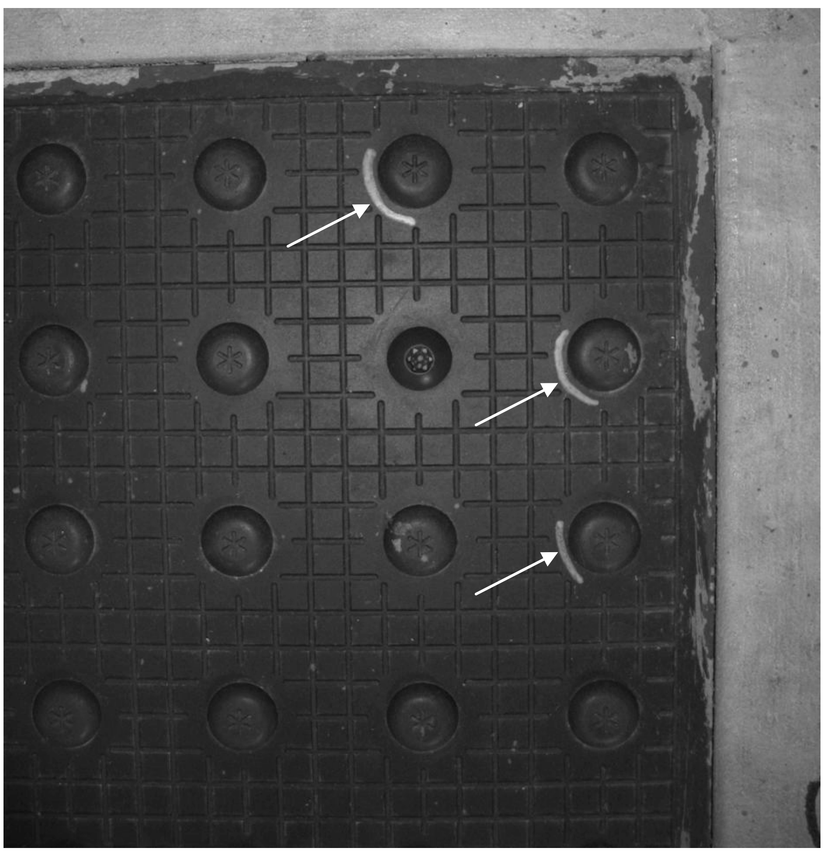


Figure 2 - Macrocracks around the edges of domes on a detectable warning system.

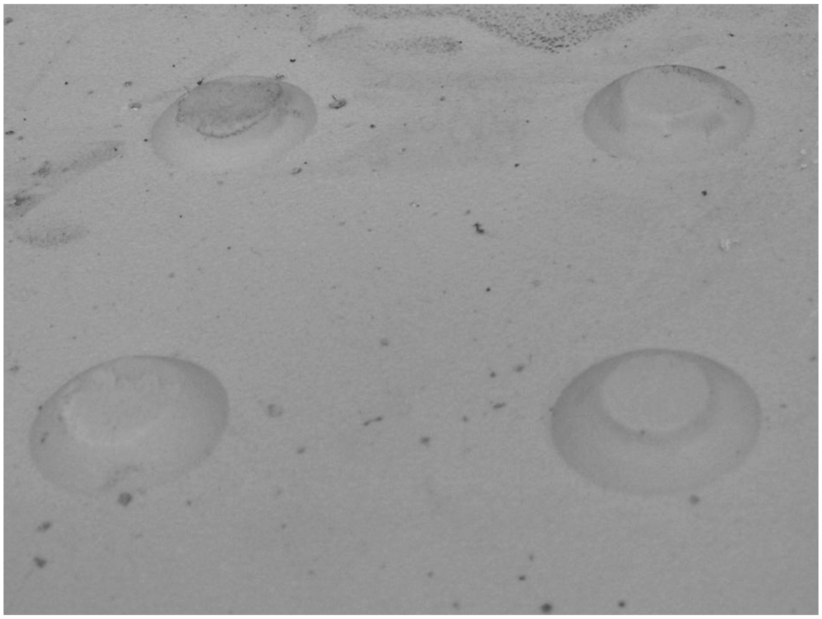


Figure 3 - Loss of dome height of a detectable warning system.

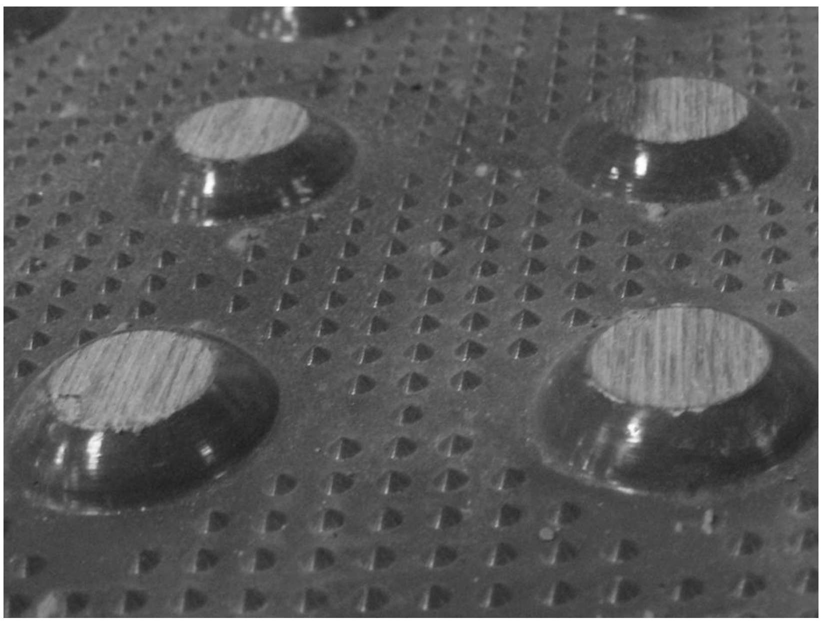


Figure 4 - Loss of dome height of a detectable warning system.

Figure 5 - Relative displacement of a detectable warning system, caused by freeze jacking.

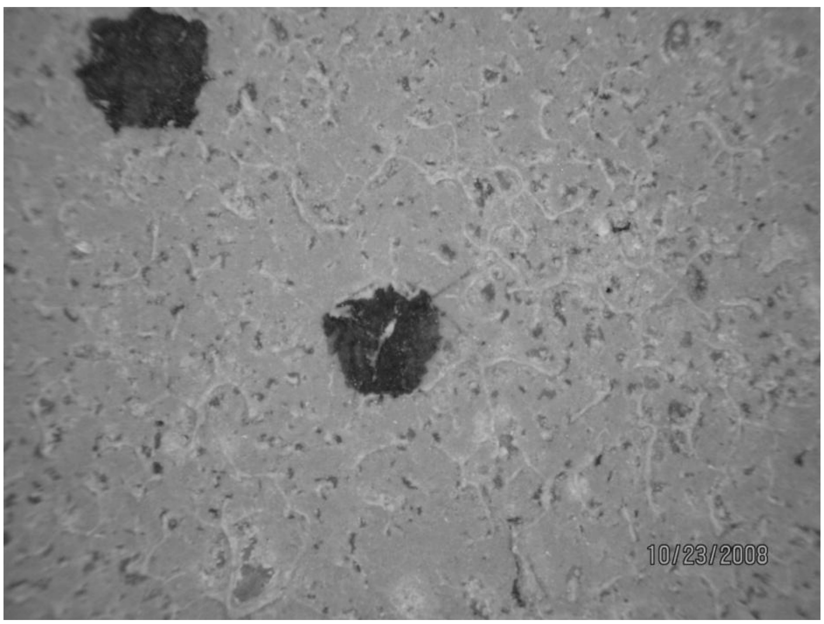


Figure 6 - Micrograph of surface features of a detectable warning system.

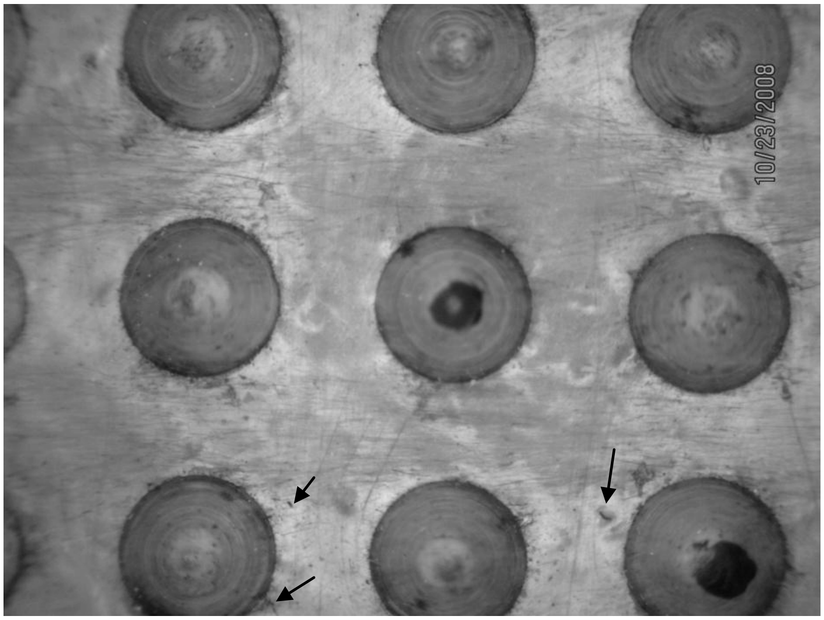


Figure 7 - Micrograph of surface features of a detectable warning system, with microcracking.

Recommended Method of Test for

Color Measurement of Detectable Warning Systems

Designation: Draft T4-33, Part 6

1. SCOPE

1.1. This test method covers the measurement of color and color change of detectable warning systems. Exposure to environmental conditions, such as ultraviolet light and abrasion, may fade the color of the detectable warning system.

1.2. The Americans with Disabilities Act Accessibility Guidelines discuss the need for color contrast between the detectable warning system and the surrounding pavement. Certain materials may experience color fading or color change upon exposure to the environment. Measurement of color and evaluation of color change is used as a tool to evaluate potential changes in color contrast of the detectable warning system and surrounding pavement.

1.3. This evaluation test is intended to be conducted as part of the test protocol outlined in Draft T4-33, which outlines the exposure and evaluation methods for determination of durability of detectable warning systems.

