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**Federal Transit
Administration**

Assessment of Detectable Warning Devices for Specification Compliance or Equivalent Facilitation

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13. ABSTRACT (Maximum 200 words)

This report evaluates the Americans with Disabilities Act Accessibility Guidelines (ADAAG) specification for detectable warnings and the applicability of equivalent facilitation to the development of detectable warning devices. Ambiguities in the specification are identified and solutions are recommended to address these problems.

Detectable warnings are intended to aid the visually impaired to detect the presence of hazards on a circulation path. Transit authorities and manufacturers developing detectable warnings for use at rail platforms have requested assistance in interpreting the specification. Lack of precision in the specification language allows different interpretations, resulting in products that vary widely in their designs. The evolution of the detectable warning specification and the human performance considerations that led to changes in the specification are discussed. Recommendations are given for clarifying the language and eliminating the ambiguity in the specification.

For transportation authorities unable to comply with the ADA detectable warning specification, the guidelines provide an alternative mechanism by which accessibility requirements may be met. Equivalent Facilitation permits the use of alternative designs provided they give equal or better access. The implications of departures from the specification are discussed and several tests are suggested for determining whether an alternative design meets the equivalent facilitation criterion.

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Americans with Disabilities Act (ADA), Detectable Warning, Equivalent Facilitation, Rail Platform, Tactile Warning, Visually Impaired

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PREFACE

This report addresses issues associated with the Architectural and Transportation Barriers Compliance Board (Access Board) specification for detectable warnings for the visually impaired. Ambiguities in the specification are identified and a proposed resolution of each ambiguity is described. A proposed method and set of standards are also described for making a determination of equivalent facilitation for detectable warnings.

This report was prepared jointly by the Service Assessment Division and the Operator Performance and Safety Analysis Division of the Office of Research and Analysis, at the Volpe National Transportation Systems Center (VNTSC). The report was prepared for the Federal Transit Administration, Office of Grants Management. The report was completed under the direction of VNTSC program manager David Spiller. The research and report preparation was the responsibility of David Spiller and Jordan Multer. Technical production support was provided by Arthur H. Rubin of EG&G/Dynatrend.

The authors would like to thank Dr. B.L. Bentzen of Boston College, Mr. Dennis Cannon of the Access Board, and Mr. Raymond Lopez of the Office of Grants Management for their collective wisdom, insight and comments.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in.) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x - 32)(5/9)] °F = y°C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (kn^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

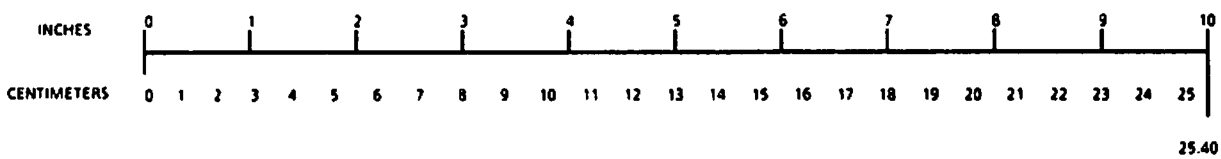
VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

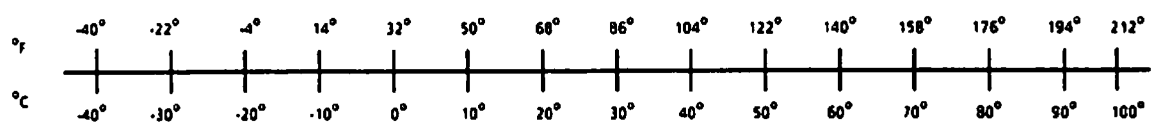
TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH-CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10286.

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EXECUTIVE SUMMARY

This report evaluates the Americans with Disabilities Act Accessibility Guidelines (ADAAG) specification for detectable warnings and the applicability of equivalent facilitation to the development of detectable warning devices. Antecedent specifications and test and evaluative data are reviewed. The human performance factors underlying the design of detectable warning devices are described and the critical importance of a standardized, consistent design is asserted.

The Federal Transit Administration (FTA) requested an indepth look at these issues because of the many requests for a finding of equivalent facilitation for alternative detectable warning designs, and confusion on the part of many Transit Authorities as to the meaning of the specification and whether specific products were compliant or not.

Because the ADAAG specification language is imprecise giving rise to multiple interpretations, a proliferation of designs is possible, each claiming to be in compliance with the specification, yet each markedly different one from the other. The authors have identified the following ambiguities or issues that require resolution to achieve the goal of a standardized detectable warning surface:

A. What are "raised truncated domes"?

B. What are the controlling dimensional tolerances that uniquely fix its shape?

C. How should center-to-center spacing be measured?

D. What are the controlling dimensional tolerances that uniquely fix the geometric pattern of "raised truncated domes"?

E. What is meant by resiliency of material or sound-on-cane contact?

F. Is visual contrast (light-on-dark or dark-on-light) the most appropriate visual cue requirement for detectable warnings?

The authors propose a resolution to each of these issues and include recommended language to redraft the specification. The specification, as clarified, would form the standard for making equivalent facilitation determinations.

The authors recommend a tightly constrained approach to the use of equivalent facilitation when applied to detectable warning devices. The authors propose a test of standardization whereby the user population can not discriminate between the product proposed for equivalent usability and a product that meets the specification (as clarified). Two psychophysical methods, the method of limits and the method of adjustments, can be used to make this determination. Using a representative sample of the visually impaired population, both tests yield a range of Just Noticeable Differences (JNDs) for the tested design parameters. A criterion representing the proportion of the population that can not discriminate the difference between the variable value and the specification standard is used to select the JND within which a proposed product value must fall. It is recommended that the criterion level be set high (e.g., 95 percent) so that the likelihood for confusion between surfaces that meet the specification and those that do not is small.

A second set of tests is proposed to determine minimum performance of products for which findings of equivalent facilitation are requested. It is recommended that the method for measuring detectability developed by Peck and Bentzen (1987) serve as the procedure to make these determinations. The key criteria are the detection rate and stopping distance following detection of the warning surface. The authors recommend that the criterion levels be set at the performance levels for surfaces meeting the specification. The authors also propose measuring resiliency by measuring the coefficient of restitution of an untextured sample of the detectable warning device (in comparison to an established criterion standard), and light reflectance by measuring the light reflectance value (LRV) of the sample (in comparison to an established criterion standard).

1. INTRODUCTION

Under the Americans with Disabilities Act of 1990 (ADA), platform edges bordering a drop-off and not protected by platform screens or guard rails must have a detectable warning. This requirement applies to both newly constructed or altered transit stations, and key stations (identified via the local planning process in accordance with Section 37.47 of the Final Rule) on existing systems. The Act also requires that detectable warnings be placed at hazardous vehicular areas to prevent any inadvertent intrusion into a hazardous vehicular area by a visually impaired person. This only applies if a walk crosses or adjoins a vehicular way and the walking surfaces are not separated by curbs, railings, or other elements between the pedestrian areas and vehicular areas. In this context, the primary application is the sidewalk ramp leading to the curb cut at street intersections.

The ADA Accessibility Guidelines (ADAAG) for Buildings and Facilities 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" (Federal Register, Sept. 6, 1991). In essence, it is a perceptual cue capable of being detected by at least one, but preferably multiple senses other than sight, and conveying a unique hazard message.

The specification for detectable warnings under the ADA is paragraph 4.29, Appendix A to Part 37 - Standards for Accessible Transportation Facilities, developed by the Architectural and Transportation Barriers Compliance Board (henceforth referred to as the Access Board) and incorporated as a mandated regulatory standard by the Department of Transportation in the Final Rule which implements the ADA (Federal Register, Sept. 6, 1991). Although referred to as guidelines, the technical specifications are, in fact, minimum compliance standards.

Departures from particular technical and scoping requirements of the Access Board's guidelines by the use of other designs and technologies are permitted where the alternative designs and technologies used will provide equivalent or greater access to and usability of the facility. This concept, referred to as "equivalent facilitation," however, requires specific and clear definition in the context of its application to specific architectural elements. In the context of detectable warnings, the critical concept needing clarification is equivalent usability.

Numerous enquiries have arisen from both manufacturers and transit system authorities concerning the interpretation of the specification or requesting a finding of equivalent facilitation for an alternative design to providing a detectable warning surface. In a recent workshop on key station alterations held on behalf of light rail, rapid rail, and commuter rail authorities at the Federal Transit Administration (Federal Transit Administration, May 28, 1992), the dominant concern focused on the requirement for installing detectable warnings that comply with the Act.

Ambiguity in the specification language makes it difficult to provide consistency in making determinations that a particular design complies with the specification or fails to comply. The concept of equivalent facilitation is also problematic in this context since no conclusive statement has to date been made defining what equivalent facilitation means when applied to detectable warning devices, and what standard test protocols to use to test for equivalent facilitation. As a result, agencies subject to the detectable warning requirement of the ADA, such as transit system authorities, may have difficulty showing that the products they install comply with the specification or provide for equivalent facilitation.

For the population of intended users of detectable warnings, the situation is also problematic. Ambiguity in the specification and in the concept of equivalent facilitation when applied to detectable warning devices means that products may be deployed in the field that are ineffective or possibly hazardous to the intended user population (i.e., the visually impaired) and/or to other populations that come into contact with detectable warnings (e.g., the general population that also crosses the boundary at the platform edge or at the street intersection and ambulatory-impaired persons).

At the request of the Federal Transit Administration (FTA), the authors were requested to review these issues and make recommendations. The purpose of this report is to identify ambiguities leading to potentially conflicting interpretations in the governing ADA specification for detectable warnings; to present recommended resolutions to the ambiguities identified within the specification; to define equivalent facilitation as it should apply to detectable warning devices; and to present functional and performance requirements and appropriate test protocols for making a determination of equivalent facilitation.

1.1 SCOPE OF REPORT

This report focuses on ambiguities in the specification, and a definition for equivalent facilitation when applied to detectable warnings as both relate solely to pedestrian usability. There are still areas of uncertainty and limited state-of-knowledge, even when the focus is limited to the domain of pedestrian usability as affected by alternative designs for detectable warnings. The objective taken in this report is to highlight where the state-of-knowledge is weak or limited, the degree of uncertainty that pertains, and what significance it may hold.

A number of other legitimate issues have been raised by agencies subject to the requirements for installing detectable warnings. These include cost, maintainability, durability, and fire load and safety considerations. These issues are not within the scope of this report. It is our opinion, however, that cost, maintainability and durability are best left to the marketplace rather than legislatively or administratively mandated via a specification. There is every incentive to develop and market a "better mousetrap" with improved cost and maintainability. We base this opinion on evidence that manufacturers are currently doing precisely this. In the course of preparing this paper, one of the authors attended an extended briefing from a manufacturer who has developed an approach to complying with the detectable warning specification at a substantially reduced cost and with a product that appears to have very good maintainability characteristics.

We believe, however, that detectable warnings meeting 4.29 of the Access Guidelines or determined to provide equivalent facilitation should comply with the relevant and latest version of the NFPA fire safety codes for public spaces, buildings, facilities and other architectural elements with respect to material toxicity, rates of smoke generation and flame spread, etc.

2. BACKGROUND: EVOLUTION OF ANTECEDENT SPECIFICATIONS

2.1 ADA SPECIFICATION FOR DETECTABLE WARNINGS

The ADA specification for detectable warnings reads as follows:

4.29.2 Detectable Warnings on Walking Surfaces. Detectable warnings shall consist of raised truncated domes with a diameter of nominal 0.9 in. (23 mm), a height of nominal 0.2 in. (5 mm) and a center-to-center spacing of nominal 2.35 in. (60 mm), and shall contrast visually with adjoining surfaces, either light-on-dark, or dark-on-light.

The material used to provide contrast shall be an integral part of the walking surface. Detectable warnings used on interior surfaces shall differ from adjoining walking surfaces in resiliency or sound-on-cane contact.

2.2 ANTECEDENT SPECIFICATIONS

It is useful to review the earlier ANSI standards since it is clear that both the ANSI committee work and the antecedent ANSI standards for detectable warnings greatly influenced the Access Board's thinking (Cannon, May 1992).

The American National Standards Institute's first accessibility standard ANSI A117.1 was established in 1961 as the result of a request by the President's Committee on Employment of the Handicapped. This standard was reaffirmed in 1971. In 1980, ANSI A117.1 was completely revised and expanded, primarily as the result of research and development by the U.S. Department of Housing and Urban Development (US ATBCB, 1989).

The proposed ANSI 1977 standards (the first to specify tactile warning signals, but which were not enacted) for making buildings and facilities accessible to and usable by physically disabled people cites a number of governing principles for tactile signals:

- Tactile signals should be standardized;

- Tactile signals can be perceived by cane or foot if they are raised from the base material or grooved into it;

- Tactile signals should have a pattern to facilitate detectability and communicate or signal meaning upon detection;

- Tactile signals should provide a change in hardness from the surrounding walking surface;

- Tactile signals should cover a large enough area so that touching it will be certain;

- Tactile signals set slightly more than one step (2-4 ft; 610 -1220 mm) in front of a hazard allow a person to perceive the signal, follow through with their last step, and stop before encountering the hazard.

The Committee concluded first that tactile signals on walking surfaces are the most effective means to warn a blind or other visually impaired person of a hazard; and, secondly, that too many warning signals or lack of standardization weaken their usefulness (American National Standards Institute, 1977). Section 5.1.5 of the 1977 standards imposes a requirement for tactile warnings along the entire edge of passenger loading platforms for public transit vehicles.

The specific language in the proposed ANSI 1977 specification (Section 7.8.4) reads as follows:

7.8.4 Tactile Warnings on Walking Surfaces

Tactile warning signals for hazards to falling or vehicular hazards shall have the following features:

A. Configuration: regularly spaced, continuous pattern of strips running parallel to the edge between a circulation path and a hazardous area.

B. Height and spacing: as shown in Figure 2-1.

C. Application: applied as strips, applied as a surface area, or grooves within a walking surface (see Figure 2-1).

D. Width, perpendicular to strips: 24 in. (610 mm) minimum if the material of the signal has a different perceived hardness than the material of the preceeding walking surface; 36 in. (915 mm) minimum if the material of the signal cannot be perceived as a different hardness (see Table 2-1 for perceived differences in hardness). No other walking surface on a site or in a building shall have the same pattern as the warning signal.