2. REFERENCED DOCUMENTS

2.1. **AASHTO Standards**

2.1.1. Draft T4-33 *Recommended Method of Test for Durability of Detectable Warning Systems*

3. TERMINOLOGY

3.1. Dome: The truncated dome on the detectable warning system.

3.2. Field: The space between the domes on the detectable warning system. The field is level with the surrounding concrete.

4. SUMMARY OF TEST METHOD

4.1. This method describes the measurement of color of detectable warning systems and the calculation of color difference after exposure.

5. SIGNIFICANCE AND USE

5.1. This test method is intended to evaluate color and color change of detectable warning systems that are cast into concrete.

5.2. This method is intended to be used as part of Draft T4-33 to evaluate the durability of detectable warning systems.

6. SAFETY HAZARDS

6.1. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7. TEST SPECIMENS

7.1. Test specimens prepared in accordance with Draft T4-33 are required.

8. APPARATUS

8.1. An apparatus with a standard illuminant suitable for measuring color in the CIELAB system.

9. CALIBRATION

9.1. Calibrate the instrument according to the manufacturer's instructions prior to making color measurements. The instrument should be suitable for measuring the color of the field, and the measuring head should be sized accordingly.

10. PROCEDURE

10.1. If measuring color for the first time on a particular specimen, select ten dome locations and ten field locations for color measurement. The locations should be selected to be representative of the typical condition of the specimen; no locations with unusual markings (ink markings, scuff marks, or excess concrete on the surface) should be selected. The locations should be selected randomly and be well distributed over the surface of the specimen. Note the locations for future comparative measurement.

Note 1: An instrument with a small measuring head that can fit between the domes has been found to produce more repeatable measurements on the field. If the instrument cannot make good contact with the surface being measured, ambient lighting conditions have a significant effect on the values obtained.

10.2. If measuring color on a specimen previously measured, measure the color on the same ten domes and ten field locations. Use the same instrument as used previously. Measure the color as outlined in Draft T4-33.

10.3. Select a standard illuminant, observer, and aperture. If this is not the original measurement on the specimen, use the same instrumental conditions as before.

Note 2: A D65 standard illuminant and a 2-degree standard observer have been found to be suitable, although other illuminants and observers may be suitable. An 8 mm (0.31 in.) aperture has been found to be suitable. Other apertures, no larger than the top diameter of the dome, may also be suitable.

10.4. Measure the color using the instrument, and record the data.

Note 3: Because the surface roughness of many detectable warning systems is high, variations in the color measured in the ten locations is expected. For this reason, an average is calculated and used in the calculation of color difference.

11. CALCULATION OF RESULTS

11.1. Calculate the average L*, a*, and b* values of the domes and field separately by averaging the ten measurements. This is the average color reading for the specimen. Domes and field are calculated and reported separately.

11.2. Calculate color difference between current reading and previous reading using the following equations. Always use the average of the ten measurements as the reading. Color difference is calculated based on the difference between the averages of one set of ten readings and another set previously measured on the same specimen, rather than as the difference between one set of readings and a standard.

11.2.1. Change in lightness: $\Delta L^* = L_2^* - L_1^*$, where L_2^* is the current reading, and L_1^* is the previous reading.

11.2.2. Change in redness/greenness: $\Delta a^* = a_2^* - a_1^*$, where a_2^* is the current reading, and a_1^* is the previous reading.

11.2.3. Change in yellowness/blueness: $\Delta b^* = b_2^* - b_1^*$, where b_2^* is the current reading, and b_1^* is the previous reading.

11.2.4. Total color difference: $\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$

Note 4: Total color difference, ΔE, is generally considered suitable for measuring color difference, although other color difference values, ΔL*, Δa*, or Δb*, may be useful for determining color fade of detectable warning systems and compliance with applicable regulations.

12. REPORT

12.1. The report shall include the following:

12.1.1. The sample identification assigned according to the Draft T4-33.

12.1.2. Type, manufacturer, and, if known, lot number of the detectable warning system(s) tested.

12.1.3. Measured L*, a*, and b* values.

12.1.4. Averaged L*, a*, and b* values.

12.1.5. Calculated color difference between current value and levels at previous exposures.

12.1.6. List of previous exposure regimes and test durations to which the sample has been exposed.

12.1.7. Make and model of instrument used.

12.1.8. Illuminant, observer and aperture used.

13. PRECISION

13.1. Data not available at this time.

14. REFERENCES

14.1. A useful discussion of the CIELAB color space and color difference calculations is provided in ASTM D 2244 *Standard Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates.*

APPENDIX (Non-mandatory Information)

Figure 1-- Measuring the color of the field with a colorimeter with a measuring head of appropriate size to fit between the domes.

Figure 2-- Measuring the color of a dome.

Recommended Method of Test for

Dome Shape and Geometry Measurement of Detectable Warning Systems

Designation: Draft T4-33, Part 7

1. SCOPE

1.1. This test method covers the measurement of dome shape and geometry of detectable warning systems. The Americans with Disabilities Act Accessibility Guidelines (ADAAG) provides geometric recommendations for the domes and dome spacing of detectable warning systems. This evaluation is intended to provide a basis for quantifying potential changes in dome shape and geometry as the result of laboratory exposure tests.

1.2. This evaluation test is intended to be conducted as part of the test protocol outlined in Draft T4-33, which outlines the exposure and evaluation methods for determination of durability of detectable warning systems.

2. REFERENCED DOCUMENTS

2.1. **AASHTO Standards**

2.1.1. Draft T4-33 *Recommended Method of Test for Durability of Detectable Warning Systems*

3. TERMINOLOGY

3.1. Dome: The truncated dome on the detectable warning system.

3.2. Field: The space between the domes on the detectable warning system. The field is level with the surrounding concrete.

4. SUMMARY OF TEST METHOD

4.1. This method is used to measure the geometry of the domes on a detectable warning system, and to compare the measured values to a specification or to another sample.

5. SIGNIFICANCE AND USE

5.1. This method is intended to be used as part of Draft T4-33, to evaluate the durability of detectable warning systems.

6. SAFETY HAZARDS

6.1. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7. TEST SPECIMENS

7.1. Test specimens prepared in accordance with Draft T4-33, are required.

8. APPARATUS

8.1. Calipers, either dial or digital, 250 mm (6 in.) span.

8.2. Depth Gauge. The depth gauge consists of a gauge plate and a dial gauge. The gauge plate shall be a flat square plate, measuring a minimum of 75 mm by 75 mm (3 in. by 3 in.), with a hole in the center for a dial gauge. The dial gauge shall have a minimum travel of 12 mm (0.5 in.), measure to a precision of 0.25 mm (0.01 in.), and have a tapered measuring point that does not penetrate the detectable warning system surface.

9. CALIBRATION

9.1. Zero calipers in a closed position.

9.2. Zero the displacement gauge against a flat surface.

10. PROCEDURE

10.1. Use the calipers to measure the dome bottom diameter, dome top diameter, and the base-to-base spacing of nearest domes. Figure 1 provides a schematic of the measurements to be made, and the current ADAAG recommendation. Measure these values on four different domes. Mark the domes measured on a data sheet.

Note 1: For the purposes of this evaluation test, the diameter of the top and bottom of some domes is not clearly delineated from the sides. In these cases, the measurement should be taken from the location that most closely appears to be the point of greatest change in the curvature of the dome.

10.2. The displacement gauge is used to measure dome heights. Place the gauge plate over four domes and measure the distance between the gauge plate and the main surface of the field (see note 2). Measure the depth of four different areas. Mark the locations measured on a data sheet.

Note 2: For the purposes of this evaluation test, the measured height of the dome includes any texture or any features that may provide slip-resistance on the top surface of the dome. For specimens with features on the field, such as discrete conical features regularly arranged on the field, the tapered measuring point of the dial gauge will measure the flat area of the field. Therefore, the measurement may include surface features on the dome tops, but not on the field.

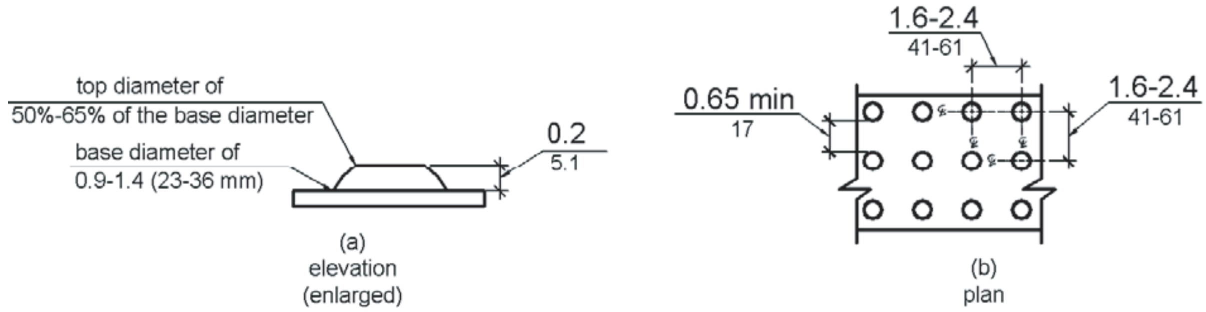


Figure 1—ADAAG dome dimensions, from Figure 705.1, Americans with Disabilities Act and Architectural Barriers Act Accessibility Guidelines, July 23, 2004, United States Access Board.

11. CALCULATION OF RESULTS

11.1. Calculate the center-to-center spacing by adding one dome base diameter to the base-to-base spacing of nearest domes.

12. REPORT

12.1. The report shall include the following:

12.1.1. The dome bottom diameter, dome top diameter, base-to-base spacing, calculated center-to-center spacing and dome height for each location measured.

12.1.2. For exposed specimens, calculate the change in dimensions from those obtained on the unexposed specimen.

13. PRECISION

13.1. Data not available at this time.

14. REFERENCES

14.1. Americans with Disabilities Act and Architectural Barriers Act Accessibility Guidelines, July 23, 2004, United States Access Board.