The ANSI 1980 and 1986 specifications are identical to each other except that the 1986 specification uses the language "detectable warning" rather than "tactile warning," but both specifications depart from the proposed 1977 standards in several areas:

- Deletion of explicit specification language to a regularly spaced, continuous pattern running parallel to the edge between the circulation path and a hazardous area;

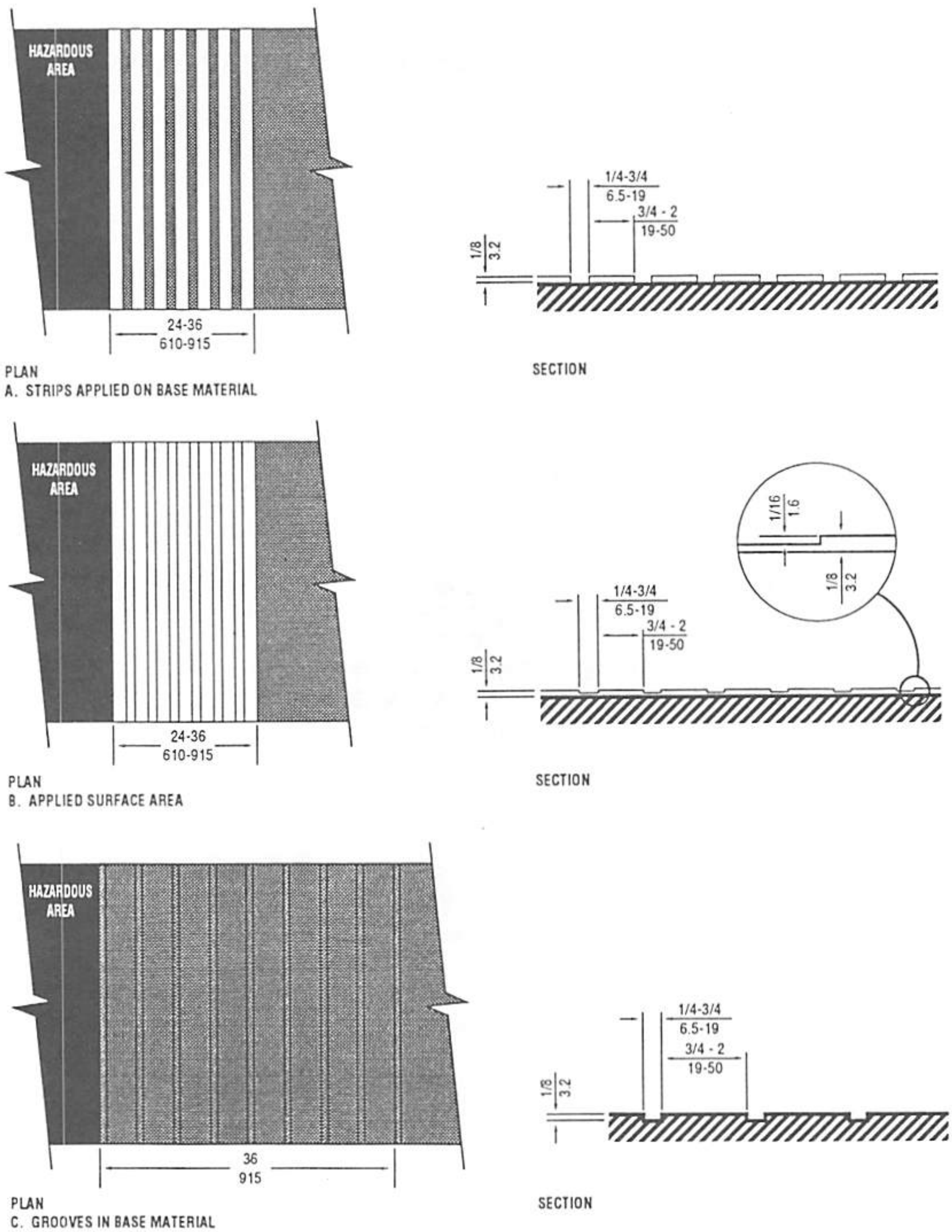


FIGURE 2-1. SCHEMATIC FOR PROPOSED DRAFT, 1977 ANSI STANDARD

(SOURCE: AMERICAN NATIONAL STANDARDS INSTITUTE, 1977)

TABLE 2-1. PERCEIVED DIFFERENCES IN HARDNESS

KEY
● DETECTABLE BY CANE
○ NOT DETECTABLE BY CANE
+ NOT APPLICABLE

SIGNAL MATERIAL \ WALKING SURFACE MATERIAL	CONCRETE	ASPHALT	STONE OR TERRAZZO	BRICK	QUARRY TILE	CERAMIC TILE	RESILIENT TILE	SHEET VINYL	WOOD	HARD PACKED DIRT	RUBBER	CARPET
CONCRETE												
ASPHALT	●											
STONE OR TERRAZZO	○	●										
BRICK	○	●	○									
QUARRY TILE	○	●	○	○								
CERAMIC TILE	○	+	○	○	○							
RESILIENT TILE	●	+	●	●	●	●						
SHEET VINYL	●	+	●	●	●	●	○					
WOOD	●	●	●	●	●	●	●	●				
HARD PACKED DIRT	●	●	●	●	●	+	+	+	●			
RUBBER	●	●	●	●	●	●	●	●	●	+		
CARPET	●	●	●	●	●	●	●	●	●	+	+	

(SOURCE: AMERICAN NATIONAL STANDARDS INSTITUTE, PROPOSED DRAFT, 1977)

- Standardization of width of the detectable warning to 36 in. (915 mm);

- Disallowance of a 24 in. (610 mm) width if the material of the signal has a different perceived hardness than the material of the preceding walking surface;

- Deletion of a table of perceived relative hardness between signal materials and adjoining walking surface materials;

- Restriction of signal material to exposed aggregate concrete, rubber or plastic;

- Restriction of grooves to indoor use only.

Although no reference in the language of the 1980 and 1986 specifications is made to a regularly spaced, continuous pattern running parallel to the edge (language explicitly used in the proposed 1977 standard), it is clear from the 1980 and 1986 schematics and dimensional tolerances illustrated therein (see Figures 2-2 and 2-3) that the structure and pattern of the tactile warning signal is identical to that proposed in the 1977 standard.

The specific language in the 1980 and 1986 ANSI specifications respectively read as follows:

4.29 Tactile Warnings (1980 ANSI specification)

4.29.1 General. If tactile warnings are required, they shall comply with 4.29.

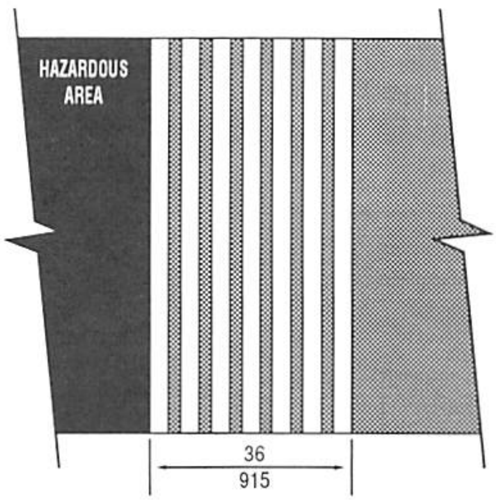
4.29.2 Tactile Warnings on Walking Surfaces. Tactile warning textures on walking surfaces shall consist of exposed aggregate concrete, rubber, or plastic-cushioned surfaces, raised strips, or grooves. Textures shall contrast with that of the surrounding surface. Raised strips or grooves shall comply with Figure 2-2. Grooves may be used indoors only.

4.27 Detectable Warnings (1986 ANSI specification)

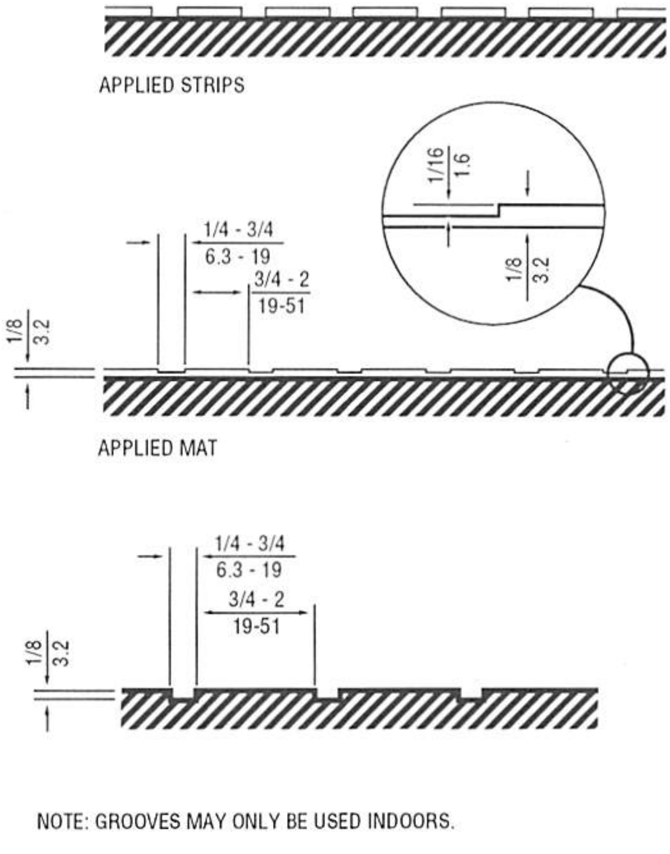
4.27.1 General. Detectable warnings shall comply with 4.27.

4.27.2 Detectable Warnings on Walking Surfaces. Detectable warning textures on walking surfaces shall consist of exposed aggregate concrete, cushioned surfaces made of rubber or plastic, raised strips, or grooves. Textures shall contrast with that of the surrounding surface. Raised strips or grooves shall comply with Fig. 2-2. Grooves may be used indoors only.

Corresponding schematics are illustrated in Figures 2-2 and 2-3, respectively.



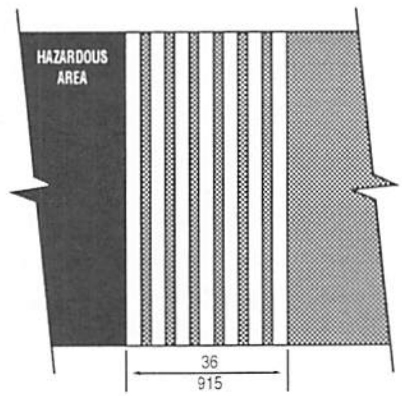
(a)PLAN OF TACTILE WARNING SURFACE



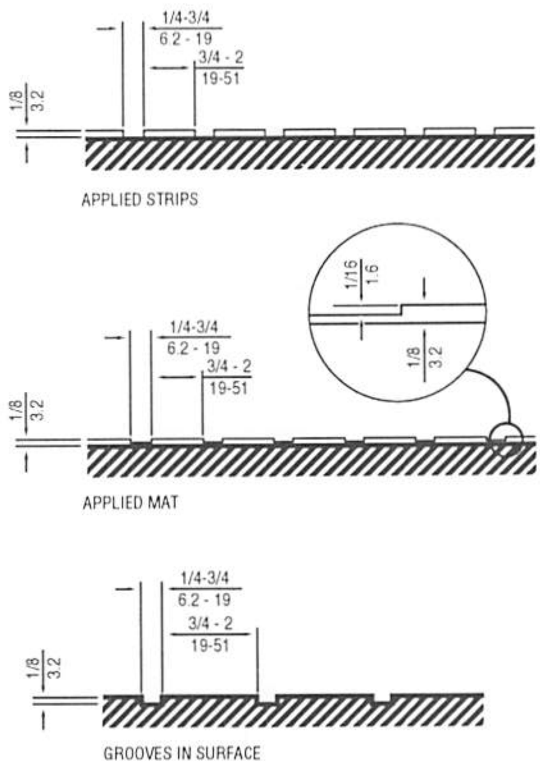
(b) SECTIONS OF TACTILE WARNING SURFACES

FIGURE 2-2. SCHEMATIC FOR 1980 ANSI STANDARD

(SOURCE: AMERICAN NATIONAL STANDARDS INSTITUTE, 1980)



(a) PLAN OF DETECTABLE WARNING SURFACE



(b) SECTIONS OF DETECTABLE WARNING SURFACES

STRIPS AND GROOVES AS DETECTABLE WARNINGS ON WALKING SURFACES

FIGURE 2-3. SCHEMATIC FOR 1986 ANSI STANDARD

(SOURCE: AMERICAN NATIONAL STANDARDS INSTITUTE, 1986)

Proposed 1992 ANSI specification - It is important to realize that earlier versions of the proposed 1992 ANSI specification were reviewed and discussed by the Access Board and had a great deal of influence in shaping its thinking for an ADA compliant specification for detectable warnings.

The language in the proposed 1992 ANSI standard is identical to 4.29, but the key difference is that two schematics have been included (see Figure 2-4): one illustrating a uniform geometric staggered pattern for the placement of the 'raised truncated domes', the other indicating a dimensional tolerance for the top truncated surface of 0.45 in. (11.5 mm).

2.3 DEPARTURE OF THE ADA SPECIFICATION FROM ANTECEDENT SPECIFICATIONS

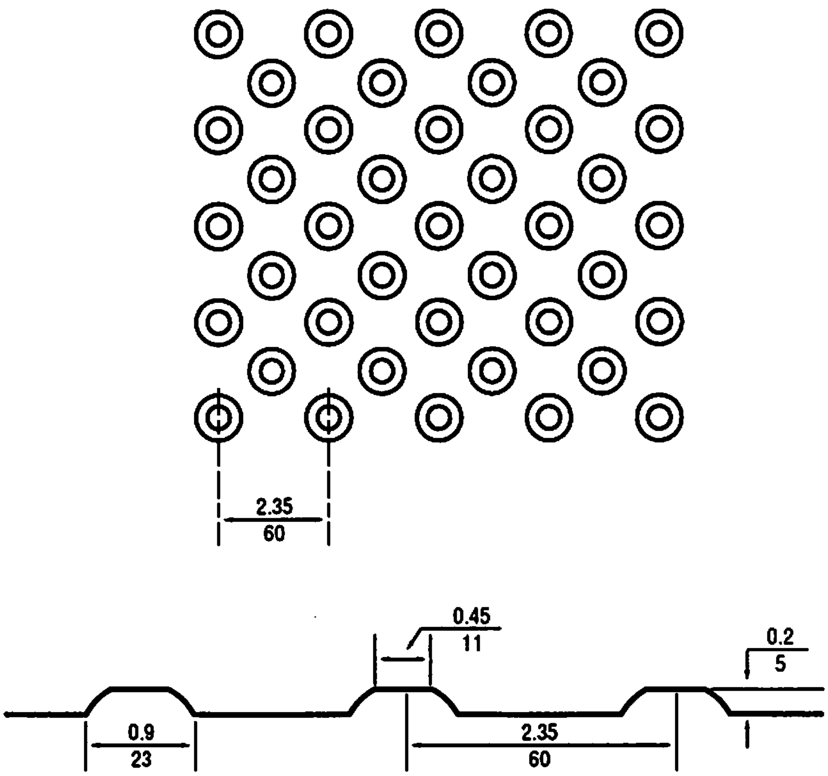
There are a number of important departures in the ADA specification for detectable warnings in comparison to the earlier ANSI standards (proposed 1977, 1980 and 1986).

Reference to a linear, continuous pattern of parallel strips or grooves is deleted. In its place, texture is defined as a (unspecified) pattern of discrete "point" structures (emphasis on the plural; i.e., many such structures) referred to as "raised truncated domes."

The diameter of the raised truncated domes has been fixed at a nominal 0.9 in. (23 mm) in contrast to a permitted range (3/4 - 2 in.; 19-50 mm) for the applied strips, or material between the grooves for the applied surface area or material between the grooves for the grooves etched in base material. The nominal 0.9 in. (23 mm) is at the lower limit for the earlier ANSI standards.

Center-to-center spacing, which conceptually corresponds to the summation of the groove width and twice the half-width of the raised strip, raised warning material in the applied surface area or raised warning material for the grooves etched in base material of the earlier ANSI standards, has been fixed at a nominal 2.35 in. (60 mm) in contrast to a permitted range under the earlier ANSI standards of 1-2.75 in. (25.5-69 mm). The nominal 2.35 in. (60 mm) is at the upper limit for the earlier ANSI standards. The corresponding groove width (i.e., spacing width between two discrete point structures) for the ADA specification measured at the perimeter of the domes for two neighboring domes on an axis parallel to and perpendicular to the treated edge (see Figure 2-5) is 1.45 in. (36.25 mm). This contrasts with a permitted range for the groove spacing width of 1/4-3/4 in. (6.5-19 mm). The ADA groove width is between two and six orders greater than the corresponding earlier ANSI standards.

Height has been increased to a nominal 0.2 in. (5 mm) from 1/16 in. (1.6 mm) for an applied surface area to 1/8 in. (3.2 mm) for strips applied on base material or grooves etched in base material. In relative terms, height has increased between 50 and 300 percent. However, nominal height of the discrete point structures has been kept below the 0.25 in. (6.4 mm) threshold; any vertical change in level on a walking surface above that threshold requires



DETECTABLE WARNING TILE

FIGURE 2-4. SCHEMATIC FOR PROPOSED 1992 ANSI STANDARD

(SOURCE: AMERICAN NATIONAL STANDARDS FOR ACCESSIBLE AND USABLE BUILDINGS AND FACILITIES, JANUARY 24, 1992)

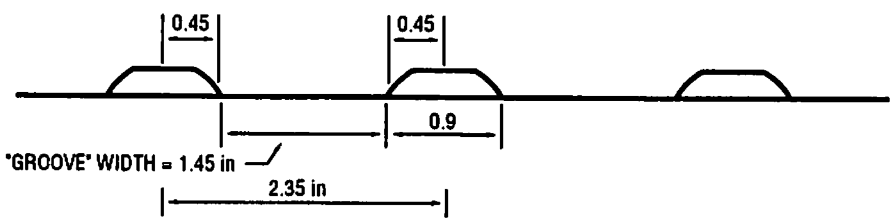


FIGURE 2-5. ILLUSTRATION OF GROOVE WIDTH MEASURED AT THE PERIMETER OF TWO NEIGHBORING DOMES ON AN AXIS PARALLEL TO AND PERPENDICULAR TO THE TREATED EDGE

beveling or other edge treatment at the level change boundary.

Restrictions on specific materials have been deleted (i.e., material is not restricted to exposed aggregate concrete, rubber, or plastic).

A requirement for visual contrast between the detectable warning and the adjoining surface has been added.

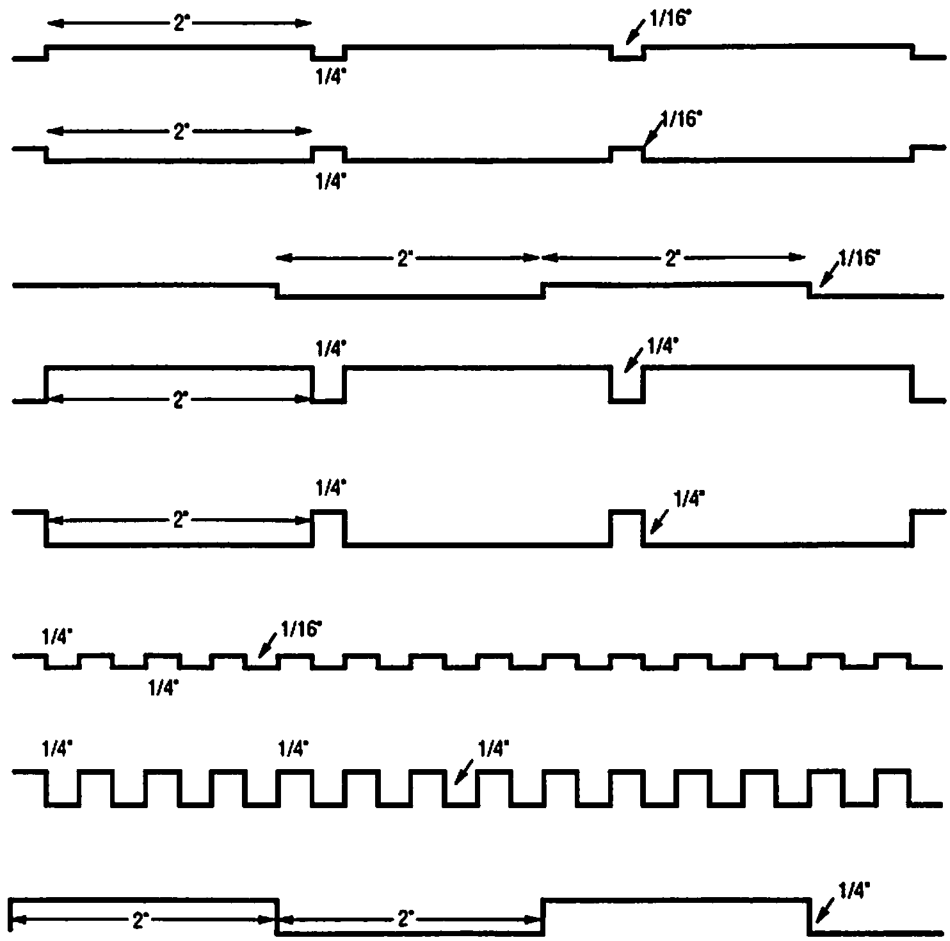
A requirement for the material to be an integral part of the walking surface (in contrast to applied strips which were permitted under the earlier ANSI standards) has been added. The color contrast must also be an integral part of the walking surface.

Additional requirements for material resiliency contrast or sound-on-cane contact have been added for indoor applications of detectable warnings.

2.3.1 Test Data and Other Evaluative Results

The focus on discrete dome-like structures rather than a linear, continuous pattern of parallel strips or grooves was based on evaluative results which indicated that linear patterns in which the lines were flat-topped were not particularly detectable under foot (Peck and Bentzen, 1987; Aiello and Steinfeld, 1980; Templer and Wineman, 1980; and Templer, Wineman and Zimring, 1982). For some test trials, high rates of detectability were achieved for certain materials having a linear, continuous pattern of strips or grooves (see Figure 2-6) but the test subjects used only cane technique. The results therefore can not be generalized to all visually impaired persons across all methods by which environmental cues are sensed.

Peck and Bentzen (1987) tested a dome-shaped linear texture (referred to in their tests as "corduroy" on the theory that research had established that for tactile discrimination based on finger perception for braille, the optimal shape for perception and legibility had been found to be half spherical or somewhat conical [Burklen, 1932, cited in Peck and Bentzen, 1987]). Subsequent to these laboratory tests, a specific material (Pathfinder [tm] tile) having approximately the same dome-like corduroy shape for elements of its surface but with individual discrete structures of this shape rather than linear, continuous strips (as in the corduroy texture) was tested at BART and found to have nearly equivalent (and equally high rates) of detectability as the linear corduroy texture using both cane technique and detection under foot. The lack of linear grooves or spaces in the manufactured product also improved the drainage characteristics of the material. Successful replication of the test results at BART were done at the Miami Dade Transit Agency (Civic Center Station) (Mitchell, 1988) using the same Peck and Bentzen test protocol used at BART. In both sets of tests, the tested product was found not to adversely affect the mobility or maneuverability of ambulatory-impaired persons. Mobility-aids that were tested included electric and mechanical wheelchairs. Three-wheeled scooters were not tested.



Cross Sections of Surfaces Found By Other
Researchers To Be Low In Detectability

FIGURE 2-6. ILLUSTRATION OF LINEAR FLAT-TOPPED PATTERNS

(SOURCE: PECK & BENTZEN, 1987)

The shape and dimensional tolerances are presented below (along with a comparison to relevant dimensional tolerances in the ADA specification) for the tested product that, according to the Access Board, was the basis for developing the ADAAG guidelines for detectable warnings because test results indicated that it worked (Cannon, May 1992):

	Tested Product	Detectable Warnings
Structure shape	truncated spherical solid: circular in plan bottom and top	raised truncated domes
Height	0.197 in.	nominal 0.2 in.
Bottom diameter	0.906 in.	nominal 0.9 in.
Top diameter	0.453 in.	unspecified
Structure center-to-center spacing measured along axes parallel and perpendicular to the treated edge	2.360 in.	center-to-center spacing of nominal 2.35 in.
Structure center-to-center spacing measured at angle 45° or 135° to the treated edge	1.660 in.	unspecified
Projected horizontal and vertical offset spacing measured between two dome-like structures in adjoining rows and columns taken parallel and perpendicular to the treated edge, respectively	1.180 in.	unspecified

There has been, to our knowledge, no systematic study to determine the optimal value or range of values for each of the above shape and dimensional tolerances. The shape and dimensional tolerances of the tested product gave acceptable results in accordance with the test protocol criteria for success or failure. (It may not be a theoretically optimal alternative from an infinite set of untested alternatives, but it is a known "good" alternative from the limited set of tested alternatives.) The height, width and center-to-center spacing of either the linear corduroy pattern or the discrete dome-like structures of the tested product substantially differed from the earlier ANSI standards and are approximately the dimensional tolerances adopted by the Access Board and defined in 4.29 for Detectable Warnings.

Access Board sponsored research by Pavlos and Steinfeld (1985) appears to be the basis on which additional redundant cues having to do with resiliency contrast or sound-on-cane contact were imposed for indoor applications of detectable warnings. In laboratory testing, materials that relied on sound and resilient cues were more detectable than materials which relied on texture cues. Sound masking, according to their test results, had little effect on rates of detectability. It should be pointed out, however, that two potential problems in the Pavlos and Steinfeld work may have biased the test results (thereby under-emphasizing the importance of tactile cues based on textural contrast):

1. Subjects utilized a cane-tapping technique only (a technique which would miss important textural cues based on surface irregularities);

2. Textural contrast was limited in the test setup by defining texture at the microscale level as relative surface roughness (similar to characterizing materials by their skid resistance values [SRV]) and excluding texture differences consisting of surface irregularities on the scale of a cane tip diameter.

A requirement for visual contrast was added based on related research sponsored by the Access Board on signing for the visually impaired (U.S. Architectural and Transportation Barriers Compliance Board, 1991). An advisory test for color contrast was suggested (Federal Register, Sept. 6, 1991). Specification of color was not made because the Access Board felt that not enough research data were available to justify restricting the design freedom of potential manufacturers.

2.3.2 ADA Specification Ambiguities

The ADA specification fails to define in precise terms the shape, dimensional tolerances and geometry of the raised truncated domes, or to set measurable criteria (for pass/fail testing) for the other requirements imposed on detectable warning surfaces such as resiliency, sound-on-cane contact, or visual contrast. The next section presents the theoretical basis for the design of detectable warning signals. Equivalent facilitation is then given precise definition for its application to this context, and recommended resolutions to the ADA specification ambiguities that we have identified are discussed at length in the last section of this report.

3. HUMAN PERFORMANCE CONSIDERATIONS SUPPORTING THE DEVELOPMENT OF DETECTABLE WARNINGS

To serve effectively as a warning signal, the design of detectable warnings must take into account several human performance considerations. First among these considerations are the different populations that these warnings will affect. Although a detectable warning is intended to primarily aid navigation by the visually impaired, placement of detectable warnings at rail platform edges, sidewalks and other surfaces intersecting hazardous vehicular ways will also affect those with mobility impairments as well as people without disabilities. A detectable warning acts primarily as a tactile cue for the visually impaired. However, the tactile features of the warning device could potentially impair the mobility of a person using a wheel chair, if the mobility requirements of ambulatory impaired people are not considered. The tactile and visual cues associated with detectable warnings may also benefit people without disabilities. A study conducted at the San Francisco transit system, BART, (Weule, 1986), found that adding detectable warning tiles to the platforms reduced the number of falls off platform edges for the general population as well as the visually impaired, compared to the period before the warning tiles were introduced.

The design of detectable warnings must balance the conflicting needs of all these groups. The need of the visually impaired to rely on tactile cues as a warning signal must be balanced by the potential of the detectable warning to impair the mobility of a pedestrian using a wheel chair.

Within the visually impaired population, the human performance considerations vary as well. The visually impaired differ in the degree of their impairment, from totally blind to low vision. Some visually impaired rely on guide dogs as a mobility aid while others use canes. Much of the research evaluating detectable warning surfaces used subjects who rely on the long cane as their primary navigation aid (Steinfeld, 1979; Aiello and Steinfeld, 1980). Among cane users, there are two commonly used techniques that may affect detectability: the sweep technique and the touch technique. In the sweep technique, the cane arcs from side-to-side and touches points outside both shoulders. In the touch technique, the cane is held in a stationary position, touching the ground or just above the ground at a point outside one shoulder. The sweep technique is primarily used in uncontrolled environments while the touch technique is primarily used in controlled or familiar environments (Steinfeld, 1979).

However, this research (Aiello and Steinfeld, 1980; Templer and Wineman, 1981; Templer, Wineman, and Zimring, 1982) did not evaluate whether the cane technique affected the ability of individuals to detect a particular surface. For tactile cues, resiliency was found to be the most significant variable affecting discriminability. However, if one technique was favored over the other by subjects, this may have biased the results in favor of resiliency. If this technique is not representative of what people do in environments where detectable warnings are placed, then this suggests that conclusions drawn about the relationship between resiliency, surface texture and cane technique need to be revisited.

For the visually impaired with low vision deficits or with guide dogs, the primary means of detecting a warning surface is underfoot detection. Studies evaluating the materials for use as detectable warning surfaces (Bentzen, 1987, Mitchell, 1988) indicate that greater stopping distance is needed to respond to the warning surface when the surface is detected under foot than when the long cane is used. This is due in part to the length of the cane which allows the pedestrian to detect the warning before stepping on it. However, the foot may also be less sensitive to changes in surface texture and other tactile cues due to the lower sensitivity of the foot to stimuli compared to the fingers and palm, and footwear which impairs the sensitivity of the foot to different surfaces (Boff et al, 1986). Additionally, the cane may be an ineffective method for detecting the surface in crowded spaces, where there is insufficent room to maneuver the cane. In any case, due to the greater stopping distance needed to avoid going past the warning surface when detected under foot, detectable warnings need to be reliably detected under foot. The understanding of under foot detection as the limiting factor in determining the discriminability of detectable warnings and the distances needed to safely avoid the edge is a recent development. A study is currently in progress to evaluate currently available warning surfaces to evaluate their efficacy for under foot detection and their effect on mobility for wheelchair users (Bentzen, 1992).