Recommended Method of Test for

Coating and Single Dome Bond in Detectable Warning Systems

Designation: Draft T4-33, Part 8

1. SCOPE

1.1. This test method covers testing of the bond of coatings on detectable warning systems and the bond of single surface-applied domes to the concrete substrate. Bond of the coating to the field and to the dome is tested. Some detectable warning systems are coated to provide slip resistance or color contrast with the surrounding sidewalk. If the coating becomes debonded from the substrate, the detectable warning system may no longer be slip resistant and the system may not meet color contrast requirements for the system. Other detectable warning systems consist of an array of surface-applied single truncated domes adhesively bonded to the concrete substrate. If the domes become debonded, functionality of the detectable warning system could be reduced. The coating bond and adhesive strength of surface-applied domes will be measured according to ASTM D 4541 *Standard Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers.*

1.2. This evaluation test is intended to be conducted as part of the test protocol outlined in Draft T4-33, which outlines the exposure and evaluation methods for determination of durability of detectable warning systems.

2. REFERENCED DOCUMENTS

2.1. **AASHTO Standards**

2.1.1. Draft T4-33 *Recommended Method of Test for Durability of Detectable Warning Systems*

2.2. **ASTM Standards**

2.2.1. ASTM D 4541 *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*

3. TERMINOLOGY

3.1. Dome: The truncated dome on the detectable warning system.

3.2. Field: The space between the domes on the detectable warning system. The field is level with the surrounding concrete.

3.3. Surface-applied single dome: A single truncated dome that is adhered to a concrete substrate as part of an array of separately applied domes composing a detectable warning system.

4. SUMMARY OF TEST METHOD

4.1. This method tests the adhesion of coatings and single surface-applied domes to detectable warning systems. Three adhesion tests will be conducted for each tested condition. Coating bond tests will be conducted at room temperature and elevated temperature (60°C).

5. SIGNIFICANCE AND USE

5.1. Coating adhesion can be an indicator of coating durability. Coating performance may be important to maintaining color contrast of detectable warning systems, if the substrate is of a different color, and to maintaining slip resistance of detectable warning systems, if the coating is textured to provide slip resistance. Coating may become degraded through exposure. Ultraviolet exposure can degrade polymeric coatings, leading to fading, cracking, and chipping. Abrasion from foot traffic or vehicular traffic (including hand carts) can wear away the coating. Cracking of the substrate from freezing and thawing can lead to debonding of the coating at the crack location. For these reasons, it is important to evaluate the bond of the coating to the substrate.

5.2. Dome adhesion is necessary to maintain the integrity of single surface-applied dome-based detectable warning systems. Dome adhesion is adhesive dependent and may be affected by exposures producing stress-generating thermal gradients and adhesive degradation. For these reasons, it is important to evaluate the adhesion of the domes to the substrate.

5.3. This method is intended to be used as part of Draft T4-33 to evaluate the durability of detectable warning systems.

6. SAFETY HAZARDS

6.1. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7. TEST SPECIMENS

7.1. Test specimens prepared in accordance with Draft T4-33 are required. Only specimens with coatings or with single surface-applied domes are required for this test.

8. APPARATUS

8.1. An adhesion tester, consistent with Type V described in ASTM D 4541-02. The diameter of the dolly should be no greater than the top dome diameter.

Note 1: A 20 mm diameter dolly has been found to be suitable for the test, although a smaller dolly may be considered.

9. CALIBRATION

9.1. Calibrate the equipment according to the manufacturer’s recommendations.

10. PROCEDURE

10.1. Follow the procedures outlined in Section 7 of ASTM D 4541-02, with the additional requirements outlined as follows:

10.2. For coated samples:

10.2.1. Test the adhesion of the coating over three domes and three areas of field at 21–27°C (70–80°F).

10.2.2. Test the adhesion of the coating over three domes and three areas of field at a surface temperature of 60 ± 3°C (140 ± 5°F).

Note 2: The sample may be heated by placing it in an oven, by using heat lamps to heat the surface, by using a heating blanket to heat the surface, or other methods. The adhesion should be tested promptly after removal of the heat source so that the surface remains within the temperature range described in Section 10.2.2.

Note 3: The dollies should be adhered to the surface with an adhesive suitable for high temperature testing prior to heating the specimen.

Note 4: More than three areas may need to be tested for each temperature condition to ensure that three results indicating cohesive or adhesive failure of the coating, the coating/detectable warning system or the dome/substrate interface (and not failure of the adhesive used to fix the dolly) are obtained.

10.3. For single surface-applied domes:

10.3.1. The test will be performed as a test of adhesion of the single surface-applied domes to the substrate, rather than a test of the coating itself. This test is performed in addition to the tests of the coating described in Section 10.2.

10.3.2. As necessary, remove the coating from the surface of the single surface-applied dome to be tested. This is necessary if initial tests indicate that the coating fails prior to the single surface-applied dome. If the single surface-applied dome fails before the coating, coating removal is not necessary. Coating can be removed by abrading with abrasive paper or suitable solvent. The means of coating removal should not affect the bond of the single surface-applied dome to the substrate.

10.3.3. Test the adhesion of three single surface-applied domes at room temperature.

10.3.4. Test the adhesion of three single surface-applied domes at a surface temperature of 60 ± 3°C (140 ± 5°F).

Note 5: More than three areas may need to be prepared and tested for each temperature condition to ensure that three results indicating cohesive or adhesive failure of the coating, the coating/detectable warning system or the dome/substrate interface are obtained.

Note 6: The dollies should be adhered to the surface with an adhesive suitable for high temperature testing prior to heating the specimen. Royal Double Bubble Extra Fast Setting Epoxy has been found to be suitable for the room temperature testing. Loctite 9340 Hysol was identified as suitable for elevated temperature testing, although other products may also be suitable.

11. CALCULATION OF RESULTS

11.1. Calculate the results according to Section 8 of ASTM D 4541-02.

12. REPORT

12.1. Report the results according to Section 9 of ASTM D 4541-02.

13. PRECISION

13.1. Data relating to the precision of this method relating to detectable warning systems is not available at this time; however, precision and bias information is available in Section 10 of ASTM D 4541-02.

Recommended Method of Test for

Slip Resistance of Detectable Warning Systems

Designation: Draft T4-33, Part 9

1. SCOPE

1.1. This test method covers the measurement of slip resistance of detectable warning systems. In use, detectable warning systems are placed as outdoor walking surfaces, often on inclined planes. Consequently, the surface must be resistant to slip. This method is applicable for use in evaluating the slip resistance of detectable warning systems as part of a laboratory testing program.

1.2. This evaluation test is intended to be conducted as part of the test protocol outlined in Draft T4-33, which outlines the exposure and evaluation methods for determination of durability of detectable warning systems.

2. REFERENCED DOCUMENTS

2.1. **AASHTO Standards**

2.1.1. Draft T4-33 *Recommended Method of Test for Durability of Detectable Warning Systems*

2.2. **ASTM Standards**

2.3. ASTM F 609-05, *Standard Test Method for Using a Horizontal Pull Slipmeter (HPS)*

3. TERMINOLOGY

3.1. Dome: The truncated dome on the detectable warning system.

3.2. Field: The space between the domes on the detectable warning system. The field is level with the surrounding concrete.

4. SUMMARY OF TEST METHOD

4.1. This method evaluates the slip resistance of detectable warning systems that have and have not been exposed to the exposure test methods referenced in Draft T4-33. Slip resistance is determined by the horizontal force required to move the slipmeter from a position of rest on the detectable warning system.

5. SIGNIFICANCE AND USE

5.1. This evaluation method is intended to measure the slip resistance of detectable warning systems that are cast into concrete.

5.2. This test method is to be used as part of Draft T4-33 to evaluate the durability of detectable warning systems.

6. SAFETY HAZARDS

6.1. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

7. TEST SPECIMENS

7.1. Test specimens prepared in accordance with Draft T4-33 are required.

8. APPARATUS

8.1. The slipmeter consists of a steel plate, feet, a pull chain, and a force gauge.

8.1.1. Slipmeter plate: A schematic of the slipmeter plate is shown in Figure 1. The dimensions of the plate are required to keep the center of the mass at the same location for varying dome spacing. The mass of the slip meter is approximately 2.5 kg (5.5 lb).

8.1.2. Feet: Three feet are used on the slipmeter. Provide a Neolite wearing surface as described in Section 7 of ASTM F 609-05. The wearing surface is glued to a metal support that fits in the slots in the slipmeter plate. Slipmeter feet shall be able to be fixed at any point in each slot in the slipmeter plate.

8.1.3. Pull chain: A rigid chain, for example, fabricated of metal links, is used to pull the slipmeter with the force gauge.

8.1.4. Force gauge. A digital or analog force gauge with the following specifications shall be used to measure the pull force on the slipmeter plate:

– Minimum capacity: 50 N (11 lbf)
– Precision: 0.1 N (0.02 lbf)
– Peak hold function

9. CALIBRATION

9.1. Condition test feet and test specimen for at least 24 hours in atmosphere maintained at 21 ± 6°C (70 ± 10°F).

9.2. Zero the force gauge with the pull chain attached. Calibrate the slipmeter weight by hanging the slipmeter plate and feet vertically from the force gauge. Record this measurement as the slipmeter weight.

10. PROCEDURE

10.1. One slipmeter measurement is defined as the average of four slipmeter readings, taken at 0, 90, 180, and 270 degree orientations.

10.2. Before each measurement, prepare the feet as directed in Sections 10.1 through Sections 10.4 of ASTM F 609-05.

10.3. Connect the force gauge to the slipmeter base by the pull chain.

10.4. Prepare the slipmeter for taking readings on the domes and on the field according to the procedure given below. Do not use additional force to press the slipmeter on to the surface. Use only the slipmeter self-weight to hold the slipmeter in place.

10.4.1. To perform one reading on the domes, align the feet in the channels of the slipmeter to center each on the top of a dome. Place the slipmeter on top of the dome surface.

10.4.2. To perform one reading on the field, keep the feet aligned in the same orientation as used for the dome reading. Place the feet of the slipmeter in the spaces between the domes. Leave space between the feet and the domes in the direction of the desired pull direction.

10.5. Pull the force gauge horizontally, aligned with the longitudinal axis of the slipmeter base. Increase the pull force gradually until the slipmeter moves.

10.6. Record the maximum pull force reached on the force gauge.

10.7. Repeat steps 10.4 to 10.6 three times for each measurement, rotating the slipmeter 90 degrees each time.

10.8. Take four sets of measurements of the slip resistance: two locations on the domes and two locations on the field of the specimen.

11. CALCULATION OF RESULTS

11.1. Determine the coefficient of friction (COF) for each reading using Equation 1.

COF = (horizontal pull force)/(slipmeter weight) **Equation 1**

11.2. Average the four coefficient of friction readings for each set of measurements.

Note 1: The coefficient of friction is typically between 0 and 1, but in some cases may exceed 1.

12. REPORT

12.1. Report each measurement obtained for the domes and the field.

12.2. Report the average of the measurements for the domes and the average of the measurements for the field.

12.3. For unexposed specimens, compare these numbers to values provided in any governing specification, if values are available in the specification.

12.4. For exposed specimens, compare these numbers to those obtained on the unexposed specimen.

13. PRECISION

13.1. Data not available at this time.

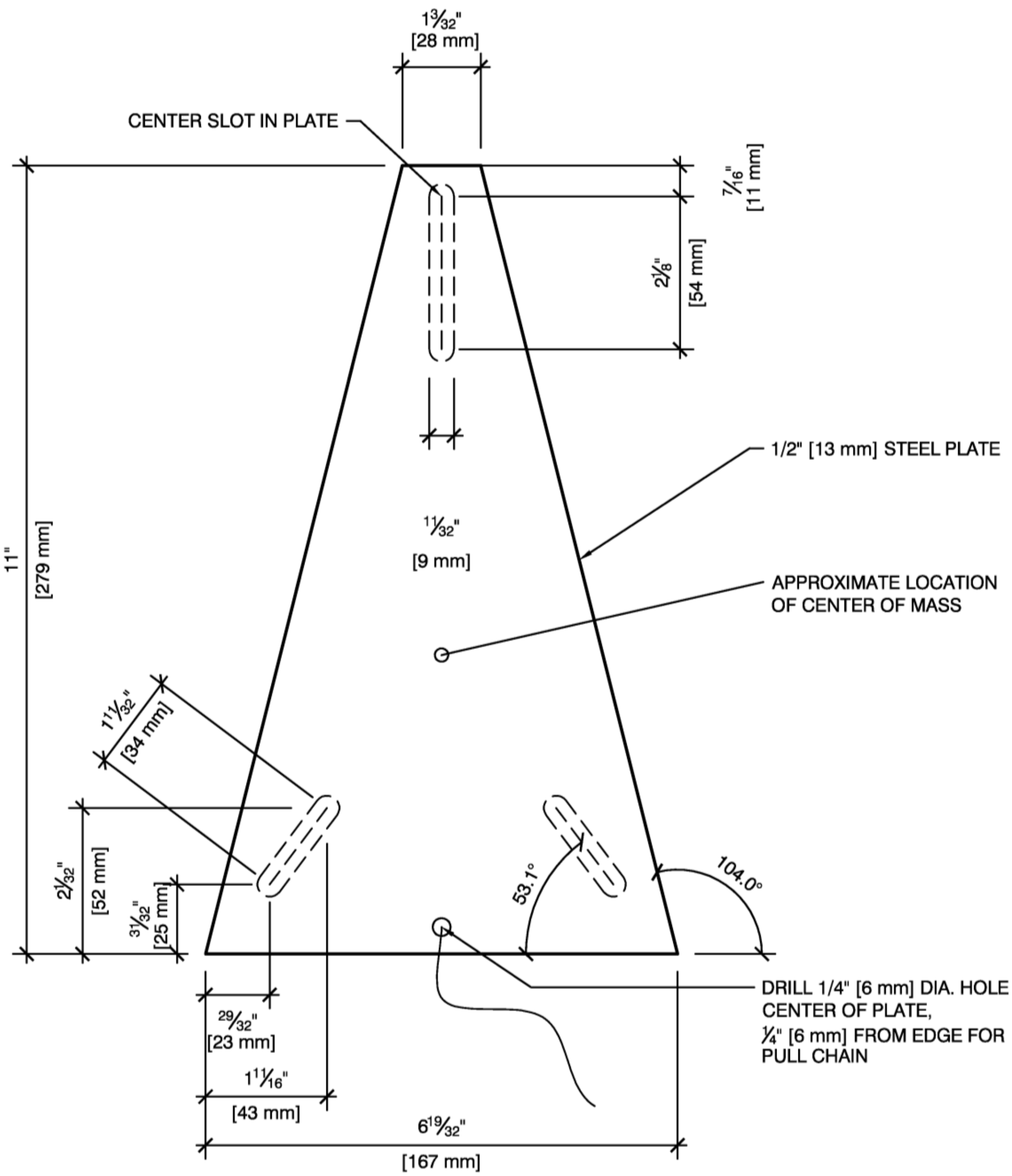


Figure 1. Schematic view of slipmeter plate, with required angles and slot dimensions.

Recommended Method of Test for

Resistance to Impact from Simulated Snowplow Blade of Detectable Warning Systems

Designation: Draft T4-33, Part 10

1. SCOPE

1.1. This test method covers the evaluation of detectable warning/concrete systems at freezing temperatures subjected to impact from a simulated snowplow blade.

1.2. This evaluation test is intended to be conducted as part of the test protocol outlined in Draft T4-33, which outlines the exposure and evaluation methods for determination of durability of detectable warning systems.

2. REFERENCED DOCUMENTS

2.1. **AASHTO Standards**

2.1.1. Draft T4-33 *Recommended Method of Test for Durability of Detectable Warning Systems*

2.2. **ASTM Standards**

2.2.1. ASTM E 18 *Standard Test Methods for Rockwell Hardness of Metallic Materials*

3. SUMMARY OF TEST METHOD

3.1. This method evaluates the durability of individual domes in detectable warning systems when they are subjected to impact from a simulated snowplow blade. The blade is mounted in a swinging pendulum and strikes a single dome from the side at a controlled energy.

4. SIGNIFICANCE AND USE

4.1. This test method is intended to evaluate performance of detectable warning systems that are cast into concrete when struck by a simulated snowplow blade. This performance is expected to be indicative of performance of detectable warning systems when subjected to snow removal operations.

4.2. This method is intended to be used as part of Draft T4-33 to evaluate the durability of detectable warning systems.

5. SAFETY HAZARDS

5.1. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

6. TEST SPECIMENS

6.1. A single test specimen consisting of a detectable warning system embedded or fixed to a concrete slab prepared in accordance with Draft T4-33 is required.

7. APPARATUS

7.1. Cold chamber capable of bringing the surface temperature of the detectable warning systems to -4 ± 3°C [24.8 ± 5°F]

7.2. Snowplow Simulation Device—This device is intended to produce an impact on the side of a dome with controlled energy at a controlled height. This device consists of a pendulum system, as pictured in Figure 1.

Note 1: Photographs of a system consistent with these requirements are given in the appendix of this method.

7.2.1. Pendulum—The pendulum consists of two connected rigid arms: (1) a rotating arm and (2) a rotating-translating arm. The rotating arm is mounted using a rotary bearing to an axle defining the axis of rotation. The rotating-translating arm is attached to the rotating arm by a connection containing a linear bearing that allows the rotating-translating arm to move along the axis of the pendulum arms. A strike plate holder capable of securely supporting the plate described in Section 7.2.2 is attached to the end of the rotating-translating arm. The portion of the rotating-translating arm extending through the bearing is fitted with a locking collar that serves as a mechanical stop, limiting the extension of the pendulum. The pendulum is defined as follows:

7.2.1.1. The overall length of the pendulum in test configuration is 145 ± 5 cm [57 ± 2 in.].

7.2.1.2. Total weight of the pendulum (both arms) is 17 ± 0.5 kg [37.4 ± 1.1 lbs.]. Weight of the rotating-translating arm is 13 ± 0.5 kg [28.6 ± 1.1 lbs.] The actual weight of the arms shall be determined to the nearest 0.05 kg [0.1 lbs.].

7.2.1.3. The distance from the center of mass of the pendulum in the fully extended position to the axis of rotation shall be 70 ± 5 cm [27.6 ± 2 in.]. The actual location of the center of mass shall be determined to the nearest 0.5 cm [0.2 in.]. This location shall be clearly marked on the pendulum.

7.2.1.4. The linear bearing and shaft of the rotating-translating arm shall be designed to produce negligible friction resisting shortening of the pendulum.

7.2.2. Strike Plate

7.2.2.1. Material—The strike plate shall be manufactured from AISI 1065 Steel with a fully pearlitic microstructure and have a hardness of 30–36 HRC, when measured according to ASTM E 18.

Note 2: This steel is used in a commercially available snowplow blade.

7.2.2.2. Geometry—The strike plate shall be nominally 5 by 3.8 cm [2.0 by 1.5 in.] and have a thickness of 0.95 ± 0.05 cm [0.375 ± 0.02 in.]. The strike edge shall be machined or ground to produce a 90º angle. Strike plates can be reused provided that the edge is reconditioned between testing.

7.2.3. Release mechanism—A mechanism for releasing the pendulum from its initial position in a way that does not produce an initial impulse, retardation or lateral force acting on the pendulum shall be used. This mechanism shall be capable of holding the pendulum at sufficient height to produce the energy specified in Section 8.4.6.

Note 3: A stable stand supporting a switched magnet has been found adequate.

7.3. Metal shims of sufficient thickness and number to create a stack of 1 to 3 mm [0.04 to 0.12 in.], to within 0.25 mm [0.01 in.].

7.4. Surface temperature measuring device capable of verifying that the detectable warning surface at the time of testing is within the range -4 ± 3°C [24.8 ± 5°F].

Note 4: A non-contact infrared thermometer has been found adequate for this task.

7.5. A scale marked out at distance intervals no greater than 0.25 cm [0.1 in.] in size and a video camera capable of recording at video at 30 Hz or greater. This is for use in the determination of friction losses.

8. PROCEDURE

8.1. Examination of Apparatus—Conduct the following test of the equipment performance before testing each time that the equipment is set up or if there is reason to believe that equipment performance has changed.

8.1.1. Determination of Friction Losses

8.1.1.1. Set up the grid scale and the video camera on opposite sides of the pendulum so that the distance intervals are clearly visible in the video picture behind the end of the pendulum and strike plate. The camera should be positioned at least 3 m [10 ft] from the pendulum along a line perpendicular to the pendulum swing path and at the same height as the pendulum at the beginning of the swing. The field of view should be as tight as possible while still including the end of the pendulum in its return position after completing two cycles when released from the starting position defined as follows.