The purpose of the detectable warning is to warn the visually impaired pedestrian about to encounter a platform edge bordering a drop off and/or vehicular crossing to stop. It is analogous to the function served by the warning track on a baseball field. On a baseball field, the warning track serves as a tactile cue, that the player is approaching a wall. In order to adequately serve as a warning device, it must be detected and recognized, the message it conveys understood, and acted upon in time to avoid encountering the hazard. Of these three issues, research evaluating detectable warnings has focused primarily on their detection and recognition. For transit systems, the message content and response to this message is considered a training issue (Washington Metropolitan Area Transit Authority, 1987).

To effectively convey a warning message, the following human factors principles are relevant (Wogalter et al, 1987) to the design of detectable warnings:

Consistency

In order to facilitate unambiguous interpretations, the detectable warning should serve a single, designated function. If a warning surface conveys more than one meaning, the message communicated will be ambiguous and open to interpretation. This may lead to situations in which the surface is detected, but is associated with the incorrect interpretation. The outcome may be an increased likelihood that the visually impaired fail to avoid edge drop-offs. In addition, it is paramount that there be consistency in the design of the warning device. Consistency is important in facilitating expectations in the general population, including the disabled. Consistency in design helps the individual to develop expectations about what constitutes a detectable warning. The ADA guidelines recognize the importance of this concept in the definition of a detectable warning as "a standardized surface feature." This principle also guides the development of traffic control systems in general (Federal

Highway Administration, 1983). The Manual on Uniform Traffic Control Devices recognizes the absolute importance of uniformity as a nationwide objective to achieve effective traffic control results, economy in the manufacture, installation, maintenance and administration of control devices, and as a defense against adverse judgements in tort liability cases. The concept of uniformity extends to:

- uniformity in design, which aids in instant recognition and comprehension; (control device design includes shape, color, size, symbol, wording, lettering, illumination and reflectorization);

- uniformity in meaning, which aids in complying with the device;

- uniformity in application, which promotes observance and avoids excessive or unwarranted use of the control devices;

- uniformity in location, which reduces the possibility of not "seeing" a control device (critical for hazard warning devices!).

Blind travelers also emphasize the importance of consistency of design and layout for navigation both within a transit system and between transit systems (Peck and Bentzen, 1987).

Conspicuity

Warnings should be conspicuous. In a cluttered or noisy environment, a signal needs to be sufficiently different from the background to be detected. The tactile, auditory, and visual cues that specify the warning device should be sufficiently different from tactile, auditory, and visual cues normally found in the environment so that the traveler can easily discriminate the warning signal from other objects in the environment. The more unique the detectable warning is from adjacent surfaces, the more quickly the visually impaired person can recognize it and act to avoid a potential hazard. Much of the research on detectable warnings has centered on identifying a surface that is easily distinguishable from the surrounding surface, which could act as a warning signal. These studies will be discussed in the following section.

3.1 PERCEPTUAL CUES ASSOCIATED WITH DETECTABLE WARNINGS

This section discusses the perceptual cues associated with different sensory modalities considered in the design of warnings. There are three sensory modalities through which detectable warnings communicate information: tactile, auditory, and visual. The three modalities work in parallel to communicate information through different sensory channels. This redundant coding of information improves the chances that the traveler will detect the warning in time to respond. Should the traveler not pick up the cues that he is approaching a platform edge from one modality, it is possible he will pick up this information through one of the other sensory modalities. However, for the visually impaired person, the redundant coding is less effective, since one modality is already unavailable or of limited value. Of the two remaining modalities, auditory and tactile, **tactile cues** are the most important for detecting the warning. Auditory cues are less valuable because the ambient noise produced by vehicular traffic may mask detection of the warning. Therefore, the visually impaired person relies most heavily upon tactile cues for the detection of warning surfaces.

3.1.1 Visual Cues

Since the primary purpose of a detectable warning is to inform *visually impaired* people they are approaching a hazard, research investigating visual cues has been minimal or non-existent. Nevertheless, visual cues are of value to people without visual impairments and those with low vision deficits. The current ADA guidelines require the detectable warning to contrast visually with the surrounding surface. Specifically, the contrast ratio between the warning and the surrounding surface is recommended to be at least 70 percent. While the goal of this requirement is commendable, to provide a warning surface that is easy to discriminate visually from the surrounding surfaces, this requirement may conflict with another stated goal: to provide a standardized warning. The problem lies in the variety of surrounding surfaces. Platform surfaces at rail stations vary from dark red tiles to lighter surfaces like concrete (Templer et al, 1982). To meet the visual contrast requirement, detectable warnings would have to be available in both dark and light versions. However, the use of two warnings that differ in brightness contrast would violate the concept of a standardized warning surface. Further, a warning that is darker than the surrounding surface may be more difficult to detect for low vision people. A dark surface may be more likely to blend in with the area following the edge drop-off and be difficult to detect. Further, it is not known whether commercially available products can meet the 70% visual contrast requirement given the variety of surfaces. It may be better to standardize the light reflectance value of the warning surface making it independent of the approach surface. This would provide a visual cue that is consistent throughout a transit system.

Although the ADA guidelines only specified visual contrast of the detectable warning, it may also be helpful to specify color as well. This would provide a redundant cue that might contribute additional conspicuity to the visually unimpaired. As a population stereotype, yellow is typically associated with cautionary behavior (i.e., traffic signs) and is frequently used as a warning signal. Several commercially available detectable warning surfaces are bright yellow which contrasts with surrounding darker colored surfaces.

3.1.2 Auditory Cues

Auditory cues are produced by comparing the difference in sound, resulting from cane-on-surface or foot contact with the surface, between the warning surface and the surrounding surface. In the only study to systematically examine the relationship between surface detectability and texture, impact noise, and rebound, Templer et al (1982) found impact noise to be the single most important predictor of detectability among the surfaces tested in a laboratory environment. However, all the materials with high "sound" contrast also exhibited resiliency differences from the adjoining material. Of the different surfaces tested, steel was the most detectable followed by plywood. However, the test materials were all compared against a surface of brushed concrete. This study did not establish whether the outcome would differ when compared to different surfaces. The results may also be limited in its applicability due to the use of canes. Auditory stimuli are more difficult to detect through under-foot cues. In addition, due to the amount of ambient noise found at transit platforms and vehicular ways, auditory cues may be masked. For this reason, visually impaired people can not rely on auditory cues to recognize detectable warnings.

3.1.3 Tactile Cues

Early research examining the construction of materials for tactile warnings evaluated a number of different materials (Aiello & Steinfeld,1980; Templer & Wineman,1981; Templer et al, 1982). Among the materials tested were: plastics, concrete, steel, tennis court surfacing, artificial grass, wood, rubber and paving brick. Aiello and Steinfeld (1980) evaluated an abrasive material and a ribbed rubber matting, both applied to a concrete floor. The ribbed rubber matting was detected 100% of the time by visually impaired subjects compared to 83% for the best abrasive surface. Texture and resiliency were among the tactile cues that were most important to subjects in discriminating the difference between the platform surface and the warning surface. Templer and Wineman (1980) tested the detectability of 11 materials by the visually impaired when approached from a broom finish concrete. They found that resilient materials like tennis court surfacing and thermoplastic strips resulted in the highest detection rates. In a follow-on to work performed by Aiello and Steinfeld (1980), Templer et al (1982) systematically varied several sound and tactile parameters: texture (defined as depth, spacing and width of grooves) and resiliency to determine their effects on detectability. As indicated previously, sound was the primary determinant of detectability. Among the textural elements, no one texture resulted in better detectability than another.

The previous studies evaluated materials that were constructed specifically to measure their detectability (finding materials that would maximize discriminability between the warning surface and the platform). More recent research has focused on the evaluation of readily available building materials. In one of the first of these studies (Pavlos and Steinfeld, 1985), a wide range of materials were evaluated against a background surface of concrete and carpeting. Unlike the previous studies, the experimenters controlled for noise in this experiment. The results indicated that resiliency was the best indicator of discriminability. Textural cues (i.e. abrasiveness) were less effective as cues to discriminate the different surfaces.

In considering the development of a tactile warning surface, the visually impaired person relies heavily on the change in texture from the approach surface to the warning surface. However, except for the Pavlos and Steinfeld study (1985), the previous research failed to take into account the effect of the approach surface on discriminability of the warning surface. Of the two approach surfaces tested by Pavlos and Steinfeld (1985), carpeting is not commonly found at transit platforms. In another study, Peck and Bentzen (1987) evaluated several warnings surfaces against a number of commonly used platform surfaces. Their experiment examined not only detectability of the warning surface for the long cane user, but also for under-foot detection as well. Among the materials tested were: a steel plate, tennis court surfacing, a ribbed rubber mat and a corduroy pattern constructed of PVC. Although the corduroy surface is not commercially available, it was selected for evaluation because it was hypothesized that a linear pattern in which the lines were domed shaped in cross-section would be more detectable under foot than a pattern in which the lines were flat-topped. The results of this study found the corduroy pattern to exhibit the best detectability for both under foot detection and detection using the long cane.

Several field studies (McGean, 1991; Peck and Bentzen, 1987; Weule, 1986, Mitchell, 1988), evaluating commercially available materials found a material that is similar to the corduroy material in design and detectability. In a study for the BART system in San Francisco, Peck and Bentzen (1987), (Weule, 1986), field tested the corduroy pattern and the Pathfinder warning tile (manufactured by Guidance Systems, Inc.) using the Peck and Bentzen methodology. The Pathfinder tile was equal to or better than the corduroy pattern in detectability. This finding applied to both cane detection and underfoot detection. Accident data collected following the placement of Pathfinder tiles at the BART system (Weule, 1986), showed a decrease in falls from platforms for both the visually impaired and the general population. In addition, the impact on wheel chair mobility was evaluated and found not to impair mobility. Another field study using the methodology developed by Peck and Bentzen, conducted by the MetroDade transit agency (Mitchell, 1988), concluded that the pathfinder tile was a superior detectable warning compared to a granite surface. Among building materials currently available at the time, this was the only material found to be highly discriminable on the basis of surface texture, alone, when approached from adjoining surfaces. At least 90% of the time, visually impaired subjects detected this surface under a variety of conditions. The Pathfinder tile did not rely on differences in resiliency or sound-on-cane contact to enhance detectability (Bentzen, 1992).

As a result of this research, showing the Pathfinder tile to be a highly detectable surface based upon surface texture cues, this design was adopted as the basis for the ADA guidelines detectable warning specification. The specification places primary emphasis on the tactile cues provided by the surface texture and secondary emphasis on the tactile cues associated with material resiliency. This reflects the empirical evidence supporting surface texture as the primary cue for tactile perception of warning surfaces by the visually impaired, followed by resiliency.

The Access board still believes research supports resiliency change as a primary cue. However, the specification in ADAAG removed resiliency from outdoor installations because of uncertainty about available materials ultraviolet stability and maintenance under severe climatic changes.

Although this design has been shown to be effective under a variety of real-world conditions, it is not known whether the actual surface texture adopted is the optimal solution for maximizing detectability and minimizing mobility hazards for the ambulatory and the ambulatory-impaired populations. The optimal spacing between the domes as well as the optimal dimensions of the domes, themselves, have not been identified with any empirical research. Bentzen (1992) is currently conducting an experiment that will attempt to address this problem. The experiment will assess the maximum and minimum spacing of the domes needed for under-foot detection by evaluating several surfaces marketed as detectable warning surfaces. If a better surface is identified, it may prove beneficial to change the ADA guidelines to accommodate the new design parameters.

4. APPLICATION OF EQUIVALENT FACILITATION TO DETECTABLE WARNINGS

4.1 CONFLICT BETWEEN A STANDARDIZED WARNING AND EQUIVALENT DESIGN ALTERNATIVES

For local transit agencies unable to comply with the ADA guidelines specification for detectable warnings, there is an alternative mechanism by which the accessibility requirements may be met. The ADA guidelines allow for *Equivalent Facilitation* in which "Departures from particular technical and scoping requirements of this guideline by the use of other designs and technologies are permitted where the alternative designs and technologies used will provide substantially equivalent or greater access to and usability of the facility" (Federal Register, Sept 6, 1991). For detectable warnings, this provision enables transit agencies to consider alternative designs as long as these designs provide equivalent or greater access to and usability of this facility than provided by the designs using the current specification.

As a practical matter, the alternative designs based upon the equivalent facilitation concept present several problems. The ADA guidelines define a detectable warning as a standardized surface feature. However, equivalent facilitation may result in a variety of designs that violate the principle of a standardized surface. Currently, products from several manufacturers have been submitted to the Federal Transit Administration (FTA) for review and acceptance in meeting the requirements of the detectable warning specification. Some of these products meet the specification and some do not. Among products that violate the detectable warning specifications, transit agencies may use those products if they are determined to be equivalent or better in design. However, the criteria for determining whether a design is functionally equivalent or better has not been established, nor has a method to compare different designs.

The difficulty with allowing products to be approved, based upon an equivalent design is that it may result in surfaces that are perceived by the visually impaired to be different from each other. This violates the need for a consistent surface that is implicit in a standardized surface. As mentioned earlier, consistency is important in facilitating expectations in the general population, including the disabled. Consistency in design helps the individual to develop expectations about what constitutes a detectable warning. The more unique the detectable warning is from adjacent surfaces, the more quickly the visually impaired person can recognize it and act to avoid a potential hazard. However, the availability of more than one warning surface places additional information processing demands upon the visually impaired to determine whether a surface represents a detectable warning. Encountering multiple surfaces that are intended to serve as detectable warnings within or between transit systems, or at street intersections in different localities, increases the opportunity for the visually impaired to fail to recognize a detectable warning where one exists and to mistake a surface for a detectable warning where one does not exist. In addition, allowing several products that differ in the nature of their tactile, auditory, and visual cues increases the burden on the visually impaired individual to know what surface represents a detectable warning. The result may be increased need for training in discriminating the warning surface from the approach surface or greater uncertainty in determining the location of platform edges and vehicular crossings. This outcome runs counter to the goal of making the environment more accessible to the disabled. **The application of equivalent facilitation to detectable warnings needs to be carefully implemented to avoid the proliferation of non-standardized warning surfaces.**

4.2 A CONSTRAINED APPROACH TO EQUIVALENT FACILITATION

For equivalent facilitation to meet the goals of the ADA guidelines, when applied to detectable warnings, several requirements are necessary. First, the concept of standardization must be maintained. This requirement applies whether the product meets the specification or not. Second, the specification for detectable warnings must clearly indicate the physical parameters to be considered in compliance. For a product to diverge from the established specification, it should be clear what the established design parameters are. Third, to be considered an equivalent or better design, there must be criteria for deciding when a product is considered equivalent and an objective, systematic method for evaluating whether those criteria have been met.