8.1.1.2. With no specimen present, fix the pendulum in the release mechanism at the height necessary to produce 25 ± 2 J [18.4 ± 1.5 lbs-ft] as specified in Section 8.4.6.

8.1.1.3. Be sure that the position of the end of the strike plate can be clearly seen in the video and begin recording video.

8.1.1.4. Release the pendulum and record at least two compete cycles. Repeat two additional times.

8.1.1.5. From the video, obtain pictures of the end of the pendulum before release and at the peak height achieved at the end of each cycle. Identify a single point on the pendulum, such as the corner of the strike plate, and determine the reduction in height during each cycle to the nearest 0.25 cm [0.1 in.].

8.1.1.6. Calculate the percent reduction in energy through each cycle as the ratio of the reduction in height to the initial height at the start of each cycle.

8.1.1.7. For the test apparatus to be acceptable, the reduction in energy during the first and second cycle shall be no greater than 3%.

Note 5: If more than 3% reduction is measured, the device configuration, such as the bearing system or the shape of the translating arms, must be modified.

8.2. Preparation of Samples

8.2.1. Confirm that sufficient clearance is provided surrounding the detectable warning system so that the strike plate will not impact the concrete before striking the test domes. If sufficient clearance is not provided, remove surrounding concrete by grinding or similar operation, taking care not to damage the detectable warning system.

Note 6: Attempting to grind the samples after they have been conditioned at freezing temperatures may locally warm the specimen to temperatures greater than the allowable range and is not recommended.

8.2.2. Condition samples to -7ºC [20ºF] in freezing chamber for at least 8 hours.

8.2.3. Hold the specimen surface temperature within the temperature range of -7ºC to -1ºC [20ºF to 30ºF] during transport of the samples from the conditioning chamber to the test apparatus and until the test is performed.

Note 7: The use of insulating blankets and ice packs containing salt solution may be useful to achieve this objective. A sodium chloride solution ice bath with 5-8% sodium chloride has been found suitable.

8.3. Preparation of Apparatus

8.3.1. Perform routine inspection of apparatus at start of each test run (consisting of tests performed on three domes of a single type of detectable warning).

8.3.1.1. Visually inspect the strike plate, pendulum, and bearings for damage and wear.

8.3.1.2. If any sign of wear is noted, install a new strike blade in the test head. The strike plate can be used on multiple samples only if very pliable samples are tested.

8.4. Test Procedure

8.4.1. Choose three domes adjacent to the edge of the detectable warning system for testing. Document the locations of testing. Visually inspect each of the domes for signs of damage. If damage is identified, select a different dome.

8.4.2. Position the test specimen such that when the pendulum is hanging freely, the leading edge of the strike plate is aligned over the near edge (i.e., where the dome meets the field) of the dome.

Note 8: It is advisable to align the specimens such that the row of domes to be tested is parallel with the axle supporting the pendulum. In this way, the pendulum can be translated along the axle for successive testing.

8.4.3. Fix the test specimen such that it does not move during testing.

8.4.4. Adjust the pendulum so that the strike plate is centered on the dome.

8.4.5. Set the collar on the rotating-translating arm of the pendulum such that the height of the strike on the domes is 3.0 ± 0.25 mm [0.12 ± 0.01 in.] above the field of the detectable warning system as follows:

8.4.5.1. Measure the height of the dome by determining the distance between the topmost feature on the dome and the field according to the method outlined in Draft T4-33, Part 7 *Recommended Method of Test for Dome Shape and Geometry Measurement of Detectable Warning Systems*. Subtract 3.0 mm [0.12 in.] from this value to get the offset distance of the locking collar on the rotating-translating arm.

8.4.5.2. Position the pendulum such that the strike plate is resting on the top of the dome to be tested. Release the locking collar. Select a shim or shim stack of thickness equal to the offset distance with a tolerance of 0.25 mm [0.01 in.]. Slide the shim or shim stack between the locking collar and the bearing surface. Snug the locking collar against the shims and securely tighten the collar. Remove the shim or shim stack.

8.4.6. Adjust the location of the release mechanism so that the center of mass of the pendulum before release is elevated sufficiently to produce 25 ± 2 J [18.4 ± 1.5 lbs-ft] of potential energy.

Note 9: In SI units, potential energy (U) is calculated as $U = mgh$, where m = mass in kg, g = 9.81 m/s^2 and h = height above resting position of center of mass in meters. In Imperial units, potential energy (U) is calculated as $U = wh$, where w = weight in pounds and h = height above resting position of center of mass in feet.

Note 10: The distance that the end of the pendulum needs to be lifted can be determined based on similar triangles: $h_{end} = l_{pendulum}/l_{cm} \times h_{cm}$, where h_{end} = height above resting position of end of the pendulum, $l_{pendulum}$ = distance from axis of rotation to end of the pendulum, l_{cm} = distance from axis of rotation to center of mass, and h_{cm} = height above resting position of center of mass.

8.4.7. Measure the surface temperature and proceed only if it is within the range -4 ± 3°C [24.8 ± 5°F]. Use an ice pack or other device to cool the specimen if this range is exceeded. Record the temperature at the start of testing of each dome.

8.4.8. Strike the dome with the pendulum five times, performing each strike as follows: Release the pendulum allowing the blade to strike the dome and carry on past the dome. Catch the pendulum before it swings back against the dome. Lift the rotating-translating arm over the dome and attach to the release mechanism. During these strikes, photograph the dome after one, three and five strikes.

8.4.9. Evaluate the condition of the test dome after five strikes. Assign a damage classification based on which of the descriptions given in Table 1 that the observed damage most closely resembles. Note and photograph any unusual characteristics of the dome response.

8.4.10. Repeat the operations outlined Sections 8.4.2 through 8.4.9 for the two remaining domes selected for testing.

9. REPORT

9.1. Report the sample identification assigned according to the Draft T4-33.

9.2. Report the exposure history of the samples at the time of testing.

9.3. Report type, manufacturer, and, if known, lot number of the detectable warning system(s) tested.

9.4. For each tested dome, report the assigned damage classification.

9.5. Report any deviation from the procedures outlined in this method.

10. PRECISION

10.1. Data not available at this time.

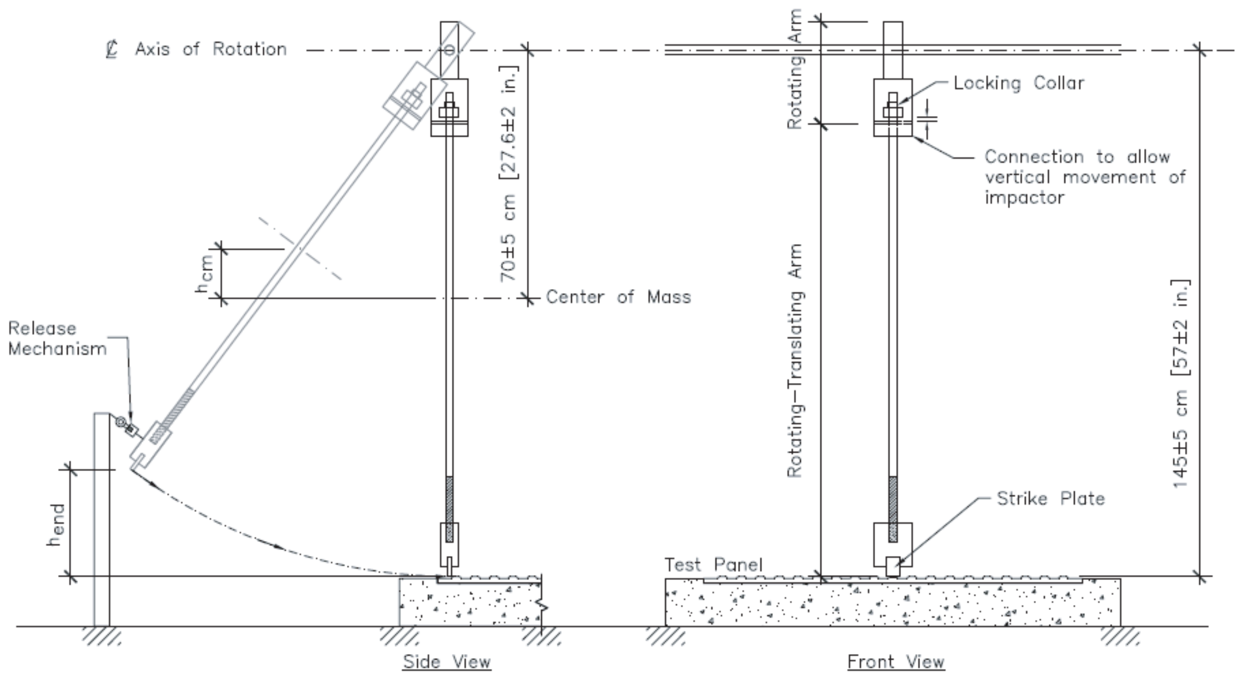
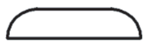
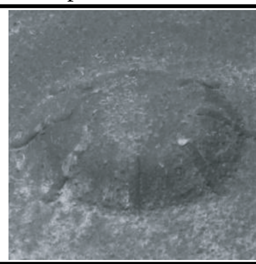
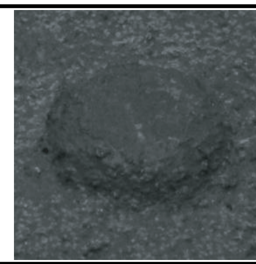
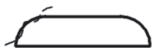
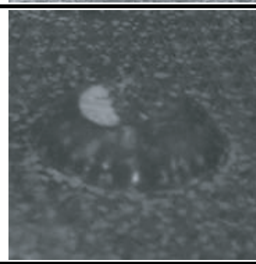
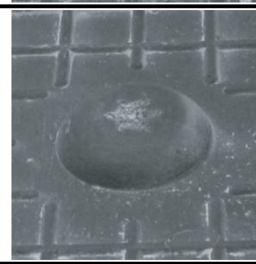
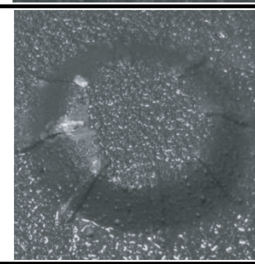
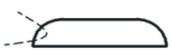
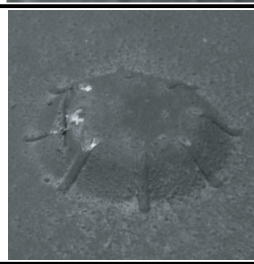
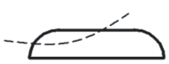
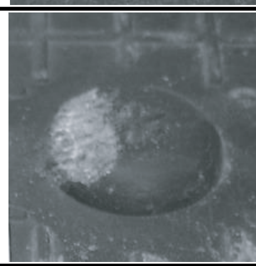
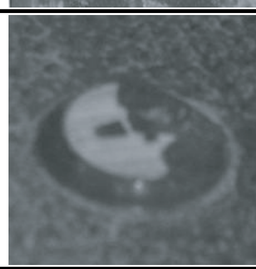
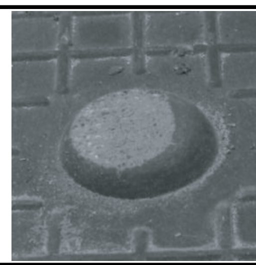
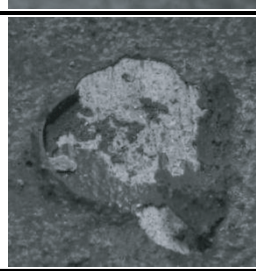
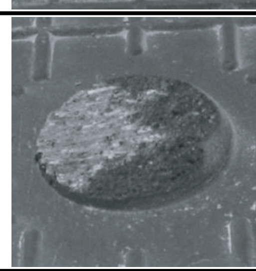