To meet the standardization test, the products should be perceived as the same by the target populations this warning surface is designed to serve. In addition, the product should exhibit detection rates equal to or better than products meeting the ADA specification. To be considered equivalent and maintain a consistent environment, a visually impaired traveler should not be able to discriminate the difference between the two surfaces. The primary cues by which detectable warnings are perceived are the tactile cues provided by surface texture and resiliency. Surface texture, in particular, is critical to the under-foot detection and recognition of a surface as a detectable warning. This is reflected in the proposed ADA specification which dictates: the shape of the dome structure, the size of the dome, and the geometric pattern and spacing between the domes that comprise the surface texture. To maximize accessibility, all products used as detectable warnings should match these design parameters as specified.

We recommend that a product may diverge from these design criteria to the extent that a significant proportion (e.g. 95%) of the visually impaired population fails to discriminate the difference between the proposed warning surface and a surface that meets the specification. In addition, the proposed warning surface must demonstrate detection rates equal to or better than the warning surface that meets the ADA specification. The methodology for testing the proposed warning surface is discussed in a subsequent section.

The current specification requires that the warning surface differ from the approach surface in resiliency or sound-on-cane contact. Given that auditory cues are often masked by ambient noise, resiliency is the more critical cue to the visually impaired. We recommend that the specification require that the warning surface differ only in resiliency and not specify a sound-on-cane contact requirement. It is possible that the resiliency and sound-on-cane contact communicate comparable information about surfaces. If so, specifying resiliency would be sufficient to address a sound-on-cane requirement. The specification, however, does not indicate what the difference in resiliency must be. The specification should provide a criterion for determining the difference in resiliency between surfaces that is acceptable and indicate the method for measuring the difference in resiliency. This subject is discussed in greater detail in Section 5.1.

Visual cues are less important in deciding whether an alternative design is appropriate, since the visually impaired can not rely on this information. Nevertheless, the visual information may aid the visually unimpaired in avoiding edge drop-offs and should not be ignored in establishing whether a product is equivalent to the specification. We recommend that a product may diverge from the ADA specification to the extent that a significant proportion (e.g. 95%) of the visually non-impaired and low vision population fail to discriminate the difference between the proposed warning surface and a surface that meets the specification for light reflectivity.

Finally, the response to this product (as measured by stopping distance) should also be equal to or better than the performance found for products that meet the specification. For the general population, including persons with visual or ambulatory impairments, the product should not impede mobility or pose a tripping hazard.

4.3 PROCEDURES FOR ESTABLISHING EQUIVALENT FACILITATION

To establish whether a detectable warning product provides equivalent or better usability than a product that is compliant with the specification, the manufacturer must demonstrate that the product is equivalent in performance to products that meet the specification. This requires tests to measure human performance associated with the product and criteria against which the product's performance will be evaluated. For each aspect of human performance that must be considered, the following section describes proposed procedures for measuring product performance and the criteria against which the product should be evaluated. The criterion levels are recommended levels that reflect a particular margin of safety. If a different level of safety is desired, then the criterion levels for making a pass/fail decision should be adjusted to reflect the desired margin of safety.

4.3.1 Test of Standardization (Consistency)

To act as a standardized warning surface, a surface must fall within a range of physical parameters for surface texture, resilience, and light reflectance value. To determine how much variation is allowable in the dimensions of the domes, pattern and spacing between the domes as well as the resilience and light reflectance value of the surface requires a test procedure than can assess whether the proposed product is perceived as different from a product that meets the specification. Two psychophysical methods, the method of limits and the method of adjustments, can be used to make this determination (Boff et al, 1986). The purpose of these tests is to determine the point at which the difference between the detectable warning surfaces can be discriminated by the observer (i.e., the product proposed as equivalent in usability and a product determined to be compliant with the specification). In the method of limits, the experimenter varies the value of the dimension that differs from the standard in small ascending or descending steps. At each step, the observer reports whether the stimulus appears smaller, equal to, or greater than the standard. The outcome is a value (e.g., light reflectance value) that reflects the smallest difference between the proposed product and the standard that the observer can detect. This is called the Just Noticeable Difference (JND). The method of adjustment is similar to the method of limits, except that *the observer* adjusts the value of the dimension(s) in question until it is equal to the standard.

Since people vary in their sensitivity, it will be necessary to test a representative sample of the visually impaired population and test sufficient numbers to obtain a measure that is representative of the population. The test will produce a range of JND's. A criterion representing the proportion of the population that can not discriminate the difference between the variable value and the standard is used to select the JND within which a proposed product value must fall. It is recommended that the criterion level be set high (e.g., 95%) so that the likelihood for confusion between surfaces that meet the specification and those that don't is small. For resiliency and light reflectance value, this procedure will only need to be performed once. Once the criterion is set, the JND value will determine whether a reflectance value or resiliency passes the test for standardization. For surface texture, the multi-dimensional aspects of the physical parameters may require this procedure to be performed each time different aspects of the surface texture are varied.

4.3.2 Test of Minimum Performance Standards

To evaluate the performance of the product to be considered equivalent to products that meet the ADA guidelines specification requires several tests to evaluate the performance of the product with respect to surface texture, resiliency, and light reflectance. The most important test evaluates performance of the visually impaired in detecting the proposed product based upon cues associated with surface texture. It is recommended that the method for measuring detectability developed by Peck and Bentzen (1987) serve as the procedure to make this determination. The criteria for this test should be the detection rate and stopping distance in inches following detection of the warning surface. We recommend that the criterion levels be set at the performance level for surfaces matching the specification.

For resiliency, the test requires measuring the coefficient of restitution of an untextured sample of the detectable warning material (Sears and Zemansky, 1963). Standard test procedures exist to calculate this coefficient. To establish an appropriate criterion threshold, an experiment using visually impaired users would be undertaken to establish a psychometric scale indicating the relationship between the just noticeable difference (JND) between materials and physical measures of resiliency as measured by the coefficient of restitution. The criterion would be set at the coefficient of restitution for materials not considered to be resilient plus the JND (e_ϕ + JND). This test is a minimum threshold test and eliminates the need to consider measurement of the resiliency of the adjoining surface.

For light reflectance, the test requires measuring the light reflectance value of the proposed surface. If the light reflectance value is equal or greater than the level set by the criterion, then the product meets the requirement for light reflectance value. The criterion should be the light reflectance value required of products that are compliant with the detectable warning specification. Again, this test is a minimum threshold test and eliminates the need to consider measurement of the light reflectance value of the adjoining surface.

5. IDENTIFICATION AND RESOLUTION OF AMBIGUITIES IN THE ADA SPECIFICATION

The ADA specification language is imprecise giving rise to multiple interpretations. The result is that a proliferation of designs is possible, each claiming to be in compliance with the specification, yet each markedly different one from the other.

We have identified the following ambiguities or issues that require resolution, via adoption of a consistent and precise interpretation, to meet the goal of a standardized detectable warning surface:

A. What are "raised truncated domes"?

B. What are the controlling dimensional tolerances that uniquely fix its shape?

C. How should center-to-center spacing be measured?

D. What are the controlling dimensional tolerances that uniquely fix the geometric pattern of raised truncated "domes"?

E. What is meant by resiliency of material or sound-on-cane contact?

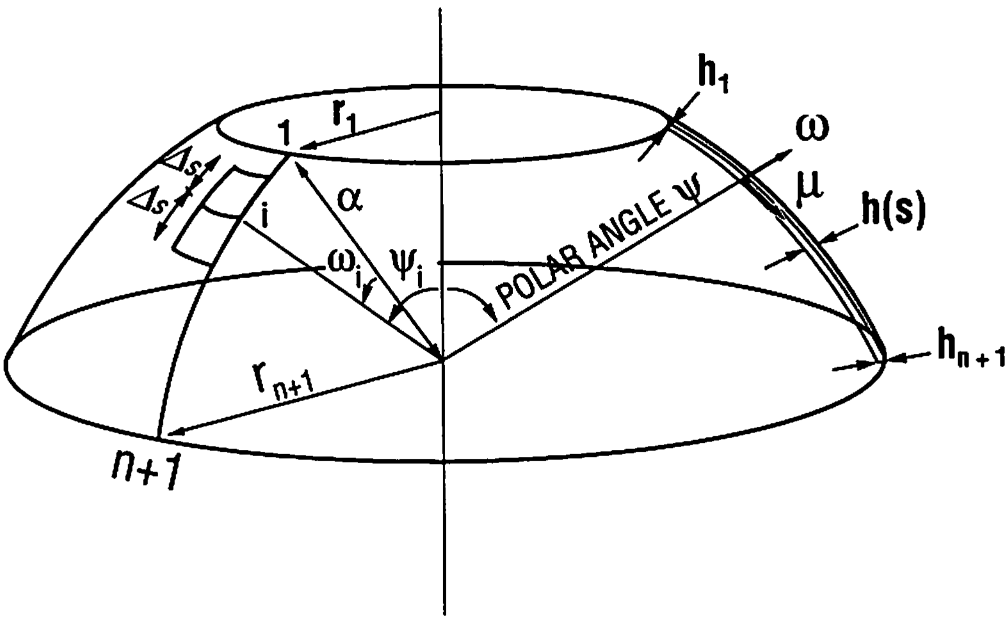
F. Is visual contrast (light-on-dark or dark-on-light) the most appropriate visual cue requirement for detectable warnings?

5.1 RECOMMENDED RESOLUTIONS TO ADA SPECIFICATION AMBIGUITIES

A. Raised Truncated Domes

The term "dome" is not a precise term in either architecture or structures (Mainstone, 1975; Schaefer, 1966; Gayland and Gayland, 1968; Cowan, 1976; Parsons, 1988). Although generally considered to be spherical in shape (i.e., the solid generated by rotating a circular curve about a vertical axis of symmetry which bisects the curve) (see Figures 5-1, 5-2, 5-3, and 5-4), the term has also been used to refer to solids of ellipsoidal, parabolic or even conic shape (see Figure 5-5).

In the context of detectable warnings, however, a review of the literature and the tests of materials of various designs reasonably indicates that "dome-like" refers to discrete structures of **spherical shape**. Discussions with Bentzen (Bentzen, May 8, 1992) and with the Access Board (Cannon, May 15, 1992) confirm that "substantially less than a hemisphere" was the intent of the specification. Bentzen also indicated that a hemisphere or one approximating a hemisphere would have its side curvature too vertical, and its truncated surface too large to be readily detectable under foot. In related work by the Transport and Road Research



The Spherical Shell And Some Notations

FIGURE 5-1. EXAMPLE 1 OF A DOME-LIKE STRUCTURE OF SPHERICAL SHAPE

(SOURCE: TUOMINEN, 1988)

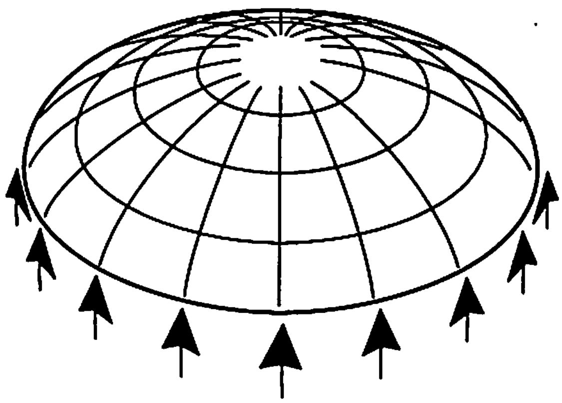
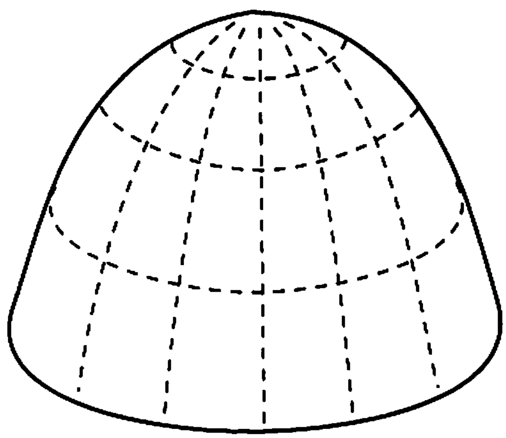


FIGURE 5-2. EXAMPLE 2 OF A DOME-LIKE STRUCTURE OF SPHERICAL SHAPE

(SOURCE: MAINSTONE, 1975)



Dome The Dome Has Double Curvature, And Spreading Is Prevented By A Tie Which Is Integral With The Dome. It Cannot Be Formed From A Flat Sheet, Or Generated By Straight Lines. This Complicates The Formwork For Casting A Dome In Concrete.

FIGURE 5-3. EXAMPLE 3 OF A DOME-LIKE STRUCTURE OF SPHERICAL SHAPE

(SOURCE: COWAN, 1976)

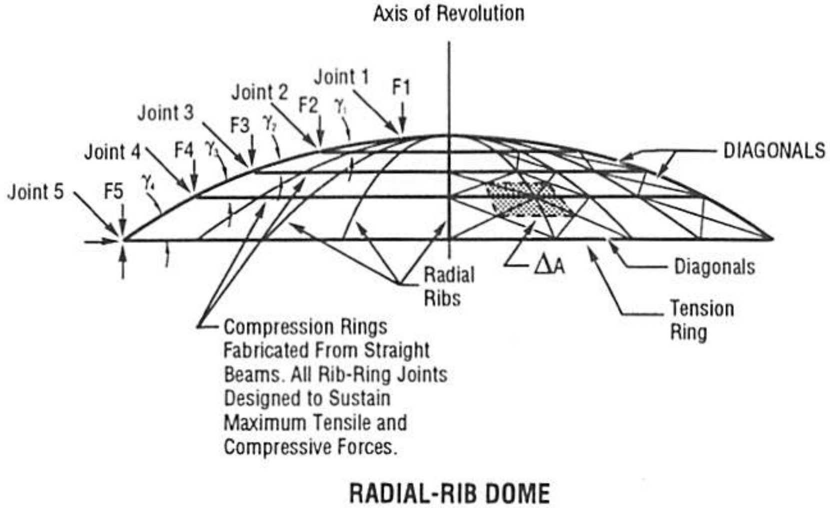
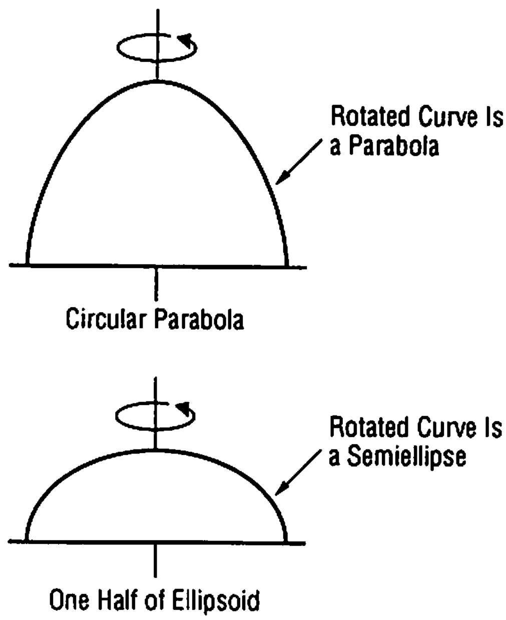


FIGURE 5-4. EXAMPLE 4 OF A DOME-LIKE STRUCTURE OF SPHERICAL SHAPE

(SOURCE: GAYLAND AND GAYLAND, 1968)



DOMICAL STRUCTURES: CURVED CIRCULAR BASE

FIGURE 5-5. EXAMPLES OF DOME-LIKE STRUCTURES NOT OF SPHERICAL SHAPE

(SOURCE: SCHAFER, 1966)

Laboratory (TRRL, 1983) on textured walkways that could be used to help blind pedestrians locate crossings, the best pattern was determined to be one consisting of rounded spherical shaped domes (like blisters) of 25 mm bottom diameter, 6 mm high, with their centers 67 mm apart on straight lines along and across the footway.