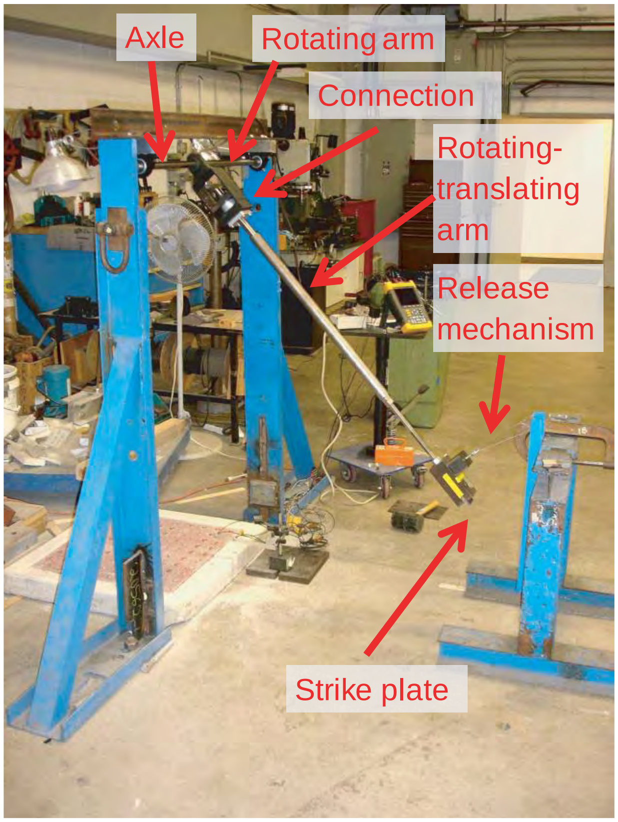
Figure 1. Schematic of Snowplow Apparatus

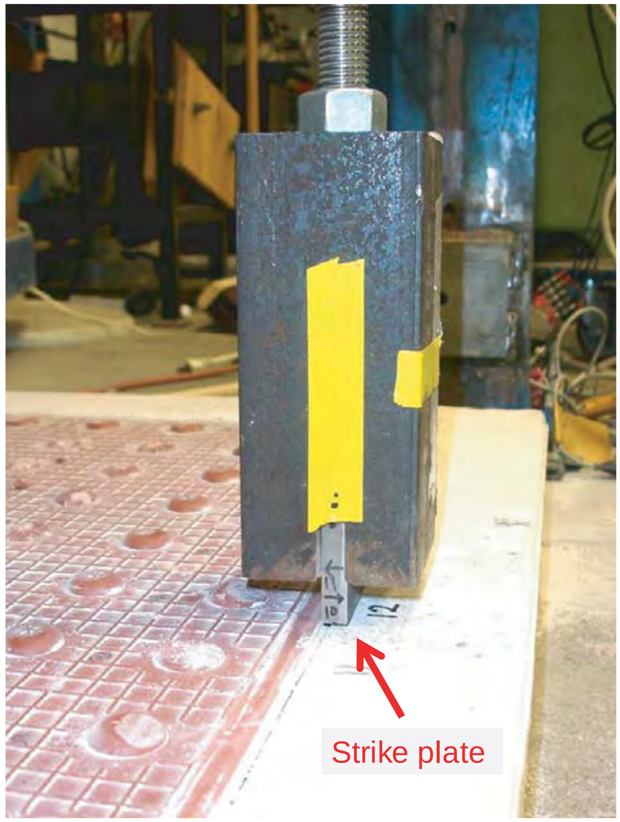
ANNEX (Mandatory Information)

Table 1. Evaluation Criteria

Classification	Description	Examples		
A 	No damage			
B 	Damage to surface texture or coating only			
C 	Dent or indentation produced in main body of dome			
D 	Top of main body of dome partially removed			
E 	Top of main body of dome fully removed			
F 	Nearly all of dome removed from system			

APPENDIX (Non-mandatory Information)





Recommended Method of Test for

Resistance to Impact from Falling Tup of Detectable Warning Systems

Designation: Draft T4-33, Part 11

1. SCOPE

1.1. This test method covers the evaluation of impact resistance of detectable warning systems. In use, detectable warning systems are subject to impact from a wide variety of sources. Pedestrians carrying objects may drop them, and if a heavy object lands with a concentrated force on a dome, damage can result. Another potential source of impact damage is from wheeled carts and hand trucks being pushed over the surface of detectable warning system.

1.2. This test involves impacts of pre-determined energies on the domes of detectable warning systems cast into concrete. Impact is provided by a weighted falling tup.

1.3. This evaluation test is intended to be conducted as part of the test protocol outlined in Draft T4-33, which outlines the exposure and evaluation methods for determination of durability of detectable warning systems.

2. REFERENCED DOCUMENTS

2.1. **AASHTO Standards**

2.1.1. Draft T4-33 *Recommended Method of Test for Durability of Detectable Warning Systems*

3. SUMMARY OF TEST METHOD

3.1. This test method is designed to test the impact resistance and durability of various detectible warning systems.

4. SIGNIFICANCE AND USE

4.1. This test method is intended to evaluate impact resistance of detectable warning systems that are cast into concrete.

4.2. This test method is intended to be used as part of Draft T4-33 to evaluate the durability of detectable warning systems.

5. SAFETY HAZARDS

5.1. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

6. TEST SPECIMENS

6.1. Test specimens prepared in accordance with Draft T4-33 are required.

6.2. Prior to testing the detectable warning panel, the surface should be clean and dry. Three domes per load will be tested at both room temperature and at -4 ± 3°C (24.8 ± 5°F), for a total of three to six domes tested at room temperature and three to six domes tested at 25 ± 5°F.

7. APPARATUS

7.1. A 25.4 mm (1 in.) diameter hemispherical tup made from steel hardened to a minimum hardness of 54 HRC or harder. The tup will be attached to the impactor described below.

7.2. An impactor to which the tup can be attached securely. The impactor must be allowed to vertically impact the tops of the domes with energies of 27 J and, if desired, 54 J (20 and 40 ft-lbs). Photographs of an impactor that has been used in this testing are provided for reference in Figures 1 and 2. Other apparatus suitable to producing an impact of specified energy with the specified tup may also be used.

Note 1: For example, a 10 kg (22 lb) impactor could be dropped from 27 and 54 cm (11 and 21 in). Different masses could be used from different heights to obtain the same impact energies.

7.3. For testing in the cold exposure category according to Draft T4-33, a thermal chamber or freezer to bring the surface temperature of the panels to -4 ± 3°C (24.8 ± 5°F), and a means to verify surface temperature, such as surface thermocouple or surface thermometer.

Note 2: As necessary, the sample can be removed from the cold chamber and testing can be conducted in a laboratory environment. If this option is pursued, a means to keep the surface within the desired temperature is required. A sodium chloride solution ice bath with 5–8% sodium chloride has been found suitable.

8. CALIBRATION

8.1. Calibrate the scale of the impact tester to ensure that the impactor is dropped from the desired height. The point at which the impactor touches the top of a dome of the sample is defined as height = 0 cm (0 in.).

Note 3: Because of height variations from sample to sample, the zero measurement should be verified for each new panel that will be tested.

9. PROCEDURE

9.1. Place the panel on a flat, rigid surface, such as a concrete floor, that will not absorb the energy of impact.

9.2. Choose three domes per impact energy.

Note 4: Experience has indicated that the degree of consolidation of concrete under the detectable warning system panels is affected by installation and varies from specimen to specimen and within a single specimen. The uniformity of consolidation should be checked by sounding the panel prior to testing. Well or poorly consolidated areas can be selected for testing, or, if both types of areas are present on a specimen, both conditions can be tested. Differences in impact resistance may be apparent.

9.3. Document the locations of the testing. Conduct a visual inspection of each of the domes and note any irregularities in appearance or condition.

9.4. Align the impactor so that the center of the tup will strike the center of the dome.

9.5. Perform impact tests at 27 J and, if desired, 54 J (20 and 40 ft-lbs) at room temperature. Each impact is to be carried out on a separate dome. Three domes are to be impacted per energy.

9.6. If testing for the cold exposure category according to Draft T4-33, perform a second round of impact tests at 27 J and, if desired, 54 J (20 and 40 ft-lbs) at a surface temperature of -4 ± 3°C (24.8 ± 5°F). Each impact is to be carried out on a separate dome not previously impacted. Three domes are to be impacted per energy.