It may be the case that a spherical-shaped dome structure, which is "substantially less than a hemisphere," provides the best side curvature that may facilitate tactile sensing via a deflection and slippage mechanism for those visually impaired persons who use a sweep technique for cane-on-surface sensing.

B. Controlling Dimensional Tolerances for Raised Truncated Domes

The ADA specification refers to a "diameter of nominal 0.9 in. (23 mm)," and a "height of nominal 0.2 in. (5 mm)." Given that the term "dome-like" is interpreted to mean spherical in shape, and the fact that the specification uses the term "diameter" which, to the best of our knowledge, is only used in the context of a geometrical loci of points equidistant from a given reference point (aka, a "circle"), we interpret the structure shape to be circular in plan (see Figure 5-6) for the top and bottom surface of the dome structure. The term "truncated" means to "cut" (American College Dictionary, 1970). The dictionary defines "truncated" in the context of geometric solids to mean having the apex, vertex, or end cut off by a plane. We interpret this to mean that the spherical solid has been cut to produce a bottom and top surface which is circular in plan. We interpret the "diameter of nominal 0.9 in. (23 mm)" to be the diameter of the bottom circular surface (see Figure 5-6). Because the dome structure is substantially less than a hemisphere, examination of a sectional schematic drawing (see Figure 5-7) indicates that the "diameter of 0.9 in. (23 mm)" corresponds to a chord length "c" of a **larger diameter sphere.** Thus, **the dome structure has been "truncated" at both top and bottom from a larger spherical solid!**

We interpret the "height of nominal 0.2 in. (5 mm)" to be the height to the truncated top circular surface of the dome structure. This corresponds to the measurement of "y" in the sectional schematic drawing (see Figure 5-7). The quantity "b" represents the height of the dome structure to its imaginary apex had the dome structure not been truncated at the top. It is highly unlikely that the "height of nominal 0.2 in. (5 mm)" refers to this quantity for two reasons: it would be difficult to measure for specification compliance; and, because the truncated top surface of the dome structure is the actual contact area for detection under foot, its height (i.e., the quantity "y") in relation to the adjoining surface is the critical vertical design parameter affecting surface irregularity or texture and tactile contrast (not the measurement of "b").

To uniquely fix the shape of the raised truncated dome structure, one additional dimensional tolerance needs specification: the diameter of the top truncated circular surface. This dimensional tolerance is unspecified in 4.29, but is illustrated in the attached schematic to the proposed 1992 ANSI standard.

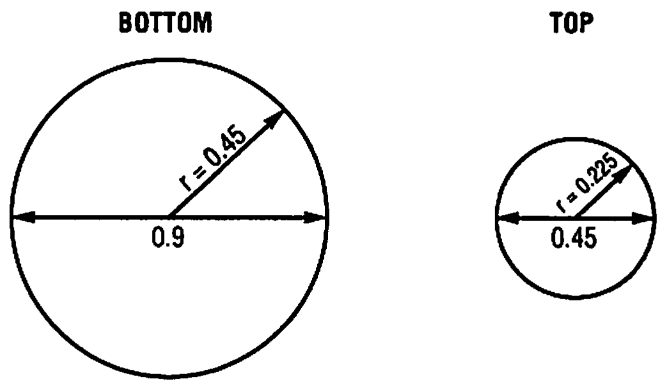
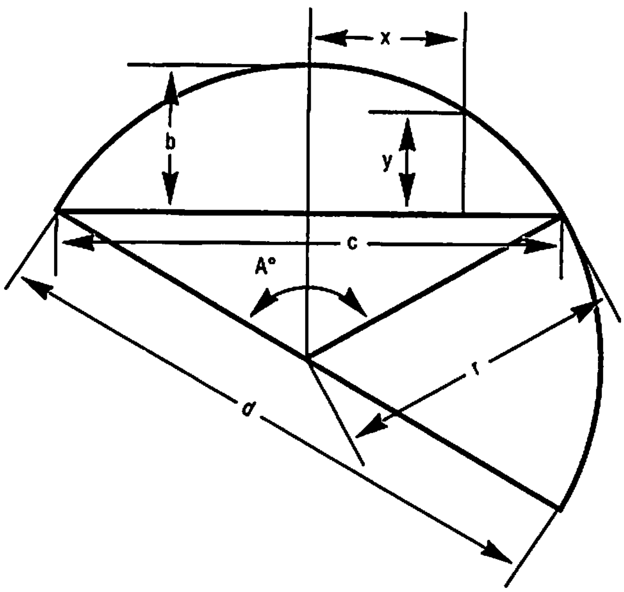


FIGURE 5-6. SCHEMATIC IN PLAN FORM: BOTTOM AND TOP SURFACE OF RAISED TRUNCATED DOME

(American Institute of Steel Construction)



Circumference		$= 6.28318\,r = 3.14159\,d$
Diameter		$= 0.31831$ circumference
Area		$= 3.14159\,r^2$
Arc	a	$= \frac{\pi r A^\circ}{180^\circ} = 0.017453\,r A^\circ$
Angle	A°	$= \frac{180^\circ a}{\pi r} = 57.29578\,\frac{a}{r}$
Radius	r	$= \frac{4b^2 + c^2}{8b}$
Chord	c	$= 2\sqrt{2br - b^2} = 2r \sin\frac{A}{2}$
Rise	b	$= r - \frac{1}{2}\sqrt{4r^2 - c^2} = \frac{c}{2}\tan\frac{A}{4}$
		$= 2r\sin^2\frac{A}{4} = r + y - \sqrt{r^2 - x^2}$
	y	$= b - r + \sqrt{r^2 - x^2}$
	x	$= \sqrt{r^2 - (r + y - b)^2}$

Diameter of circle of equal periphery as square	= 1.27324 side of square
Side of square of equal periphery as circle	= 0.78540 diameter of circle
Diameter of circle circumscribed about square	= 1.41421 side of square
Side of square inscribed in circle	= 0.70711 diameter of circle

FIGURE 5-7. SCHEMATIC SECTIONAL DRAWING FOR A SPHERICAL SOLID (DOME) STRUCTURE

(SOURCE: FOSTER, 1965)

Taking the 4.29 specification tolerances for "c" = 0.9 and "y" = 0.2, we have calculated the diameter of the top truncated surface (d = 2x) for a range of interpretations for the dome-like structure being "substantially less than a hemisphere." The results are illustrated in Table 5-1. Column 2 corresponds to a calculated diameter of the top truncated surface which closely approximates the proposed 1992 ANSI standard (d = 2x = 0.449 versus 0.45 for the proposed 1992 ANSI standard). It may be that this relatively small contact area increases the effectiveness of tactile sensing in that the reactive pressure exerted by the dome structure on the foot is greater the smaller this contact area is. The corduroy texture tested by Peck and Bentzen (1987) and the domes tested by TRRL (1983) actually had no flat truncated surface on top (i.e., d = 2x = 0).

TABLE 5-1. CALCULATION OF TRUNCATED DIAMETER OF TOP SURFACE

Rise (b)	0.2	**0.25**	0.30	0.35	0.40	0.45
Radius (r)	0.6063	**0.530**	0.4875	0.4643	0.4531	0.4500
Volume of spherical segment (V_s)	0.0680	**0.0880**	0.1096	0.1338	0.1607	0.1908
Volume of hemisphere($V_{½}$)	0.4668	**0.3118**	0.2427	0.2097	0.1948	0.1909
Ratio of volumes ($V_s/V_{½}$)	0.1457	**0.2822**	0.4516	0.6381	0.8249	1.000
x	0.0000	**0.2247**	0.2957	0.3417	0.3758	0.4031
Truncated diameter (d = 2x)	0.0000	**0.4494**	0.5914	0.6834	0.7516	0.8062

Notes: Calculation of truncated diameter assumes the following dimensional tolerances as found in ADA specification 4.29: y = 0.2; c = 0.9.

Equations:

$$x=\sqrt{r^2-(r+y-b)^2}$$

$$r=\frac{4b^2+c^2}{8b}$$

$$V_s = \frac{1}{3}\prod b^2(3r-b)$$

$$V_{½} = ⅔\prod r^3$$

Because of the desirability of bringing the 4.29 specification into agreement with the proposed 1992 ANSI standard, we interpret "substantially less than a hemisphere" to mean a truncated spherical solid with implied dimensional tolerances of "b" = 0.25, "r" = 0.530, "c" = 0.9, "y" = 0.2, "d" = 2x = 0.45, and the ratio of the volume of the spherical segment (see Figure 5-8) (including the volume of the top truncated portion of the sphere) to the volume of the hemisphere (with radius "r" = 0.530), $V_s/V_{½}$, of 0.2822. Figure 5-9 illustrates a section drawing of our interpretation of a "raised truncated dome."

C. Center-to-Center Spacing Measurement

Discussions with the Access Board (Cannon, May 15, 1992) indicated that "center-to-center spacing" is a function of the assumed geometric pattern formed by the raised truncated domes in situ. Since the intent of the geometric pattern is that the "raised truncated domes" are staggered (within the required detectable warning width) between adjoining rows and columns parallel to and perpendicular to the treated edge respectively, center-to-center spacing is interpreted to mean measurement of the spacing between successive domes (measured from the center of the top truncated surface to the center of the top truncated surface) that are co-linear on axes parallel to and perpendicular to the treated edge. Both spacings (i.e., axes parallel to and perpendicular to the treated edge) must hold concurrently (see Figure 5-10).

(Note: If the domes are in a regular, rectilinear pattern as manufactured (see Figure 5-11), but are installed in a herringbone or diagonal fashion so that the domes appear staggered in situ, center-to-center spacing when measured along the axes parallel to and perpendicular to the treated edge corresponds to a measurement on the product sample taken diagonally between successive domes in adjoining rows and columns (see Figure 5-11).

D. Controlling Dimensional Tolerances to Uniquely Fix the Geometric Pattern of Raised Truncated Domes

As mentioned above, discussions with the Access Board (Cannon, May 15, 1992) indicated that the intent of the specification is to require that the raised truncated domes form a staggered, regular geometric pattern in situ (see Figure 5-10). The theoretical rationale for this pattern is that this geometric pattern increases the density of raised truncated domes under contact and therefore facilitates detection under foot which is the critical design requirement. Test data from BART and Miami also indicate that this geometric pattern works. A staggering of raised truncated domes also makes it more difficult for wheelchairs

FINDING SURFACES AND VOLUMES OF SOLIDS
(S = LATERAL OR CONVEX SURFACE; V = VOLUME)

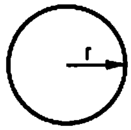
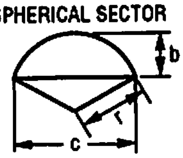
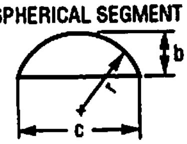
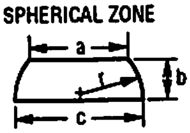
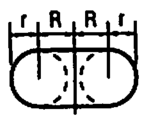
SHAPE	FORMULAS
SPHERE 	$S = 4\pi r^2 = \pi d^2 = 3.14159265\, d^2$ $V = 4/3\, \pi r^3 = 1/6 \pi d^3 = 0.52359878\, d^3$
SPHERICAL SECTOR 	$S = 1/2 \pi r(4b+c)$ $V = 2/3\, \pi r^2 b$
SPHERICAL SEGMENT 	$S = 2\pi rb = 1/4\pi\,(4b^2 + c^2)$ $V = 1/3\, \pi b^2 (3r - b) = 1/24 \pi b\,(3c^2 + 4b^2)$
SPHERICAL ZONE 	$S = 2\pi rb$ $V = 1/24\, \pi b\,(3a^2 + 3c^2 + 4b^2)$
CIRCULAR RING 	$S = 4\pi^2 Rr$ $V = 2\pi^2 Rr^2$

FIGURE 5-8. VOLUMES OF SOLIDS, INCLUDING A SPHERICAL SEGMENT

(SOURCE: FOSTER, 1965)