9.7. Evaluate the results according to the criteria provided in Table 1.

10. REPORT

10.1. The report shall include the following:

10.1.1. The sample identification assigned according to the Draft T4-33.

10.1.2. Type, manufacturer, and, if known, lot number of the detectable warning system(s) tested.

10.1.3. Rating for each dome according to the criteria listed in Table 1.

10.1.4. Impact energy for each dome.

10.1.5. Surface temperature.

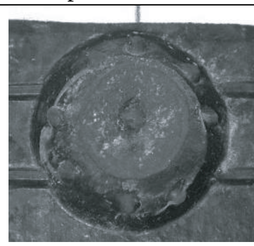
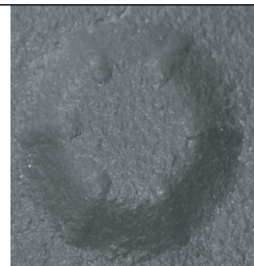
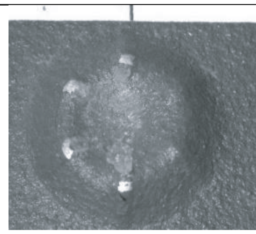
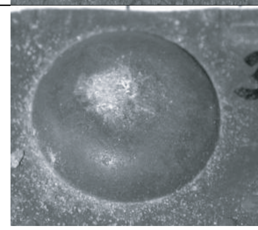
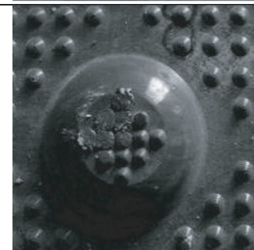
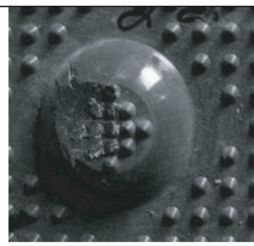
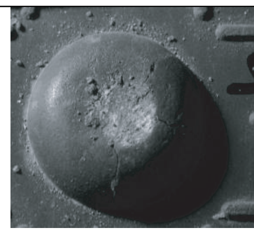
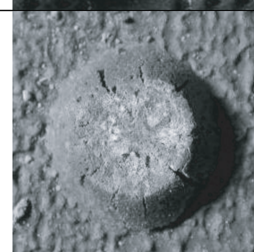
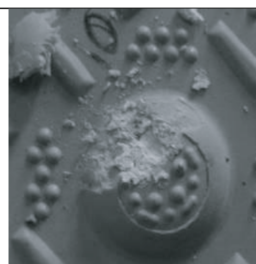
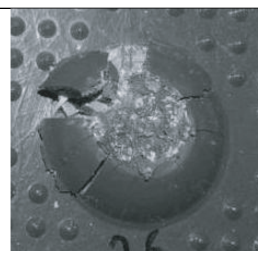
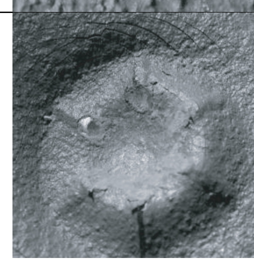
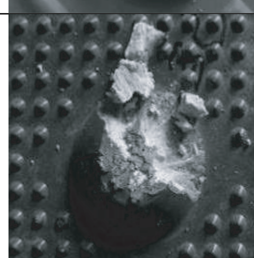
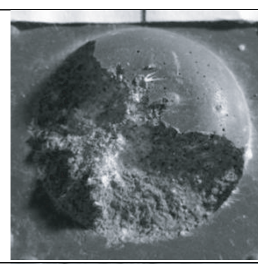
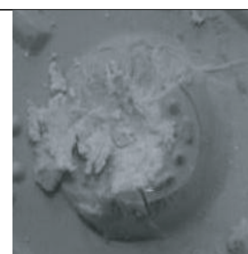
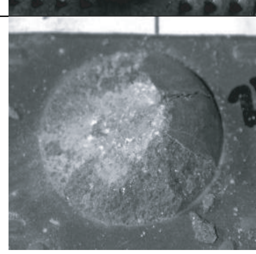
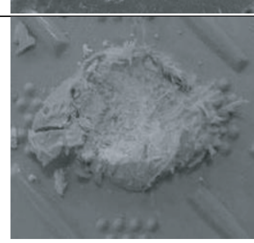
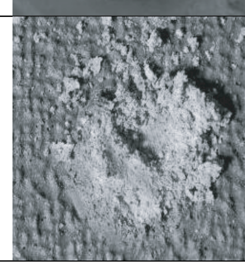
10.1.6. Any additional comments describing irregularities in the tested domes or system and any deviations from the test procedure outlined herein.

11. PRECISION

11.1. Data not available at this time.

ANNEX (Mandatory Information)

Table 1--Evaluation Criteria

Classification	Description	Examples		
A	No Damage			
B	Damage to surface texture or coating only			
C	Damage to less than 25% of the dome			
D	Damage to 25 - 50% of the dome			
E	Damage to 50 - 75% of the dome			
F	Damage to 75 - 100% of the dome			

APPENDIX (Non-mandatory Information)

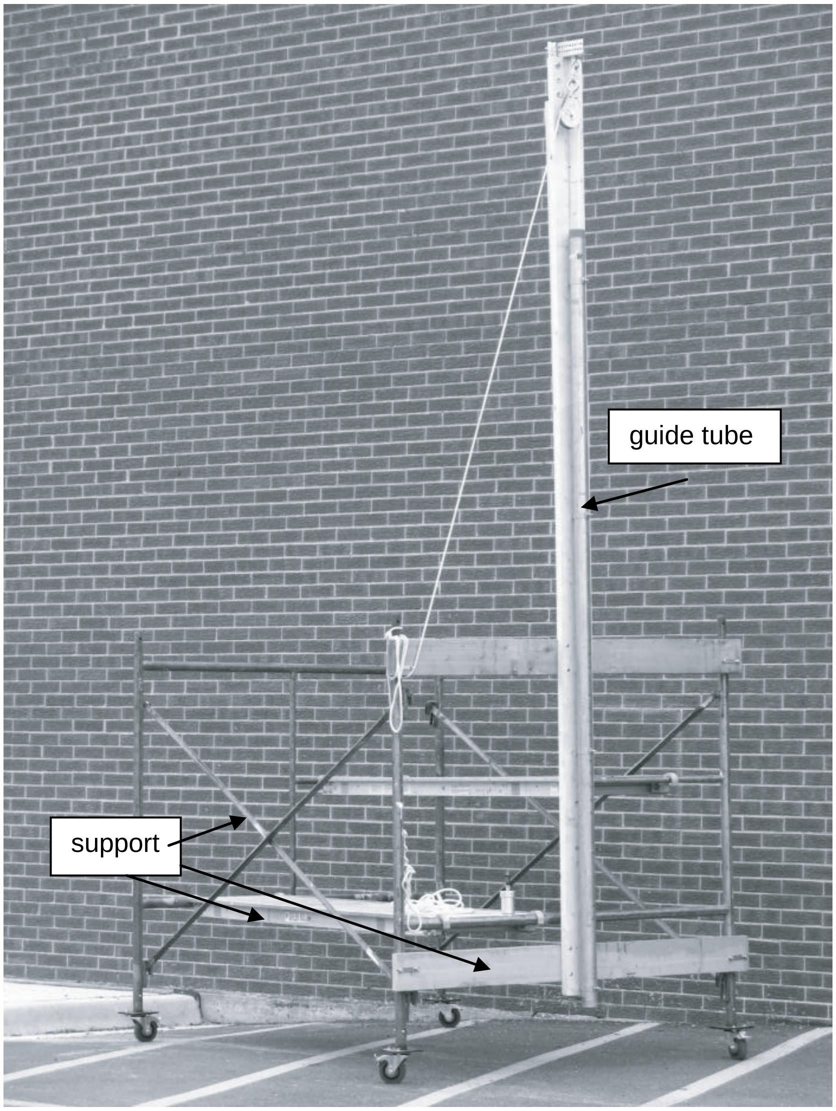


Figure 1-- An impact tester used in the performance of these tests.

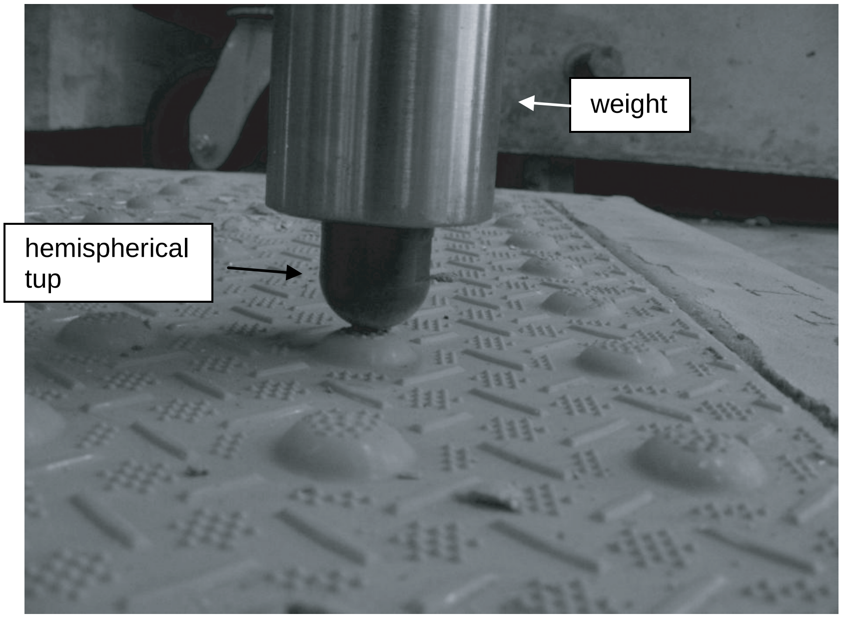


Figure 2--The impact head, showing the weight and hemispherical tup.

Recommended Method of Test for

Wear Resistance of Detectable Warning Systems

Designation: Draft T4-33, Part 12

1. SCOPE

1.1. This test method covers the evaluation of wear resistance of detectable warning systems. Note that this wear resistance test is distinguished from the procedure outlined in Draft T4-33, Part 4 *Recommended Method of Test for Abrasion Exposure of Detectable Warning Systems.* That test is intended to evaluate the resistance of the test sample to an intense abrading action, while this test is intended to condition the sample in preparation for other evaluation tests.

1.2. This evaluation test is intended to be conducted as part of the test protocol outlined in Draft T4-33, which outlines the exposure and evaluation methods for determination of durability of detectable warning systems.