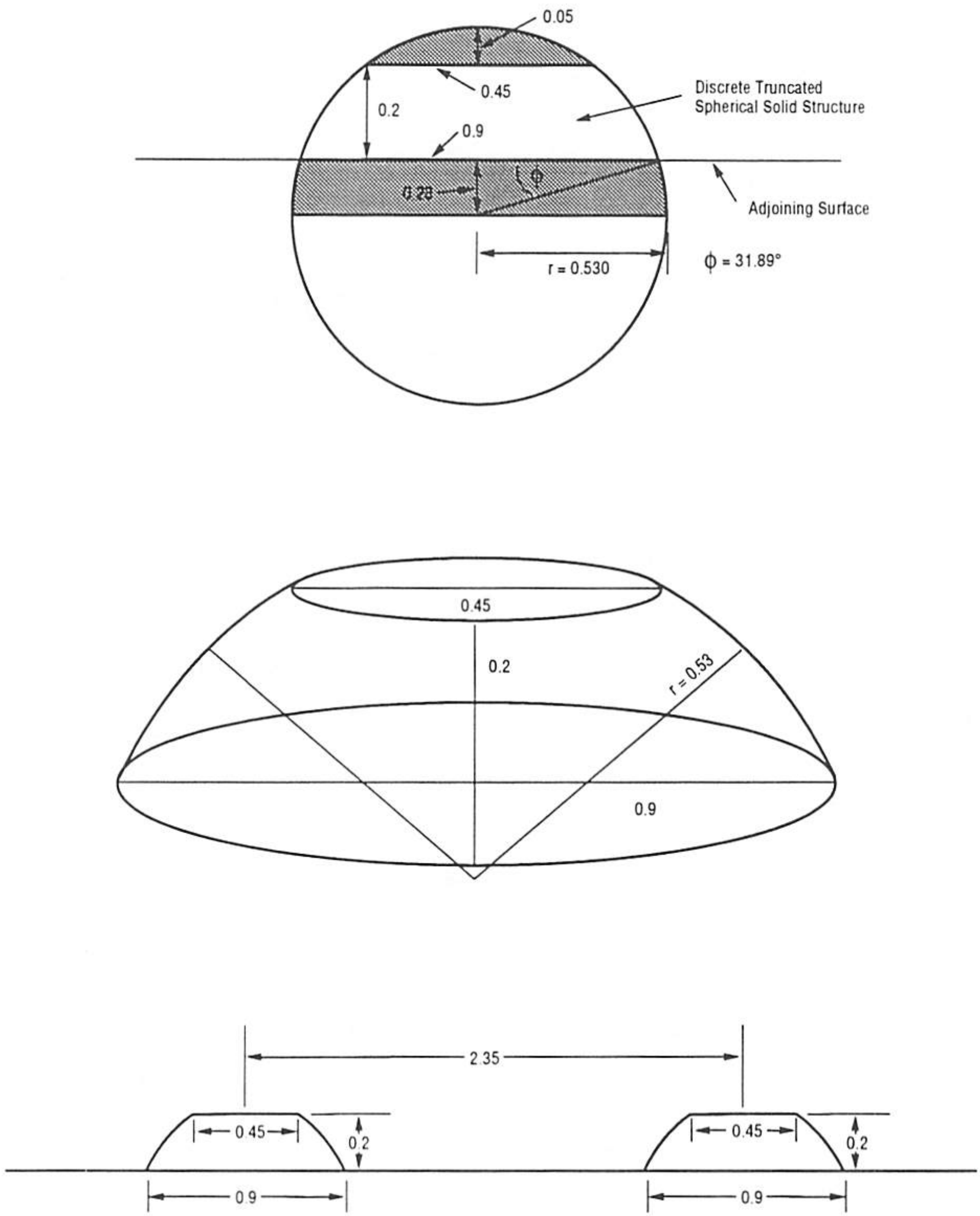
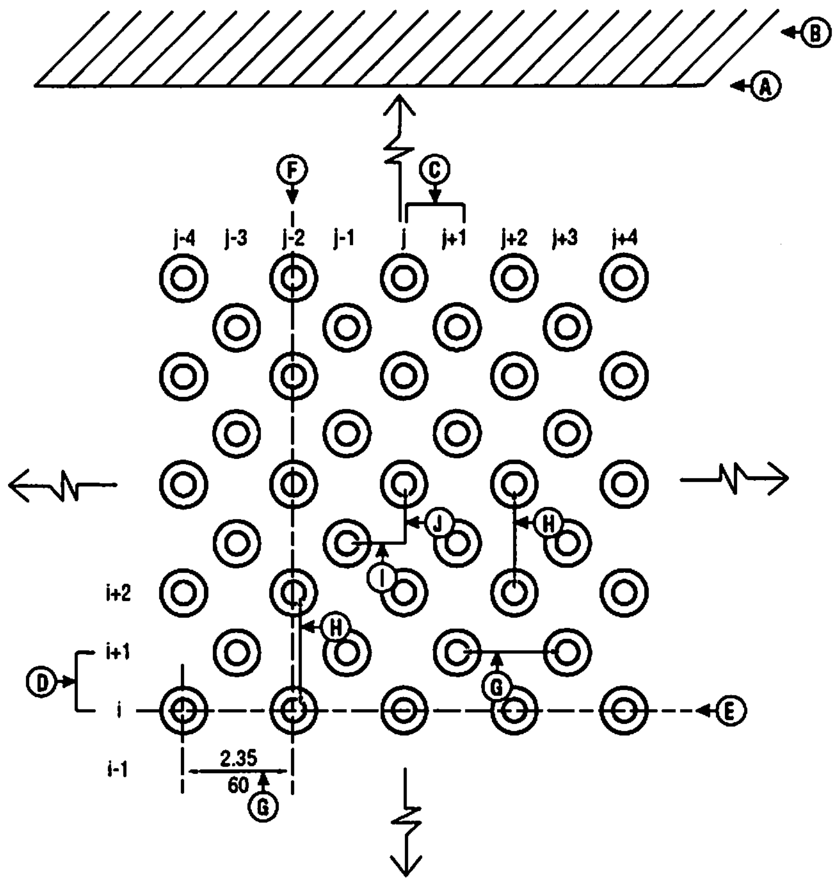


FIGURE 5-9. SCHEMATIC DRAWING FOR A RAISED TRUNCATED DOME



A. Treated edge

B. Hazardous area

C. Adjoining columns perpendicular to the treated edge

D. Adjoining rows parallel to the treated edge

E. Axis parallel to the treated edge

F. Axis perpendicular to the treated edge

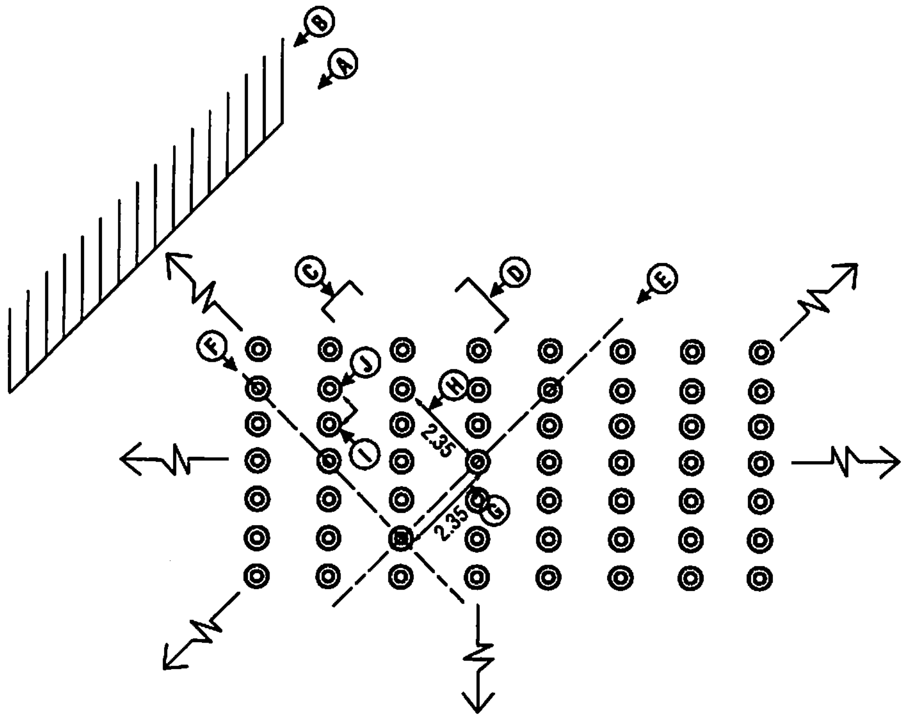
G. Center-to-center spacing between successive domes on axis parallel to the treated edge

H. Center-to-center spacing between successive domes on an axis perpendicular to the treated edge

I. Stagger offset spacing between successive domes on adjoining rows

J. Stagger offset spacing between successive domes on adjoining columns

FIGURE 5-10. GEOMETRIC STAGGER PATTERN FOR A DETECTABLE WARNING SURFACE AND OTHER TERMS OF REFERENCE



A. Treated edge

B. Hazardous area

C. Adjoining columns perpendicular to the treated edge

D. Adjoining rows parallel to the treated edge

E. Axis parallel to the treated edge

F. Axis perpendicular to the treated edge

G. Center-to-center spacing between successive domes on axis parallel to the treated edge

H. Center-to-center spacing between successive domes on an axis perpendicular to the treated edge

I. Stagger offset spacing between successive domes on adjoining rows

J. Stagger offset spacing between successive domes on adjoining columns

FIGURE 5-11. GEOMETRIC STAGGER PATTERN FOR A DETECTABLE WARNING SURFACE (IN SITU) USING A RECTILINEAR MANUFACTURED PRODUCT to track within the grooves (particularly when approaching the warning along an angle of approach parallel to or perpendicular to the treated edge). Tracking within the "groove" could impair maneuverability. The density, stagger of the raised truncated domes, and the flat truncated top surface probably facilitate movement of mobility aids on top of the domes (the tests for mobility of other ambulatory-impaired persons on detectable warning surfaces of this texture, shape and geometric pattern have been limited to date).

To uniquely fix the geometric pattern of raised truncated domes in accordance with the intended pattern, the specification needs to set an additional dimensional tolerance: a stagger "offset" spacing. Given two arbitrary adjoining rows (parallel to the treated edge) within the required width of the detectable warning surface, if the raised truncated domes were slided so that the raised truncated domes were co-linear on a single axis or row (parallel to the treated edge), the center-to-center spacing measured at the tops of the truncated surfaces would be 1.175 in. (30 mm). Given two arbitrary adjoining columns (perpendicular to the treated edge) within the required length of the detectable warning surface, if the raised truncated domes were slided so that the raised truncated domes were co-linear on a single axis or column (perpendicular to the treated edge), the center-to-center spacing measured at the tops of the truncated surfaces would be 1.175 in. (30 mm). In effect, the stagger "offset" spacing is the projected horizontal and vertical distance (i.e., spacing) between successive (i.e., closest-neighbor) domes in adjoining rows and columns, respectively (see Figures 5-12 and 5-13).

To provide a uniform, regular stagger pattern, the horizontal and vertical stagger "offset" spacing (using a frame of reference relative to the treated edge) are equal (set to 1.175 in. (30 mm) and are set to one half the center-to-center spacing [2.35 in. (60 mm]). This means that the centers of the top truncated surfaces for raised truncated domes that are co-linear are spaced a nominal 2.35 in. (60 mm) apart on axes parallel to and perpendicular to the treated edge, and are spaced a nominal 1.66 in. (41.5 mm) apart($\sqrt{(1.175^2+1.175^2)}$) on axes which make a 45 and 135 degree angle of approach to the treated edge (Note: all axes are taken relative to the treated edge; degrees are measured in a clockwise direction relative to the treated edge).

E. Resiliency of Material and Sound-On-Cane Contact

Test results from research sponsored by the Access Board (Pavlos and Steinfeld, 1985) indicated that both resiliency and sound-on-cane contact are important discriminatory cues for the visually impaired.

Concern about outdoor applications of detectable warnings (for example, shearing off of the raised truncated domes as a result of snow removal operations if the material were insufficiently rigid, i.e., if the material were too resilient or elastic) led the Access Board to restrict a requirement for resiliency or sound-on-cane contact to indoor applications only.

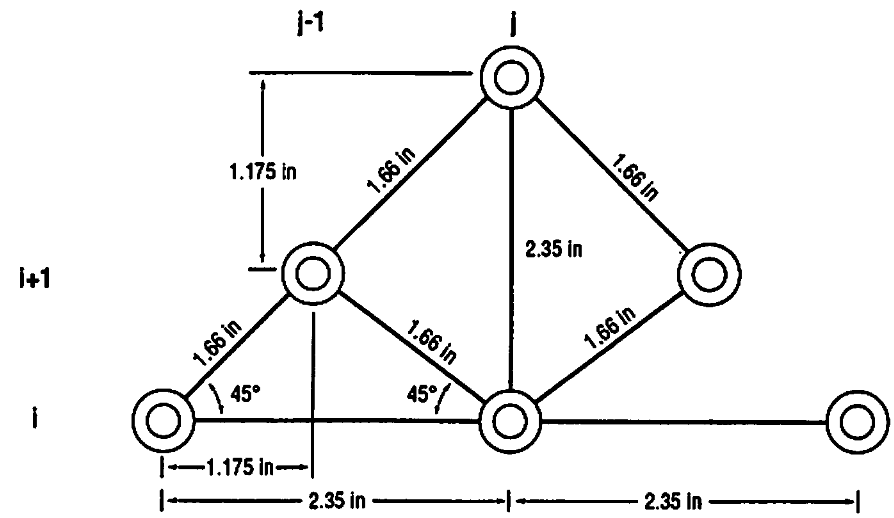
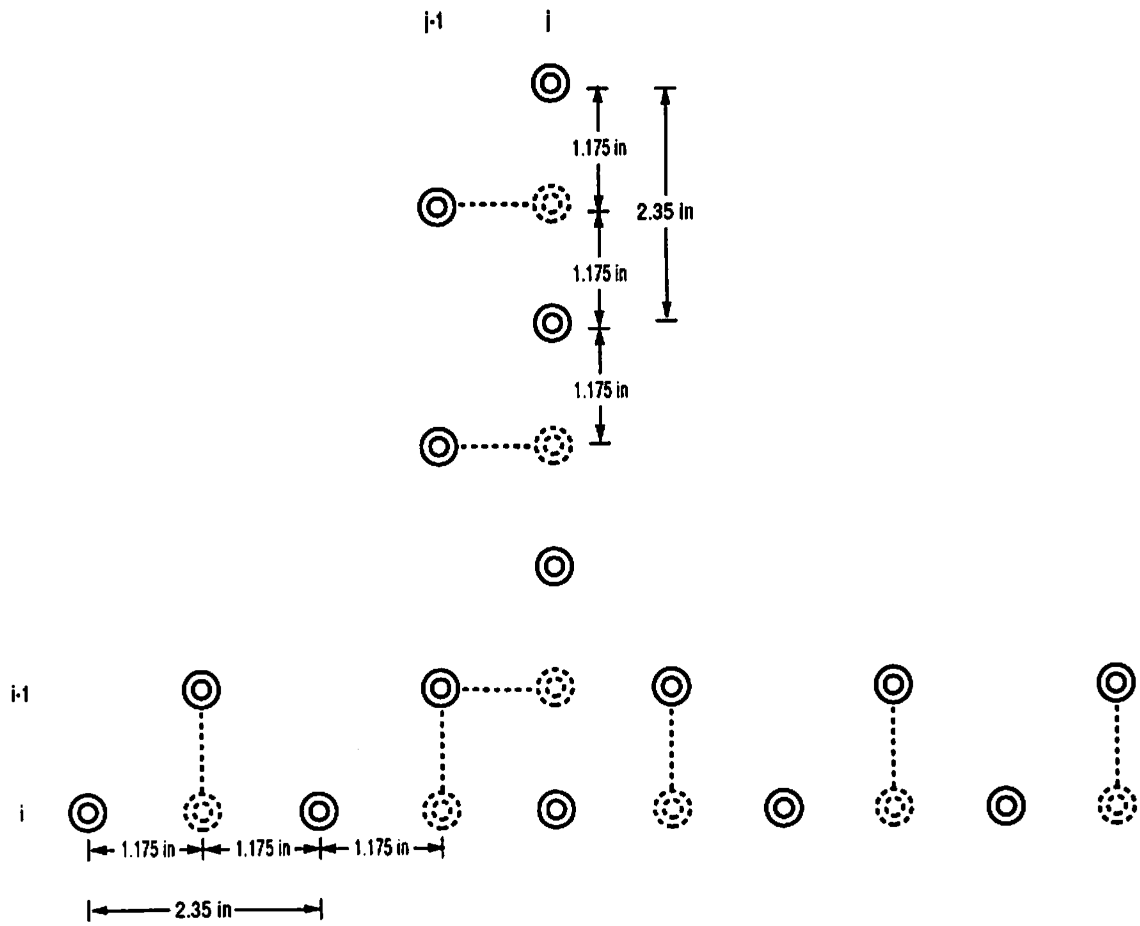


FIGURE 5-12. ILLUSTRATION OF A STAGGER PATTERN AND A STAGGER OFFSET DIMENSION



Sliding Of Any Two Arbitrary Rows Or Columns To Produce A Uniform Spacing Of 1.175 In. Between "Domes" Illustrating The Horizontal And Vertical Stagger "Offset" Spacing

FIGURE 5-13. ILLUSTRATION OF THE HORIZONTAL AND VERTICAL STAGGER OFFSET SPACING

The Access Board chose not to specify tests and quantitative criteria employing measurable limits for assessing resiliency or sound-on-cane contact. Earlier research by Temple, Wineman and Zimring (1982) employed test instrumentation and a standardized procedure to measure impact noise (an A-weighted sound pressure level, in db) and rebound height based on a simulated long cane tapping technique (calibrated from a small sample of blind users).

It is known, from the adaptation of resilient elastomeric materials for shock and vibration isolators (Harris, 1979), that sound impact and transmission are both significantly affected by the change in material resiliency between two surfaces. Given that auditory cues are often masked in any potential application for detectable warnings (i.e., whether in a transit station environment or in an external street environment), and that sound-on-cane contact, to the extent it provides additional information, would simply corroborate a detectable change in surface resiliency, we recommend that a requirement for sound-on-cane contact be dropped in favor of a single requirement for detectable warnings to meet a specific measurable threshold for material resiliency.

See Section 4.2 for a discussion of a recommended test protocol for assessment of material resiliency for a finding of equivalent facilitation. We recommend that the same approach be used for specification compliance as well.

We recommend that a requirement for material resiliency apply to detectable warnings for both indoor and outdoor applications. The use of resilient materials as shock and vibration isolators in environments (e.g., temperature ranges, humidity, corrosiveness, fuel vapors, etc.) far more severe than would likely be the case for application of detectable warnings suggests to us that no conditional restriction should apply. Furthermore, this would strengthen the degree of standardization to be achieved for detectable warnings.

The issue of snow removal operations deserves further comment. Many objections have been raised (Federal Transit Administration, May 28, 1992) to the use of detectable warnings with raised truncated domes in external environments because of the difficulties in snow removal operations. It should be observed that any textured surface will fill with snow and ice in the interstices of the textured surface. The problem is not unique to a texture consisting of raised truncated domes. Commenters also assume, however, that the techniques and technologies (e.g., plows and shovel) currently used on the platform or on the sidewalks would or should continue to be used. Adaptation of snow removal operations, for example, use of a hand-held or vehicular-attached hot air blower, a stiff broom, or chemically compatible liquid solutions (e.g., de-icing solutions such as glycol) or granular materials, could be used without adversely affecting the efficiency of the overall snow removal operation. Accordingly, the Access Board's concern that raised truncated domes may shear off due to snow removal operations can be addressed by alternative solutions. We recognize, however, the paucity of evaluative research and test data for detectable warnings in external environments and strongly support additional work in this area.

F. Visual Contrast

The Access Board's recommendation for establishing a visual cue for detectable warnings was based on sponsored research on signage for the visually impaired (U.S. Architectural and Transportation Barriers Compliance Board, 1991). Within the Access Board, there are concerns as to the strict applicability and relevance of the research on signage to detectable warnings. The Access Board ultimately settled on a non-quantitative visual contrast requirement permitting use of light-on-dark or dark-on-light to establish visual contrast. (For a discussion of potential problems associated with a permitted dark-on-light contrast, see Section 3.1).

In the advisory portion of the ADAG guidelines, a visual contrast ratio equaling or exceeding a minimum criterion of 70 percent is suggested. The problem is that the contrast ratio test for a product sample requires that the adjoining surface also be known. Since there are a variety of surface materials in both indoor and external applications, a product could be compliant with respect to visual contrast for some adjoining surfaces but not for others.

The intended user populations that would be affected by a visual cue requirement for detectable warnings are non-visually impaired persons who also benefit from edge treatments that easily identify level changes or the pedestrian/vehicular boundary, and low vision persons for whom visual cues add redundant sensory information. We recommend that the following principles that govern visual cues for traffic control devices (FHWA, 1978) be applied to detectable warnings:

1. Detectable warnings shall equal or exceed a specified light reflectance value (LRV) which depends on the material;

2. Detectable warnings should be standardized with respect to color. Yellow is proposed because it also has a standardized meaning for General Warning (FHWA, 1978). The color yellow should comply with the current version of the Standard Color Tolerance Charts issued by the Federal Highway Administration.

We recommend that additional research be undertaken to identify an acceptable minimum criterion for light reflectance value, considering its application to detectable warnings and the two user populations that could benefit from visual cues associated with detectable warnings.

G. Slip Resistant Surface

There is a generalized requirement in the ADAG guidelines that all walking surfaces be slip resistant and we recommend that a formal requirement for achieving a static coefficient of friction ≥ 0.6 using an acceptable ASTM test protocol be incorporated into the specification for detectable warnings.

5.1.1 Proposed Language for Amending the ADA Specification for Detectable Warnings (4.29)

The following language is recommended to amend the ADA specification for detectable warnings:

4.29 Detectable Warnings

4.29.1 General. Detectable warnings required by 4.1 and 4.7 shall comply with 4.29.

4.29.2 Detectable Warnings on Walking Surfaces

Definitions: The terms "horizontal" and "vertical" are synonomous with parallel to and perpendicular to the treated edge, respectively.

Detectable warnings shall consist of discrete truncated spherical solid structures conforming to the following dimensional tolerances (see schematic illustration, Figure 5-14): bottom and top structure surface are circular in plan with a bottom diameter of nominal 0.9 in. (23 mm) and a top diameter of nominal 0.45 in. (11.5 mm). The height of each discrete truncated spherical solid structure, measured from the center of the bottom surface to the center of the top surface, shall be a nominal 0.2 in. (5 mm).

Discrete truncated spherical solid structures shall be placed within the required width and length dimensions of the detectable warning surface in accordance with a geometrically uniform staggered pattern of rows and columns having the following properties which hold concurrently (see schematic illustration, Figure 5-15):

a. Discrete truncated spherical solid structures shall be co-linear in rows and columns that are parallel to and perpendicular to the treated edge, respectively and shall have a center-to-center spacing that is a uniform nominal 2.35 in. (60 mm).

b. Any two closest-neighbor discrete truncated spherical solid structures, each in a row that is adjoining to each other, shall have a projected horizontal stagger offset spacing that is uniform and of nominal 1.175 in. (30 mm).

c. Any two closest-neighbor discrete truncated spherical solid structures, each in a column that is adjoining to each other, shall have a projected vertical stagger offset spacing that is uniform and of nominal 1.175 in. (30 mm).

d. Because of equal projected horizontal and vertical stagger offset spacings that are a uniform nominal 1.175 in (30 mm), discrete truncated spherical solid structures shall be co-linear on axes that form a 45 and 135 degree angle of

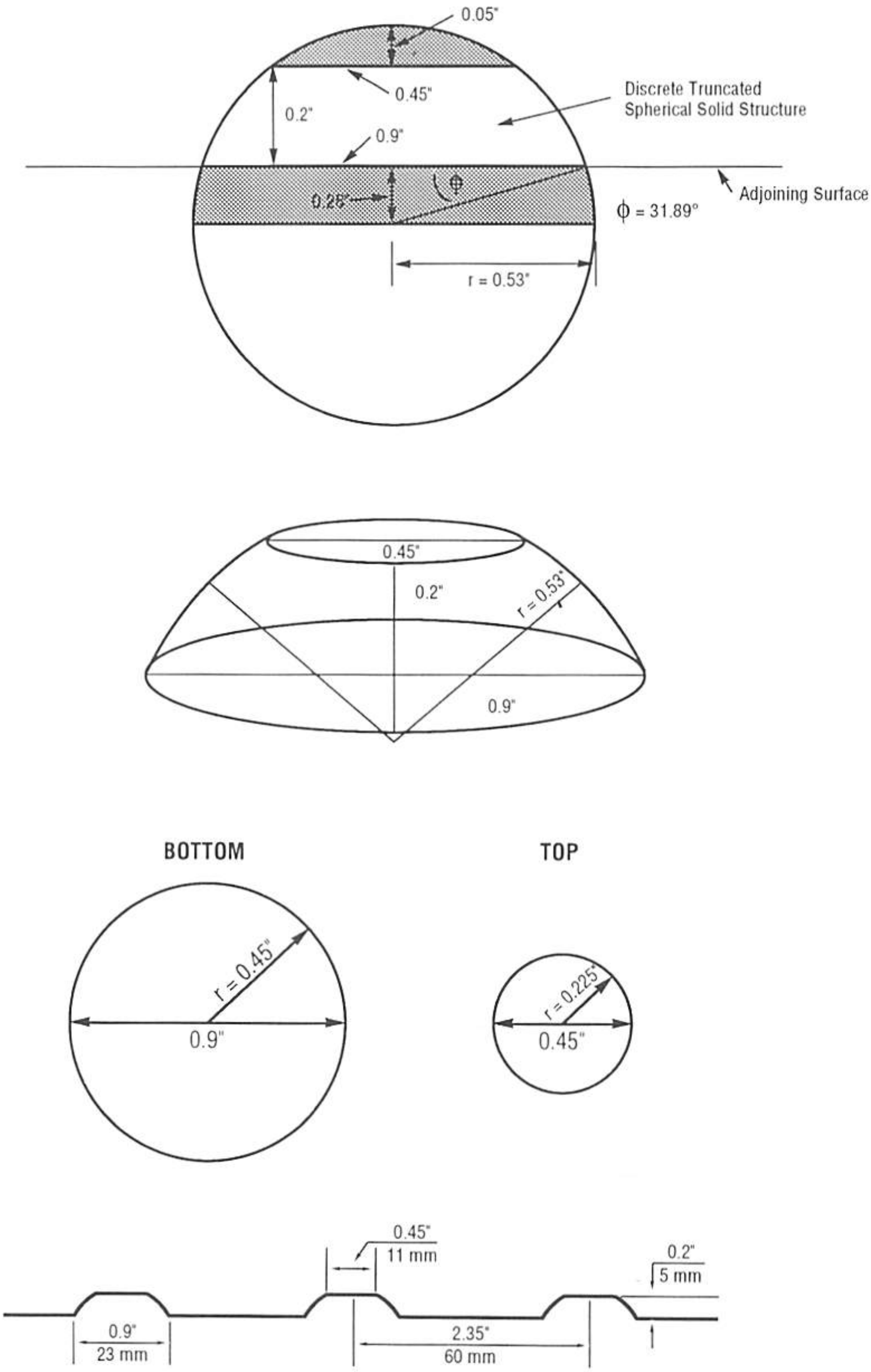
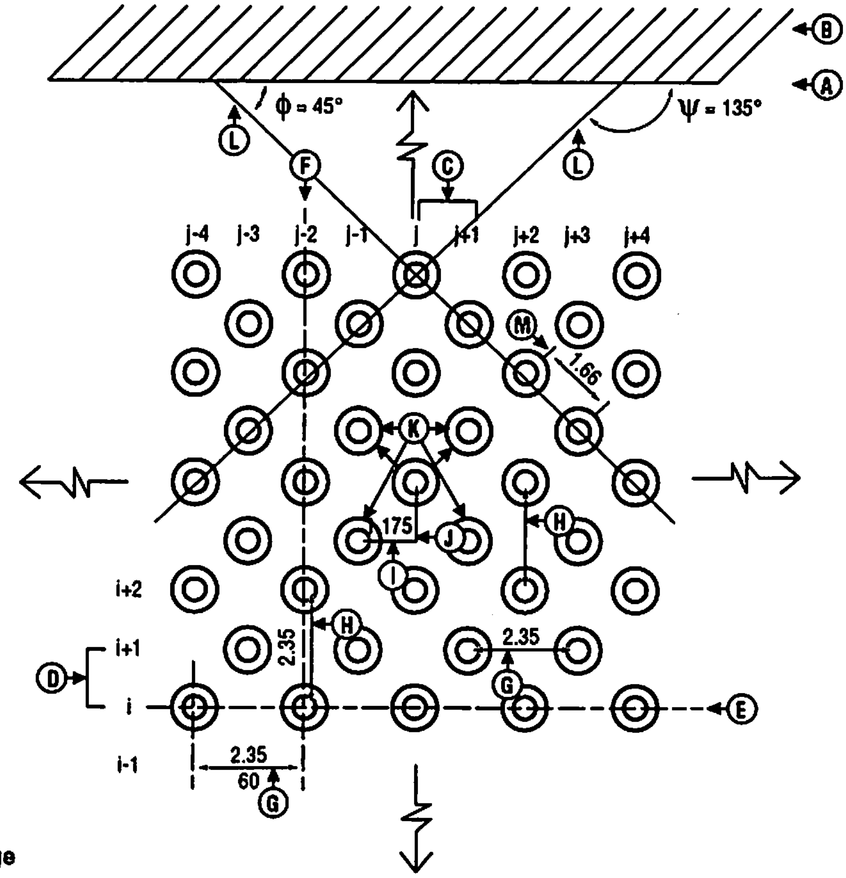


FIGURE 5-14. SCHEMATIC ILLUSTRATION OF DISCRETE TRUNCATED SPHERICAL SOLID STRUCTURES



A. Treated edge

B. Hazardous area

C. Adjoining colums perpendicular to the treated edge

D. Adjoining rows parallel to the treated edge

E. Axis parallel to the treated edge

F. Axis perpendicular to the treated edge

G. Center-to-center spacing between successive discrete truncated spherical solid structures on an axis parallel to the treated edge

H. Center-to-center spacing between successive discrete truncated spherical solid structures on an axis perpendicular to the treated edge

I. Horizontal stagger offset spacing between two closed neighbor discrete truncated spherical solid structures on adjoining rows

J. Vertical stagger offset spacing between two closed neighbor discrete truncated spherical solid structures on adjoining columns

K. Closest neighbor discrete truncated spherical solid structures to a given discrete truncated spherical solid structure in adjoining rows and columns

L. Axes on a 45° and 135° angle of approach to the treated edge

M. Center-to-center spacing between successive discrete truncated spherical solid structures on an axis which made a 45° or 135° angle of approach to the treated edge

FIGURE 5-15. SCHEMATIC ILLUSTRATION OF GEOMETRIC STAGGERED PATTERN AND TERMS OF REFERENCE approach to the treated edge (all degrees measured in a clockwise direction relative to the treated edge) and shall have a center-to-center spacing along these axes that is a uniform nominal 1.66 in. (41.5 mm).

Detectable warning surfaces shall be of resilient material having a coefficient of restitution ≥ a minimum value that must be determined.

Detectable warning surfaces shall be a standard yellow and have a light reflectance value (LRV) ≥ a minimum value that must be determined.

Detectable warning surfaces shall be skid resistant with a static coefficient of friction ≥ 0.6.

Detectable warning surfaces shall be an integral part of the walking surface.

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