2. REFERENCED DOCUMENTS

2.1. **AASHTO Standards**

2.1.1. Draft T4-33 *Recommended Method of Test for Durability of Detectable Warning Systems*

3. SUMMARY OF TEST METHOD

3.1. This method evaluates the durability of domes in detectable warning systems when they are subjected to wearing action produced by abrasive paper. For this test, the test sample consists of a representative portion of the detectable warning system removed from the larger test specimen. This sample is held with known force against a translating surface on which abrasive paper has been fixed.

4. SIGNIFICANCE AND USE

4.1. This test method is intended to evaluate the response of detectable warning systems to an abrasive action. This response of the test samples to this action is expected to be indicative of performance of detectable warning systems when subjected to abrasion from foot traffic.

4.2. This method is intended to be used as part of Draft T4-33 to evaluate the durability of detectable warning systems.

5. SAFETY HAZARDS

5.1. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

6. TEST SPECIMENS

6.1. The test specimens are two 15.2 cm (6 in.) diameter circular representative portions cut from the detectable warning system.

6.1.1. The location of samples should be selected to maximize the included number of domes, while maintaining symmetry. Any partial domes at the edges of the sample should be removed by grinding or other means. A dome shall be considered partial if less than 95% of the area based on the bottom diameter is within the circular portion.

6.1.2. When the sample is to be tested in an unexposed condition, it may be obtained from a representative sample of the detectable warning system that has never been installed in concrete.

6.1.3. When the sample is to be tested in an exposed condition, such as may be done to evaluate the influence of exposure regimes on wear resistance, the specimens are cut or cored from test specimens prepared and exposed in accordance with Draft T4-33.

Note 1: If the samples are cored and it is possible to remove the detectable warning system from the backing concrete in the core without damaging the sample, it is advisable to do so. Otherwise, it is advisable to cut the backing concrete such that approximately 1 cm (½ in.) of concrete remains attached to the sample.

6.1.4. The sample must be rigidly supportable in a horizontal plane. Detectable warning systems that are flexible should be fixed to a rigid plate, such as a ¼ in. or thicker steel plate, to assist in achieving this goal.

7. APPARATUS

7.1. Abrader wheel—A 460 mm (18 in.) diameter or greater power-driven abrader wheel, such as a lapping wheel commonly used for preparing the surface of concrete samples, shall be used. Self-adhesive abrasive paper shall be fixed to the wheel.

7.1.1. This wheel shall rotate at 45 ± 1 rpm.

7.1.2. The abrasive disc shall be 60-grit aluminum oxide X-weight abrasive cloth. The disc shall conform with the following specifications:

- The backing shall be abrasive grade X-weight cloth.
- The abrasive shall be P60 FEPA-graded, coated abrasive grade, low titania, heat treated aluminum oxide.

Note 2: Aluminum oxide, resin bond, X weight heavy duty cloth discs with 60 grit adhesive available from Global Abrasive Products, 62 Mill Street, Lockport, New York 14094 conforms with these requirements.

7.2. Sample frame—The two test samples will be supported in a mechanism consisting of the sample frame and sample assembly. This mechanism shall maintain the surface of the detectable warning in a horizontal orientation (parallel to the plane of the abrader wheel) and allow fixing the rotation of the assembly relative to the frame at four 90° intervals, while allowing the sample assembly to freely translate vertically. The sample frame is fixed over the abrader wheel so that the samples are positioned 11.4 ± 0.25 cm (4.5 ± 0.1 in.) from the center of rotation of the wheel.

7.3. Sample assembly—The sample (or the sample fixed to a rigid plate) shall be supported within the sample frame on a sample assembly. This assembly shall be rigid and weigh 4.5 ± 0.1 kg (10 ± 0.2 lbs). Since the weight of the sample itself may vary, a means for adjusting the weight of the combined sample assembly using steel plates of various thicknesses or similar is needed. The assembly shall provide a means for fixing the rotation of the assembly relative to the frame at four 90º intervals.

Note 3: A photograph and sketch of a system consistent with these requirements is given in the appendix of this method.

Note 4: The alignment of the assembly and frame is important to produce an even wearing action on each of the domes in the sample. No chattering should occur.

7.4. Balance for weighing sample assembly shall have capacity greater than 4.5 kg (10 lbs) and resolution of 0.01 kg (0.02 lbs).

8. PROCEDURE

8.1. Install a new sheet of abrasive paper on the abrader wheel.

8.2. Install the sample in the assembly.

8.3. Measure the height of two domes on each of the two test samples by determining the distance between the topmost feature on the dome and the field according to the method outlined in Draft T4-33, Part 7 *Recommended Method of Test for Dome Shape and Geometry Measurement of Detectable Warning Systems*. Note the location of the measured domes.

8.4. Install the assembly in the frame. Adjust the orientation of the sample relative to fixed rotation intervals in the frame mechanism so that, at the start of the test, the overlap in paths formed in the abrasive paper by each dome is minimized. In other words, the number of independent paths produced through the abrasive paper by the domes should be maximized.

8.5. Fix the test specimen such that it does not rotate.

8.6. Start the rotation of the sample wheel and abrade the samples for 60 seconds. Rotate the specimen 90º clockwise.

8.7. Repeat the previous step three times for a total of 4 minutes of abrasion.

8.8. Repeat the measurement of the height of each dome tested in Section 8.3.

9. REPORT

9.1. Report the sample identification assigned according to the Draft T4-33.

9.2. Report the exposure history of the samples at the time of testing.

9.3. Report type, manufacturer, and, if known, lot number of the detectable warning system(s) tested.

9.4. For each tested dome, report the initial and final dome height and the change in height.

9.5. Report any deviation from the procedures outlined in this method.

10. PRECISION

10.1. Data not available at this time.

APPENDIX (Non-mandatory Information)

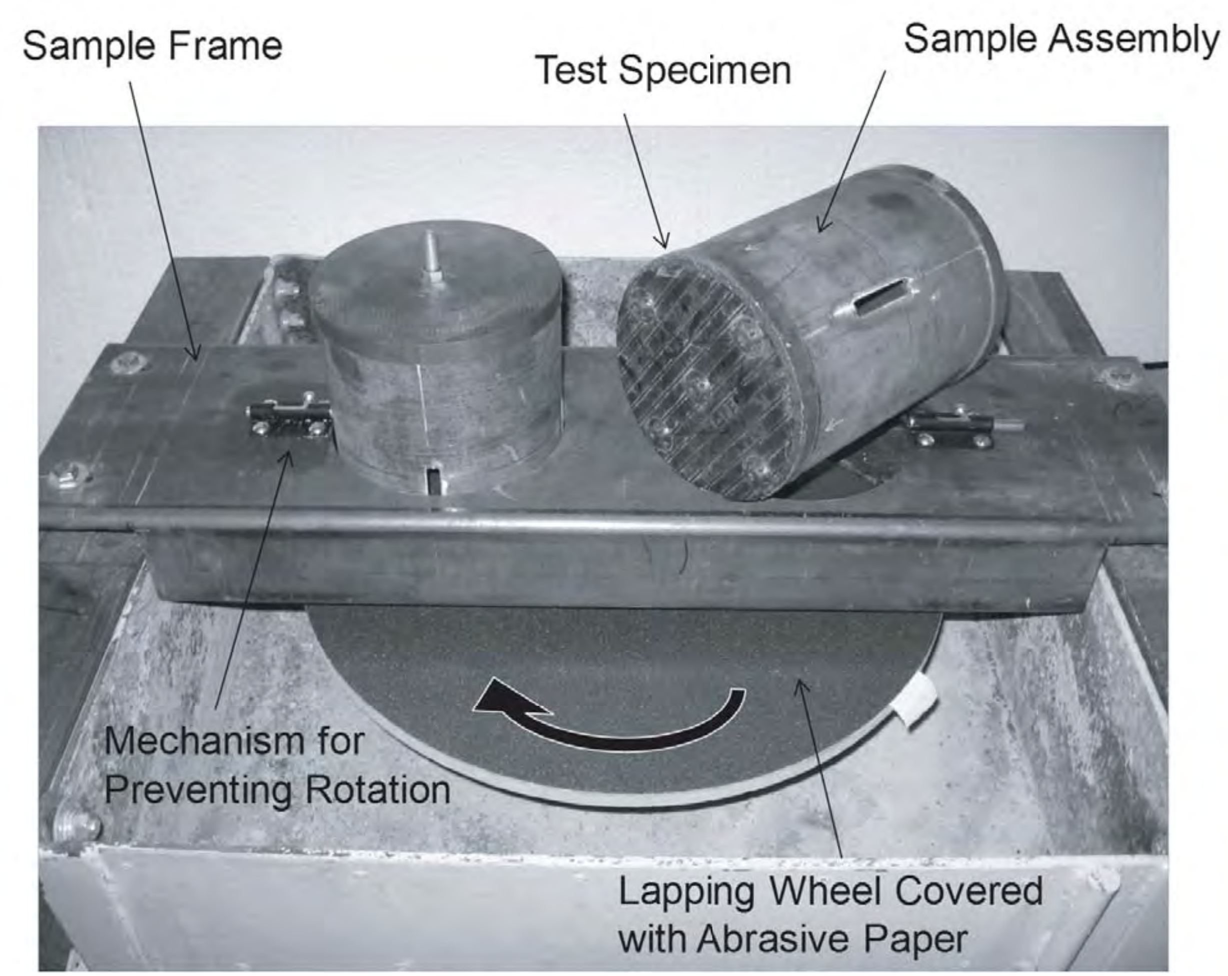


Figure 1 - Photo of wear resistance sample frame assembly.

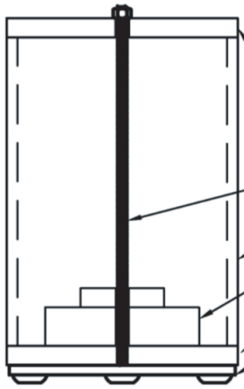


Figure 2 - Schematic of cross section of sample assembly used to hold test specimen vertically in sample frame. The size and number weights were adjusted to produce the specified assembly weight.

APPENDIX

Research Leading to the Development of Methodology for Durability Assessment of Detectable Warning Systems

The appendix is available on the *NCHRP Report 670* summary web page at www.trb.org/Main/Blurbs/163989.aspx.

Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation