FTA-MA-06-0201-94-2
DOT-VNTSC-FTA-94-4

U.S. Department
of Transportation
**Federal Transit
Administration**

# Detectable Warnings: Detectability by Individuals with Visual Impairments, and Safety and Negotiability on Slopes for Persons with Physical Impairments

Research and
Special Programs
Administration
Volpe National
Transportation Systems Center
Cambridge, MA 02142-1093

Final Report
September 1994

Office of Engineering Evaluations
Washington, DC 20590

# REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188



| 1. AGENCY USE ONLY (Leave blank) | 2. REPORT DATE<br>September 1994 | 3. REPORT TYPE AND DATES COVERED<br>Final Report<br>June 1992 - March 1994 |
|---|---|---|

**4. TITLE AND SUBTITLE**
Detectable Warnings: Detectability by Individuals with Visual Impairments, and Safety and Negotiability on Slopes for Persons with Physical Impairments

**5. FUNDING NUMBERS**
U4025/TT401

**6. AUTHOR(S)**
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**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142

**8. PERFORMING ORGANIZATION REPORT NUMBER**
DOT-VNTSC-FTA-94-4

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
U.S. Department of Transportation
Federal Transit Administration
Office of Engineering Evaluations
Washington, DC 20590

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
FTA-MA-06-0201-94-2

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**12a. DISTRIBUTION/AVAILABILITY STATEMENT**
This document is available to the public through the National Technical Information Service, Springfield, VA 22161

**12b. DISTRIBUTION CODE**

**13. ABSTRACT (Maximum 200 words)**
This report presents the results of research on human performance on detectable warning surfaces. The first portion of the report presents an evaluation of the underfoot detectability of thirteen detectable warning surfaces by persons who are blind. The second portion is an evaluation of the safety and negotiability of nine detectable warning surfaces for persons having varied physical disabilities.

In the first study, thirteen detectable warning surfaces were evaluated for underfoot detectability by twenty-four persons who are blind, in association with four transit platform surfaces varying in roughness and resiliency.

In the second study, forty participants having a wide range of physical disabilities, who traveled either with no aid, aids having wheels, or aids having tips, traveled up and down 4-foot-by-6-foot ramps having a slope of 1:12. All trials were videotaped; the videotapes were then rated, by three independent raters, for observable incidents indicating decreased safety and negotiability.

Given the moderately increased level of difficulty which detectable warnings on slopes pose for persons with physical disabilities, it is desirable to limit the width of detectable warnings to no more than that required to provide effective warning for persons with visual impairments.

**14. SUBJECT TERMS**
Detectable Warning Surface, Truncated Dome, Detectability, Safety and Negotiability, Underfoot, Mean Stopping Distance, Cumulative Stopping Distance, Transit Platform Surface, "Wheels," "Tips"

**15. NUMBER OF PAGES**
124

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | |

## PREFACE

This document presents the results of two research efforts: first, a study of the detectability—by individuals who are blind—of thirteen similar detectable warning surfaces; and second, a test of the safety and negotiability of detectable warnings on a 1-in-12 slope, by individuals with physical impairments. For the detectability research, thirteen surfaces were selected, representing the extremes as well as the midpoints of dimensions, for truncated domes and for dome spacing, meeting the minimum compliance standards as specified in the Americans with Disabilities Act Accessibility Guidelines (ADAAG).

We are indebted to Vincent R. DeMarco, Deputy Director, Office of Engineering Evaluations, Federal Transit Administration (FTA), for his sponsorship of the project. His commitment to resolving technical problems associated with providing accessible transit has been the driving force behind FTA research on detectable warnings.

The unfailing support of Patricia Ryan, Project Manager, VNTSC, was invaluable in seeing all phases of this research through to conclusion. Without her persistent and very active support, this project would have foundered at several critical junctures.

We would also like to thank Project ACTION of the National Easter Seal Society for financial support and technical assistance to the portion of the project concerned with safety and negotiability of detectable warnings.

The Massachusetts Bay Transportation Authority (MBTA) provided not only the setting for this research, but also substantial resources contributing to its successful completion. The expertise and assistance of MBTA managers William Bregoli, Joseph Curtin, and James McCarthy were essential to the project.

Insightful questions, observations, and suggestions by Dennis Cannon, U.S. Architectural and Transportation Barriers Board, Raymond Lopez, Federal Transit Administration, and William Hathaway, VNTSC, helped to assure accuracy and relevance of the content of this report.

The research reported in this publication was managed in large part by Tina Nolin, Ph.D., with the assistance of Winifred De Karsi, R.P.T.A., and Philip De Joseph, MBTA video photographer. They endured untold hours together in challenging, often cold and damp, situations in order to collect the data which are the substance of the research.

We would also like to acknowledge Lee Tabor, A.I.A., and Joni Bergen for production of art work for this report.

Our greatest indebtedness, however, is to those persons with disabilities who participated in this research, putting up with inconveniences and interruptions in their own lives, to complete our prescribed tasks and to share their insights. It is only because of their commitment to accessible transit for all people that such research can take place.

## 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 ($km^2$) = 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 milliliters (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

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INCHES | 0 | | | 1 | | | 2 | | | 3 | | | 4 | | | | 5 | | | 6 | | | 7 | | 8 | 9 10 |
| CENTIMETERS | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 25.40 |

### QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| °F | -40° | -22° | -4° | 14° | 32° | 50° | 68° | 86° | 104° | 122° | 140° | 158° | 176° | 194° | 212° |
| °C | -40° | -30° | -20° | -10° | 0° | 10° | 20° | 30° | 40° | 50° | 60° | 70° | 80° | 90° | 100° |

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 presents the results of research on human performance on detectable warning surfaces differing slightly in dimensions, as well as in resiliency and nature of materials. The first portion of the report presents an evaluation of the underfoot detectability, by persons who are blind, of 13 detectable warning surfaces when applied to four different types of platform surfaces. The second portion is an evaluation of the safety and negotiability of 9 detectable warning surfaces applied to slopes and how persons having varied physical disabilities are affected.

## Detectability

Thirteen detectable warning surfaces representing the extremes as well as the midpoints of dimensions for truncated domes and for dome spacing were evaluated for underfoot detectability in association with four transit platform surfaces varying in roughness and resiliency, by 24 persons who are blind. The detection rate was greater than 95% for all but one surface (a prototype which has never been manufactured for sale). Therefore, there can be some variation in detectable warning dimensions without compromising detectability.

Factors which appeared to have little or no effect on detectability were: (1) differences in resiliency (within the range of differences afforded by the available products tested); (2) horizontal and vertical vs. diagonal alignment of domes; (3) the nature of additional (small) textural elements incorporated into some products to increase slip resistance; (4) irregularities in spacing, where the spacing of domes across adjoining tiles resulted in greater or lesser spacing between domes than the spacing within each tile; and (5) a small increase in dome height within the first several inches of a detectable warning. Surfaces incorporating all these factors were included in those having detectability of at least 95%.

One factor which appeared to decrease detectability of warning surfaces as well as to increase stopping distance on detectable warnings, was the use of detectable warning surfaces in association with coarse aggregate concrete—the platform surface which most nearly resembled the detectable warnings in its "bumpiness." Therefore, use of coarse aggregate, or any other material having a "bumpy" pattern in relief, should be discouraged when these surfaces will be used in association with detectable warnings.

Data on stopping distances indicates that 24 inches of a highly detectable warning surface (better than 95%) enables underfoot detection and stopping on at least 90% of approaches. In order to enable detection and stopping on 95% of approaches, 36 inches is required.

**Safety and Negotiability**

Forty participants having a wide range of physical disabilities, who traveled either with no aid, aids having wheels (such as wheelchairs and scooters), or aids having tips (such as canes, crutches and walkers, including rollator walkers) traveled up and down 4-foot by 6-foot ramps, having a slope of 1:12. All trials were videotaped; the videotapes were then rated by three independent raters, for observable incidents indicating decreased safety and negotiability relative to a brushed concrete ramp.

Participants also rated each detectable warning surface for safety and ease of negotiability relative to brushed concrete.

Although some effect on safety and negotiability was noted for 26 of the 40 participants, no participant was judged by the consultant physical therapist to be at serious risk as a result of the addition of detectable warning surfaces to slopes such as curb ramps. Seven participants accounted for 59% of all observable incidents. The remaining 33 participants had few or no observable difficulties, and appeared to compensate quite well for difficulties they experienced as a result of the detectable warnings.

An unglazed tile surface having relatively small truncated domes, aligned horizontally and vertically (as opposed to the more common diagonal alignment), and having domes which were rather widely spaced, resulted in the fewest observable difficulties for persons using "wheels," and for those using "tips." In addition, it was subjectively rated as causing minimal difficulty. The horizontal/vertical alignment of the truncated domes was observed to result in fewer instances of wheel entrapment than surfaces having diagonal alignment.

Given the moderately increased level of difficulty and decrease in safety which detectable warnings on slopes pose for persons with physical disabilities, it is desirable to limit the width of detectable warnings to no more than that required to provide effective warning for persons with visual impairments.

# 1. INTRODUCTION

The Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities (ADAAG), issued on July 26, 1991, includes specifications for detectable warnings, and minimum compliance standards scoping their use in certain areas. These specifications and standards, originally developed by the Architectural and Transportation Barriers Compliance Board (hereafter referred to as the Access Board), were adopted by the Department of Transportation as Standards for Accessible Transportation Facilities in a Final Rule implementing the Americans with Disabilities Act (ADA) (Federal Register, Sept. 6, 1991).

A detectable warning is defined 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." It is a unique and standardized feature, intended to function much like a stop sign. It alerts perceivers to the presence of a hazard in the line of travel, whereupon they stop, and determine the nature and extent of the hazard before proceeding further.

The surface is specified in ADAAG 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."

There are five situations in which detectable warnings are to be used.

**Curb ramps.**

> "4.7.7. Detectable Warnings. A curb ramp shall have a detectable warning complying with 4.29.2. The detectable warning shall extend the full width and depth of the curb ramp."

**Hazardous vehicular areas.**

> "4.29.5 Tactile Warnings at Hazardous Vehicular Areas. If a walk crosses or adjoins a frequently used vehicular way, and if there are no curbs, railings, or other elements detectable by a person who has a severe visual impairment separating the pedestrian and vehicular areas, then the boundary between the areas shall be defined by a continuous 36 inch (915-mm) wide tactile warning texture complying with 4.29.2."

**Reflecting pools.**

> "4.29.6 Detectable Warnings at Reflecting Pools. The edges of reflecting pools shall be protected by railings, walls, curbs, or detectable warnings complying with 4.29.2."

**Transit platform edges.**

> "10.3.1 (8) Platform edges bordering a drop-off and not protected by platform screens or guard rails shall have a detectable warning. Such detectable warnings shall comply with 4.29.2 and shall be 24 inches wide running the full length of the platform drop-off."

**Level crossings.**

> "10.3.1 (13) Where it is necessary to cross tracks to reach boarding platforms, the route surface shall be level and flush with the rail top at the outer edge and between the rails, except for a maximum 2-1/2 inch gap on the inner edge of each rail to permit passage of wheel flanges. Such crossings shall comply with 4.29.5. Where gap reduction is not practicable, an above-grade or below-grade accessible route shall be provided."

The specifications for detectable warnings in ADAAG (4.29.2) are ambiguous in several respects. First, it is not clear how center-to-center spacing is to be measured. Second, the geometry precisely describing the shape of the truncated domes is not provided. Thus it is unclear, for example, whether the 0.9 in. truncated dome diameter is to be measured at the base of the truncated dome or at the top. (Spiller and Multer, 1992, have recently provided an excellent technical discussion of the geometries of detectable warnings, and have suggested language clarifying existing ambiguities.)

Following publication of ADAAG, manufacturers working in a variety of materials quickly began producing a number of different detectable warning products intended to comply with the specifications. These products now include ceramic, hard composite, and resilient tiles, cast pavers, pre-cast concrete and concrete stamping systems, stamped metal, rubber mats, and resilient coatings. These products, while typically falling generally within the specifications, differ somewhat from each other in dome dimensions and inter-dome spacing, as well as in material and in the presence, for some products, of additional texture elements intended to increase slip resistance.

Some manufacturers have varied the dimensions deliberately (while still maintaining a truncated dome pattern) in attempts to create surfaces which, while being highly detectable underfoot, may be less likely to cause trips, slips and falls, particularly for persons having physical impairments, and for women in high heels. In addition, as different industries have attempted to create detectable warnings using different materials, standard dimensions in some industries, most notably tile and paver dimensions, have made it difficult to achieve the specified geometry or to hold the geometry constant across adjoining units of the detectable warnings surfaces.

This research was undertaken to provide human factors data on which to base refinements in the specification of detectable warnings. First, it was desired to determine the dimensional tolerances for surfaces which were highly detectable. The ADAAG specification, while based on substantial demonstration that a particular pattern, produced in a rubber tile, provided a highly detectable surface (Peck & Bentzen 1987; Weule 1986; Mitchell 1988), was not based on systematic manipulation of critical dimensions such as diameter and spacing of domes. Existing commercially available and prototype detectable warning materials differing from one another in critical dimensions were tested for underfoot detectability, using a research design similar to that in Peck & Bentzen (1987).

Second, it was desired to learn how the presence of detectable warning surfaces would affect ease of negotiability and safety, for persons having a wide variety of physical disabilities. Previous research and accumulated experience documenting minimal difficulties had been obtained only on level transit platforms. ADAAG, however, also required detectable warnings on slopes such as curb ramps.

Therefore, detectable warnings in this research were placed on slopes of 1:12, to examine the effect of detectable warnings on slopes, on safety and ease of negotiation for persons having physical disabilities.

## 1.1 OVERVIEW OF THIS RESEARCH

This research was carried out in a number of phases, each differing in their research objectives and methods. The following outline briefly characterizes each phase. This outline provides the structure for reporting all the work conducted under this project. (The arabic numbers correspond to sections of this manuscript.)

2. **Phases I and II —Underfoot Detectability of Warning Surfaces by Persons with Visual Impairments**
   In Phase I, detectability of ten warning surfaces was determined.
   In Phase II, detectability of an additional three surfaces was determined.
3. **Phase III —Detection of Warning Surfaces by Use of a Long Cane**
   A sub-set of four of the detectable warning surfaces was tested for detectability by persons who traveled using a long cane, to confirm that the direction of results for long cane detection is similar to that for underfoot detection.
4. **Phase IV —Pilot study: Negotiability and Safety of Detectable Warning Surfaces on a Level Platform**
   Persons with physical disabilities traveled over 13 detectable warning surfaces and provided subjective data to aid in the choice of 9 surfaces for subsequent extensive objective and subjective testing on slopes.
5. **Phase V —Negotiability and Safety of Detectable Warnings on Slopes, for Persons Having Physical Disabilities**
   Persons with a wide variety of physical disabilities, using varied aids, negotiated up and down nine 6-ft.-long ramps (slope 1:12) having detectable warnings, and a comparable ramp having a brushed concrete surface. Participants provided subjective judgments of safety and negotiability of each surface, in comparison to brushed concrete. Video data were rated to provide objective measures of performance on each surface.

### 1.1.1 Detectability (Phases I, II, and III)

The first question in any research program on detectable warnings must always be "Is a surface highly detectable underfoot to persons who are visually impaired?" If a surface is not detectable, it is inappropriate to consider it for use as a detectable warning regardless of the other merits it may have. Thus, this research began by testing detectability.

This research obtained psychophysical data (detection rates and stopping distances) on 13 detectable warning surfaces represented by available detectable warning products, which varied from one another in dimensions of their truncated domes, as well as in inter-dome spacing. A detectability rate of 90% has generally been considered "high enough" for a surface to be considered a detectable warning (see Review of Literature ff.). It was desired to learn whether surfaces falling roughly within the ADAAG specifications were all highly detectable ($\geq$ 90%).

"Stopping distance" is the amount of a detectable warning material which is required to enable persons who are visually impaired to detect the warning and come to a stop without stepping beyond the warning. The ADAAG require detectable warnings to be 24 in. wide on transit platforms having a drop, 36 in. wide at hazardous vehicular ways, and to extend the full width and depth of curb ramps. Thus it was of interest to obtain additional information on stopping distance.

The primary emphasis on detectability in this research was placed upon "underfoot" detection, rather than detection by use of a long cane. Therefore, participants were desired whose vision was insufficient to enable visual identification of detectable warnings.

Underfoot detection was considered to be more important than detection by use of a long cane for a number of reasons. First, many persons who are visually impaired do not use long canes, yet they may not have sufficient vision to reliably detect platform edges using visual information. These persons include those who are gradually losing sight and who have not begun to use a travel aid, those whose vision fluctuates and who do not always use a long cane, and those who do not choose to use a long cane. These persons, representing a larger proportion of the legally blind persons than those who travel using a long cane, have only underfoot information available to enable them to locate platform edges or the precise junction between a curb ramp and a street. In addition, persons who travel with the aid of dog guides are also dependent on underfoot information regarding changes in surface texture. Thus, the first phases of the research concentrated on underfoot detectability. In Phase I, 10 surfaces were tested; in Phase II, an additional 3 surfaces were tested.

This was a very conservative test, intended to determine the detectability of warning surfaces under somewhat difficult circumstances. First, it is often more difficult to detect surface changes underfoot than by using a long cane, and stopping distances are typically much longer for persons relying on underfoot detection. Surfaces which have been demonstrated to be highly detectable by use of a long cane have not always proved to be highly detectable underfoot.

Second, detectable warnings were paired for detectability with four different, adjoining ("platform") surfaces representative of extremes of roughness (rough vs. smooth) and resiliency (resilient vs. non-resilient) currently in use on transit platforms in the United States. An effective standard must provide for a surface which is highly detectable in association with all surfaces with which it is likely to be paired.

Warning surfaces selected for detectability testing differed from one another in resiliency as did "platform" surfaces. This provided the opportunity to look at the effects on detectability, of differences in resiliency between adjoining surfaces. It will be recalled that a difference "in resiliency or sound-on-cane-contact" is required by ADAAG for indoor applications.

Phase III was a test of detectability by use of a long cane, of a sub-set of four of the surfaces tested in Phase I, to determine whether, in this research as in previous research, surfaces highly detectable underfoot were also highly detectable using a long cane.

### 1.1.2 Safety and Negotiability (Phases IV and V)

Once the question of detectability was examined, it was appropriate to test safety and negotiability. It is important that an accessibility feature which assists some segments of the population not do so at the expense of others. The installation of curb ramps, needed by persons who are unable to negotiate curbs, unfortunately removes the cue most reliably detectable to persons with visual impairments that they have arrived at a street. Thus ADAAG has provided for curb ramps to have detectable warnings. However, if the addition of detectable warnings to curb ramps impairs safety of other persons, the measure is, nonetheless, counterproductive.

A limited amount of prior research on safety and negotiability of detectable warnings by persons with physical disabilities has found that the addition of detectable warnings to transit platforms does not significantly reduce safety and negotiability of these platforms by persons having physical disabilities. In addition, two transit properties who have had detectable warnings on platform edges system-wide for five or more years have documented no adverse impacts on persons having physical disabilities (BART, San Francisco, R. Weule 1994; METRO DADE, Miami, A. Hartkorn 1994). However, this was the first project undertaken to obtain information on safety and negotiability of detectable warnings on **slopes** (such as curb ramps) for persons having physical disabilities.

In order to select from surfaces known to be highly detectable, those to be tested on slopes, a pilot test, Phase IV, was conducted. Eleven persons having various physical disabilities rated safety and negotiability of the 13 different detectable warning surfaces tested for detectability in Phases I and II. Nine surfaces were then chosen for testing on slopes, from those which were both highly detectable and rated as relatively safe and negotiable, including several surfaces which seemed to offer potential for use in retrofit situations.

In Phase V, 40 persons varying considerably in their physical disabilities, travel aids and amount of loss of sensation negotiated on 4-ft.-wide-by-6-ft.-long ramps, having a slope of 1:12, the steepest slopes normally permitted for ramps. Persons with physical disabilities were videotaped as they negotiated up and down each ramp having detectable warnings, as well as a comparison ramp having a brushed concrete surface. While on each surface, participants started, stopped, and initiated a turn, thus performing the range of activities they might have occasion to perform on ramps. After negotiating up and down each ramp, each participant rated that ramp for safety and negotiability relative to the brushed concrete ramp.

Performance on the videotapes was subsequently rated by three raters on a scale developed in consultation with a senior Registered Physical Therapist, in which specific behaviors were rated which are indicative of effort and safety. The rated items differed somewhat according to the aids used. For example, where wheelchairs were used, entrapment of wheels in the truncated domes was rated, as this would result in impaired ability to control the direction of the chair, affecting both ease of negotiating and safety. Where crutches were used, slipping of the tips was rated, indicating decrease in safety.

Finally, participant ratings (subjective data) were compared with video ratings (objective data) to determine the extent of agreement.

This project obtained information regarding the impact of detectable warnings in situations and on individuals where difficulties were expected to be most evident. That is, on the steepest permissible slopes, and not just on those persons who are the most active, independent travelers, but also on persons whose disability, aid and/or stamina makes all travel difficult.

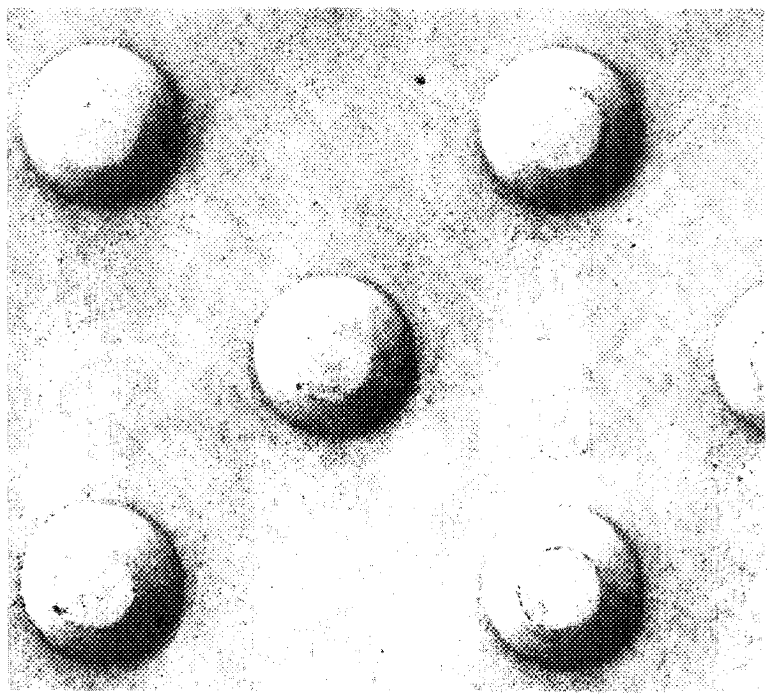
The detectable warning surfaces tested in the various phases of this project are illustrated on the following pages.

**Surfaces Tested** Detectable warning surfaces are illustrated full size on the following pages. One truncated dome from each surface is shown in a cross-section drawing.

| Surface | Description | Page |
|---|---|---|
| | ***Surfaces Tested for Detectability Only*** | |
| A′ | Cross-linked thermoset polyurethane tile | 1-10 |
| C | Vitrified polymer composite | 1-11 |
| E | Unglazed ceramic tile | 1-12 |
| G | Matte glazed ceramic tile | 1-13 |
| H | High-gloss glazed ceramic tile | 1-14 |
| J | Precast polymer concrete | 1-15 |
| | ***Surfaces Tested for Detectability, and for Safety and Negotiability*** | |
| A | Cross-linked thermoset rubber tile* | 1-16 |
| B | Fiberglass reinforced composite | 1-16 |
| D | Vitrified polymer composite | 1-17 |
| F | Unglazed porcelain tile | 1-18 |
| I | Precast polymer concrete | 1-19 |
| L | Flexible coating over polyurethane domes | 1-20 |
| M | Stamped metal with epoxy coating | 1-21 |
| O | Stamped metal with co-polymer coating* | 1-21 |

*Not tested for detectability

## Tested for Detectability Only



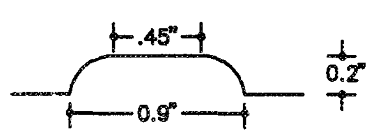
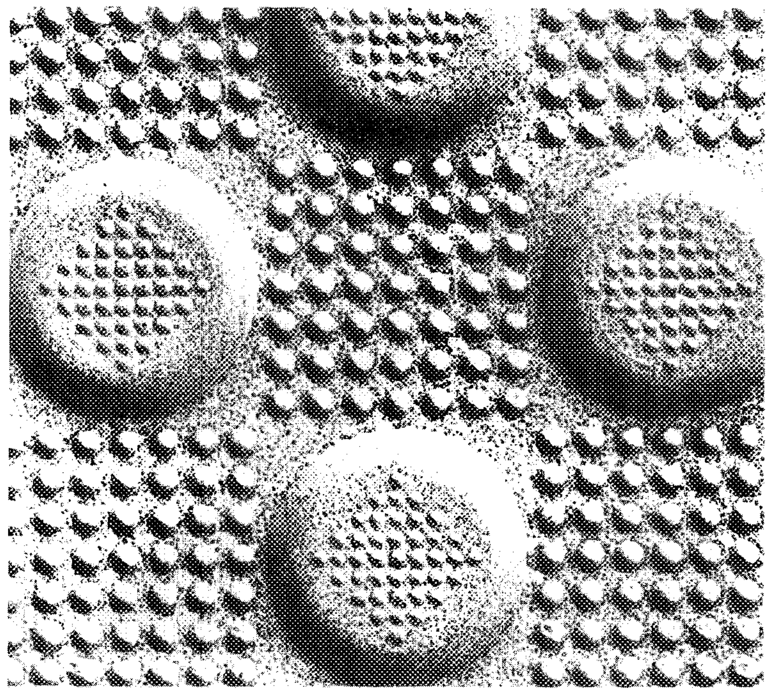



Figure 1-1. **Product A′:** Cross-linked thermoset polyurethane tile, "Pathfinder"-resilient prototype; inconsistent dome spacing between adjacent tiles (domes farther apart). Carsonite International, Carson City, Nevada

**Tested for Detectability Only**



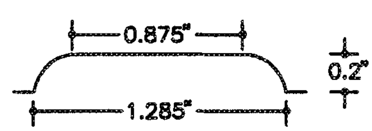
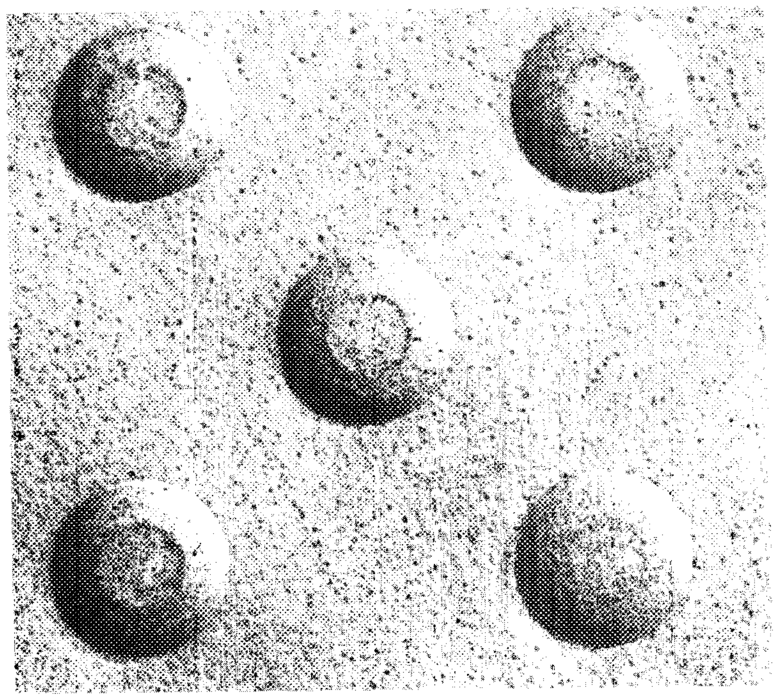



Figure 1-2. **Product C:** Vitrified polymer composite, "Armortile;" consistent spacing across adjacent tiles. Product C is the same as Product D, except was installed using tiles having consistent dome height. Engineered Plastics, Inc., Buffalo, New York

## Tested for Detectability Only



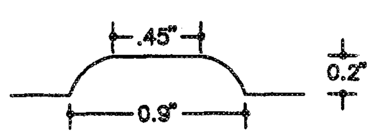
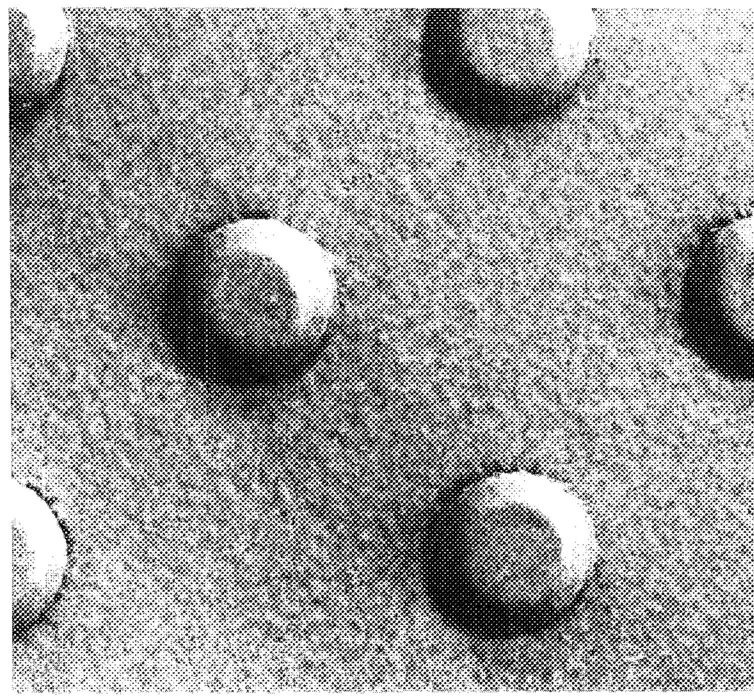



Figure 1-3. **Product E:** Unglazed quarry body ceramic tile, "Transit Tile." Inconsistent spacing across adjacent tiles. American Olean Tile Co., Lansdale, Pennsylvania

## Tested for Detectability Only



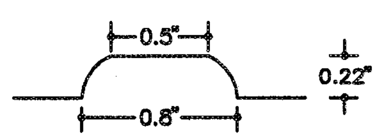
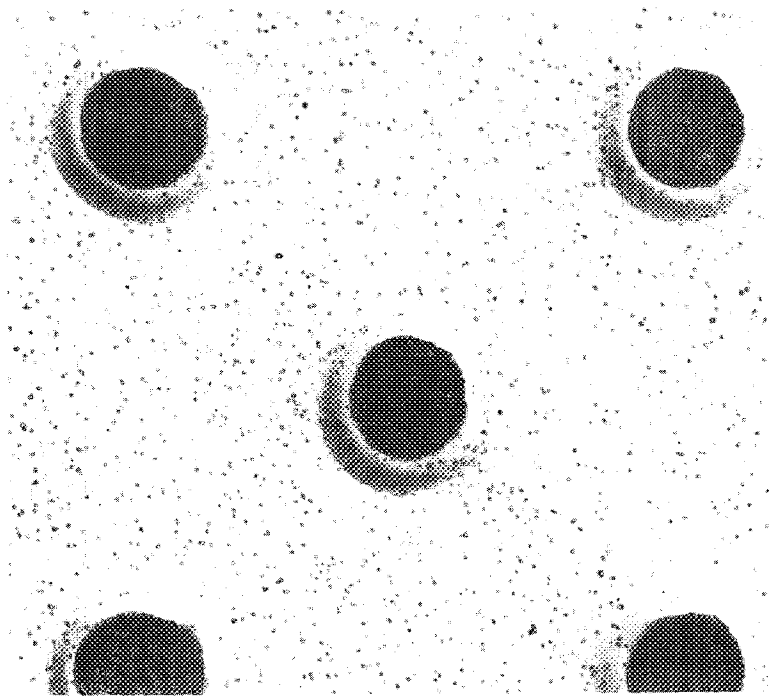



Figure 1-4. **Product G:** Porcelain body ceramic tile, skid-resistant matte glaze, "ADAPT Tile #100." Consistent spacing across adjacent tiles. Terra Clay Products, Roanoake, Alabama

**Tested for Detectability Only**



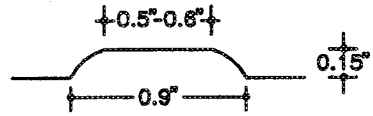
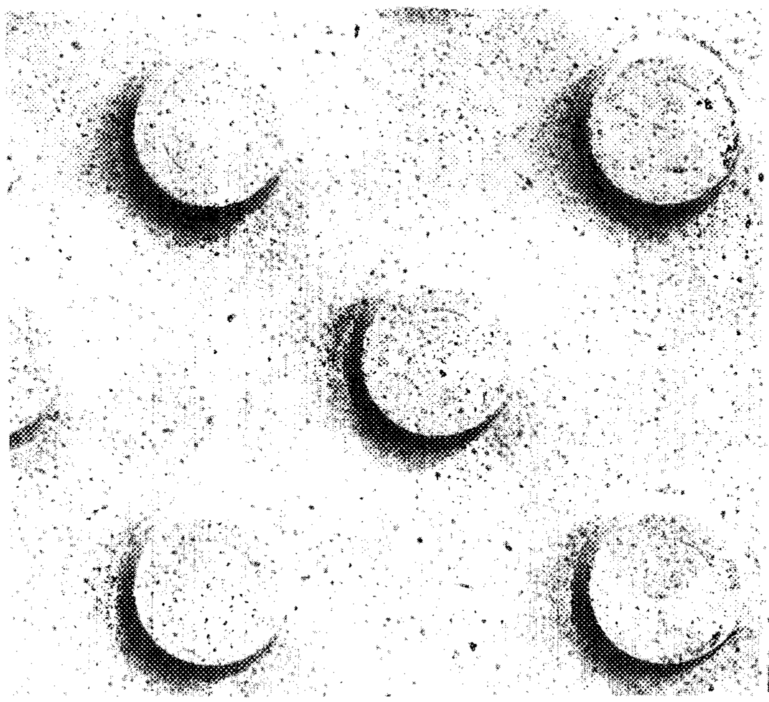



Figure 1-5. **Product H:** High-gloss, glazed ceramic tile. Tops of truncated domes not glazed. Inconsistent spacing across adjacent tiles. Design Technics, New York, New York

## Tested for Detectability Only



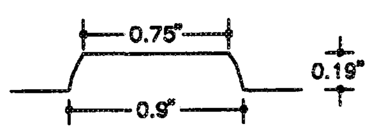
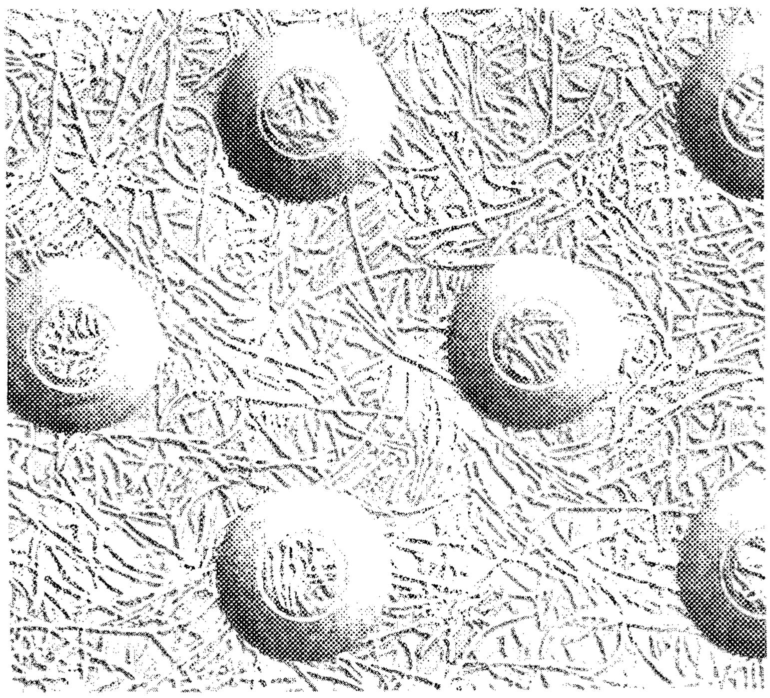



Figure 1-6. **Product J:** Precast polymer concrete. Consistent spacing across adjacent tiles. Prototype product never marketed. Transpo Industries, Inc., New Rochelle, New York

## Tested for Detectability, and for Safety and Negotiability



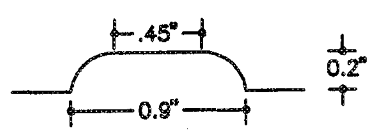
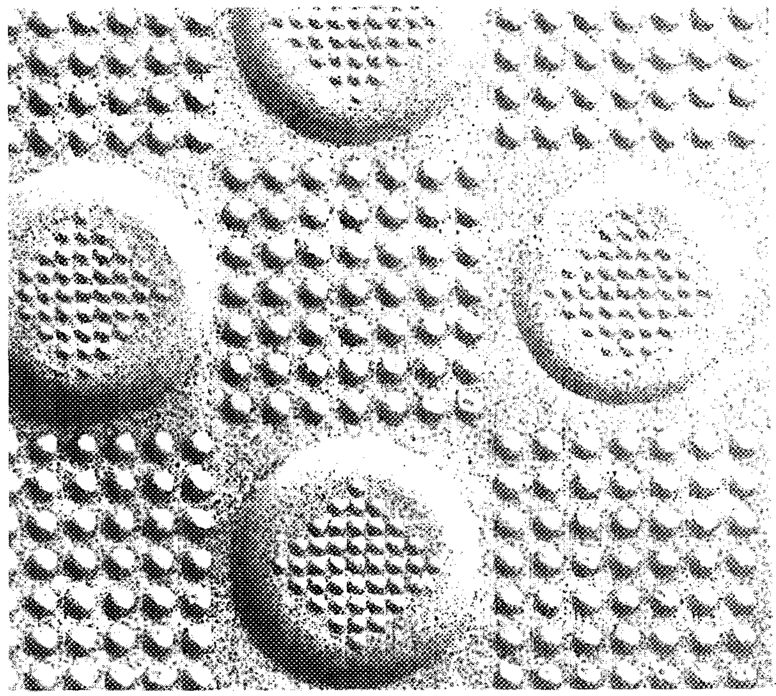



Figure 1-7. **Product A:** Cross-linked thermoset rubber tile, "Pathfinder"-resilient; inconsistent dome spacing between adjacent tiles (domes farther apart). Not tested for detectability. Carsonite International, Carson City, Nevada

**Product B:** Fiberglass reinforced composite, "Pathfinder"-composite; inconsistent dome spacing between adjacent tiles (domes farther apart). Carsonite International, Carson City, Nevada



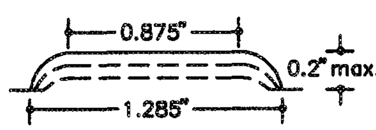
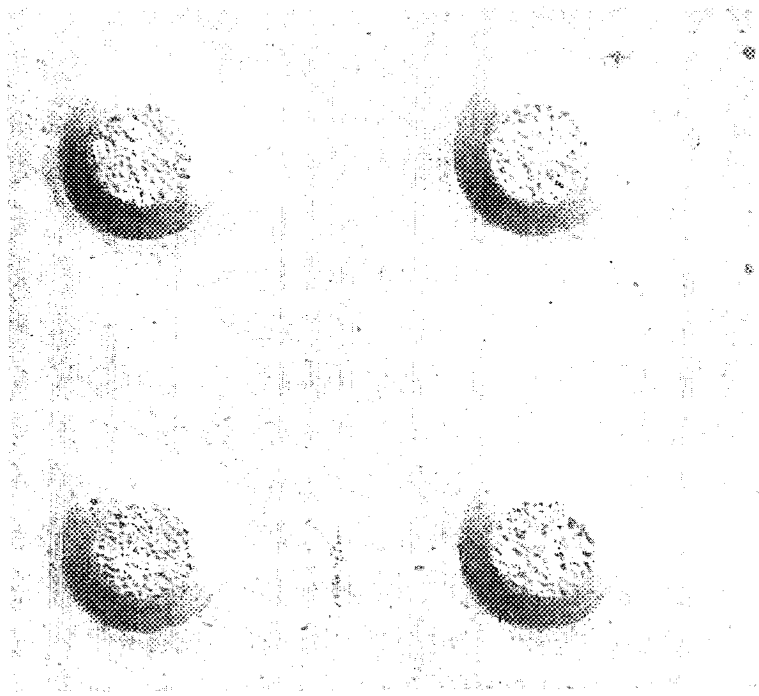



Figure 1-8. **Product D:** Vitrified polymer composite, "Armortile;" consistent spacing across adjacent tiles. Domes gradually increase in height and diameter in first 3 inches of leading edge of tile. Engineered Plastics, Inc., Buffalo, New York

Tested for Detectability, and for Safety and Negotiability



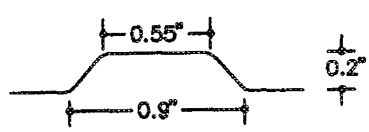
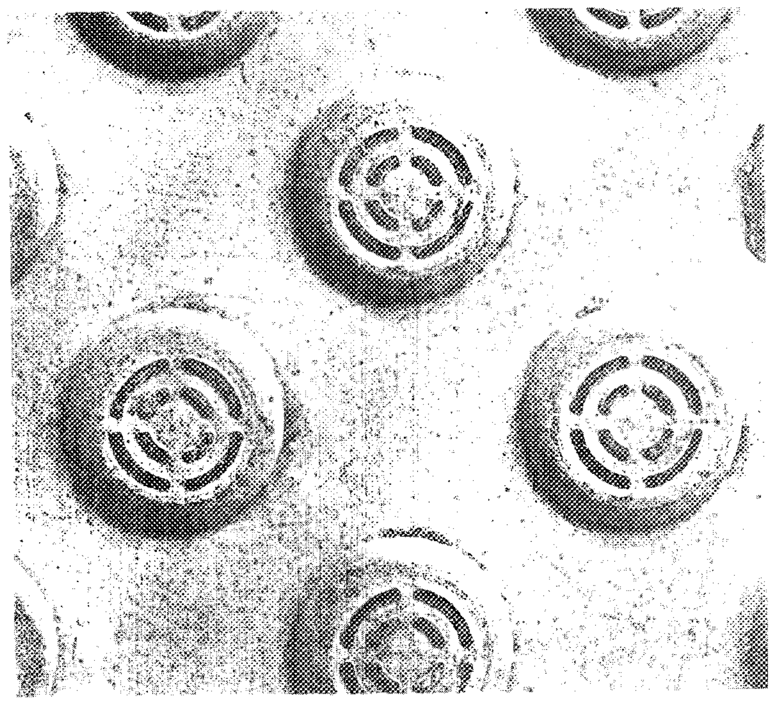



Figure 1-9. **Product F:** Unglazed porcelain tile, "Tactile" – type C; only tested surface with domes aligned on square grid. Consistent spacing maintained across adjacent tiles. Crossville Ceramics, Crossville, Tennessee



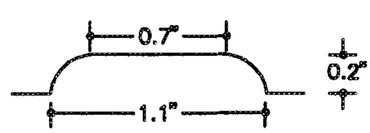
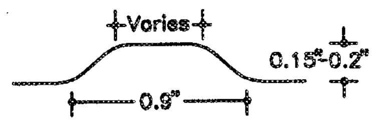
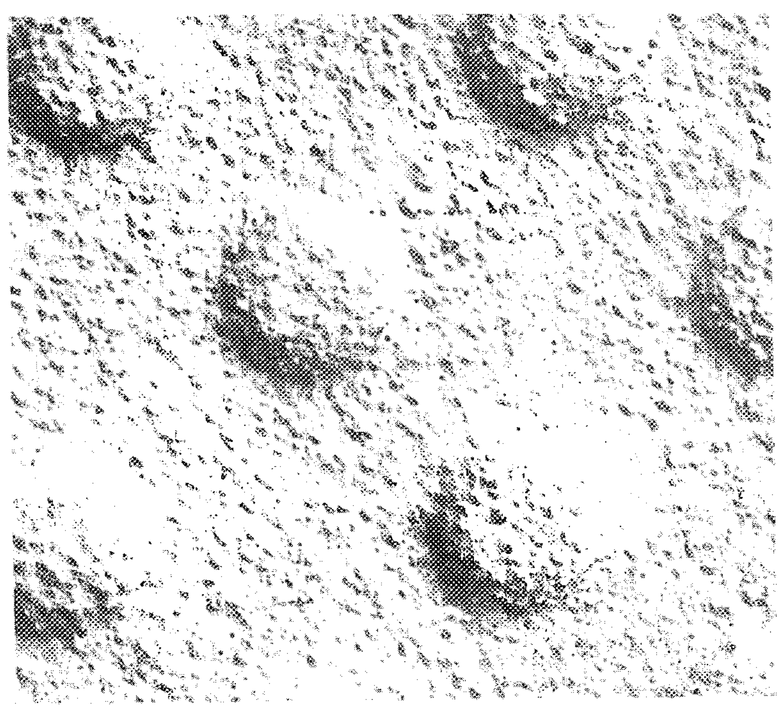



Figure 1-10. **Product I:** Precast polymer concrete, "Step-safe;" consistent spacing across adjacent tiles. Transpo Industries, Inc., New Rochelle, New York

## Tested for Detectability, and for Safety and Negotiability




There is no available sample of Product K, named "Rapidcrete," which was a stamped concrete surface made by Rapidcrete, Inc. of Syracuse, New York. The truncated dome dimensions of this surface were inconsistent due to installation difficulties, including sagging of concrete. A cross-sectional dome dimension diagram of "Rapidcrete" appears above.



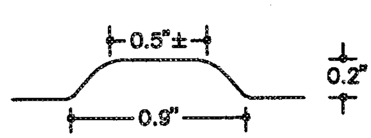
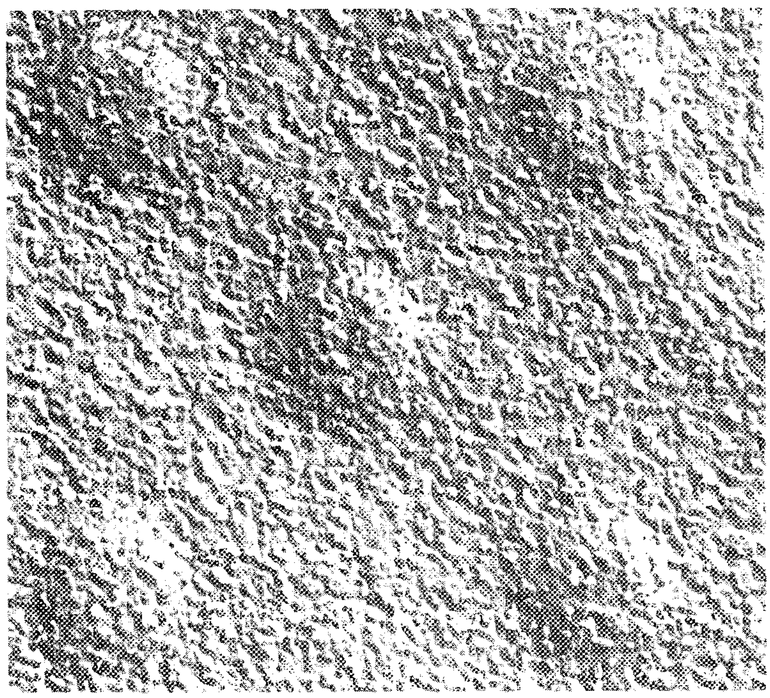



Figure 1-11. **Product L:** Flexible non-skid coating over polyurethane domes, "Safti-trax;" COTE-L Enterprises, Teaneck, New Jersey



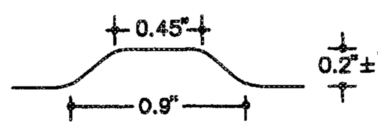



Figure 1-12. **Product M:** Stamped metal with epoxy-type non-slip coating, "Metal Tactile Panel;" has rubberized membrane underneath. Advantage Metal Systems, Brockton, Massachusetts

**Product O:** Stamped metal with non-slip co-polymer coating, "Tac Strip." Not tested for detectability. High Quality Manufacturing, Woburn, Massachusetts

## 1.2 BACKGROUND

Research in the United States to identify floor or paving surfaces which could be used to alert persons with visual impairments to the presence of hazards (such as vehicular ways) in the circulation path, began in 1980, and has proved to be very complex. Many commercially available materials as well as prototype materials have been utilized in this research, with few found to be highly detectable. A review of this research is provided in Appendix A.

The specifications for the truncated dome surface in ADAAG 4.29.2 are based primarily on research by Peck and Bentzen (1987), in which a surface having the specified dimensions was found to be highly detectable to persons who are blind, both underfoot and by use of a long cane. High detectability was demonstrated both on a transit platform, and in a laboratory setting in which the surface was paired with four adjoining surfaces differing in texture and in resiliency.

The truncated dome surface was found to have little effect on the travel of persons having physical disabilities (Peck and Bentzen 1987).

Following this research, Pathfinder Tile was installed in all platforms of all stations in BART. After more than five years of continuous use, visually impaired riders are very pleased with the warnings, and no individual or group of riders has expressed dissatisfaction with the truncated dome material (Personal communication, R. Weule, BART Safety Department, 1994). The overall incidence of trips, slips and falls at the platform edge appears to have decreased. BART riders tend to stand farther from the platform edge than MUNI riders standing at different tracks, in the same stations, but not having detectable warnings (McGean 1991).

The high detectability of this surface was subsequently demonstrated by research undertaken by Mitchell (1988) for MetroDade in Miami, and by the Toronto Transit Commission (1990).

Detectable warnings have been in wide use in Japan since the 1960's, both on sidewalks and in public transit. Although there has never been a national standard in Japan providing specifications and scoping for detectable warnings, and the design of warnings was not based on empirical research, the most commonly used surfaces are truncated dome patterns similar to those specified in ADAAG (O. Shimizu, personal communication 1993).

Recent research in Japan and Australia, using one detectable warning surface, the dimensions of which are within the ADAAG specifications, also found this surface to be highly detectable (Murakami, et al. 1991; Peck, et al. 1991). It is important to note that in research in which participants who were totally blind were required to discriminate between the detectable warning tiles and guiding tiles having a linear pattern, there were confusions between these two patterns.

Confusion between warning tiles (implying "Stop. Check out this potentially hazardous area."), and guiding tiles (implying "Follow me. I'll keep you out of danger.") may be the cause of train platform accidents in Japan reported by Murakami and Shimizu (1990). Warning tiles on transit platform edges are inconsistently placed in Japan, but a common pattern is to place them 36 in. away from the platform edge, in a 12-in.-wide strip, the length of the platform. Twelve in. of a detectable warning surface has been demonstrated in research reviewed above, to be insufficient to enable detection and stopping.

Research in England (Transport and Road Research Laboratory 1983; Gallon, et al. 1991; and Department of Transport 1992) to identify surfaces which are sufficiently detectable to function as detectable warnings on curb ramps and at platform edges confirms that a surface similar to that specified in ADAAG is highly detectable. Initially, a surface having rounded domes was recommended for use on curb ramps; subsequently, after some difficulties were reported by persons having physical disabilities, a surface having truncated domes was recommended, as it was found to be more readily negotiated.

# 2. PHASES I AND II—UNDERFOOT DETECTABILITY OF WARNING SURFACES BY PERSONS WITH VISUAL IMPAIRMENTS

In Phases I and II, underfoot detectability of 13 detectable warning surfaces was tested by persons who are blind. Both objective measures (detection and stopping distance), and subjective measures (participant judgments) were obtained.

## 2.1 METHOD

### 2.1.1 Subjects

Twenty-four blind travelers (totally blind or having no more vision than light projection) participated in Phase I, in which detectability of ten surfaces was tested. Eight participants (one of whom had participated in Phase I) participated in Phase II, in which three more warning surfaces were tested for detectability. Participants for the studies were obtained through the help of three private agencies, one public agency and one organization serving the needs of persons who are visually impaired.

Participants who represented a wide range of attributes of visually impaired transit users were purposefully sought. In addition to varying sex and age, cause of blindness and travel aid (long cane or dog guide), particular care was taken to obtain participants who had additional disabilities, such as hearing loss, cognitive impairments, and peripheral neuropathy (as a result of diabetes). Information concerning these attributes was obtained during an initial telephone interview and is presented in Table 2-1.

**Table 2-1. Matrix of Participant Attributes for Phase I**

| Age | Sex | Travel Aid | Additional Disability | Etiology |
|---|---|---|---|---|
| 8 | M | Long Cane | | Retinopathy of Prematurity |
| 21 | M | Long Cane | | Retinitis Pigmentosa |
| 34 | F | Long Cane | | Diabetic Retinopathy |
| 38 | F | Long Cane | | Retinopathy of Prematurity |
| 38 | M | Long Cane | Cognitive | Retinopathy of Prematurity |
| 39 | F | Long Cane | | Retinopathy of Prematurity |
| 39 | F | Cane or Dog | | Retinopathy of Prematurity |
| 40 | M | Long Cane | Cognitive | Glaucoma |
| 40 | F | Dog Guide | | Retinopathy of Prematurity |
| 41 | F | Dog Guide | | Glaucoma |
| 41 | F | Long Cane | | Retinopathy of Prematurity |
| 41 | M | Long Cane | Neuropathy | Diabetic Retinopathy |
| 42 | M | Long Cane | Balance Problem | Retinopathy of Prematurity |
| 42 | F | Long Cane | | Retinopathy of Prematurity |
| 43 | F | Dog Guide | | Glaucoma, Aniridia |
| 43 | M | Cane or Dog | | Retinopathy of Prematurity |
| 43 | M | Dog Guide | | Unknown |
| 44 | F | Dog Guide | | Cerebral Hemorrhage |
| 45 | M | Long Cane | | Retinopathy of Prematurity |
| 46 | F | Long Cane | Hearing Loss | Usher's Syndrome |
| 50 | F | Long Cane | | Retinopathy of Prematurity |
| 51 | M | Long Cane | | Retinopathy of Prematurity |
| 58 | F | Long Cane | Hearing Loss | Usher's Syndrome |
| 71 | F | Dog Guide | | Unknown |

### 2.1.2 Materials

Human performance testing was conducted on a laboratory platform constructed by the Massachusetts Bay Transportation Authority (MBTA) in an unused portion of a rapid rail transit station.

This platform as originally constructed for Phase I, was designed to permit travel from each of four walking surfaces (subsequently referred to as "platform surfaces") in use on transit platforms, to each of ten potential detectable warning surfaces. (See Figure 2-1). The four platform surfaces were chosen to represent the extremes of roughness (rough or bumpy versus smooth) and resiliency (hard versus resilient) in common use on transit platforms. These four surfaces were brushed concrete, coarse aggregate concrete, wood, and Pirelli tile. The ten detectable warning surfaces

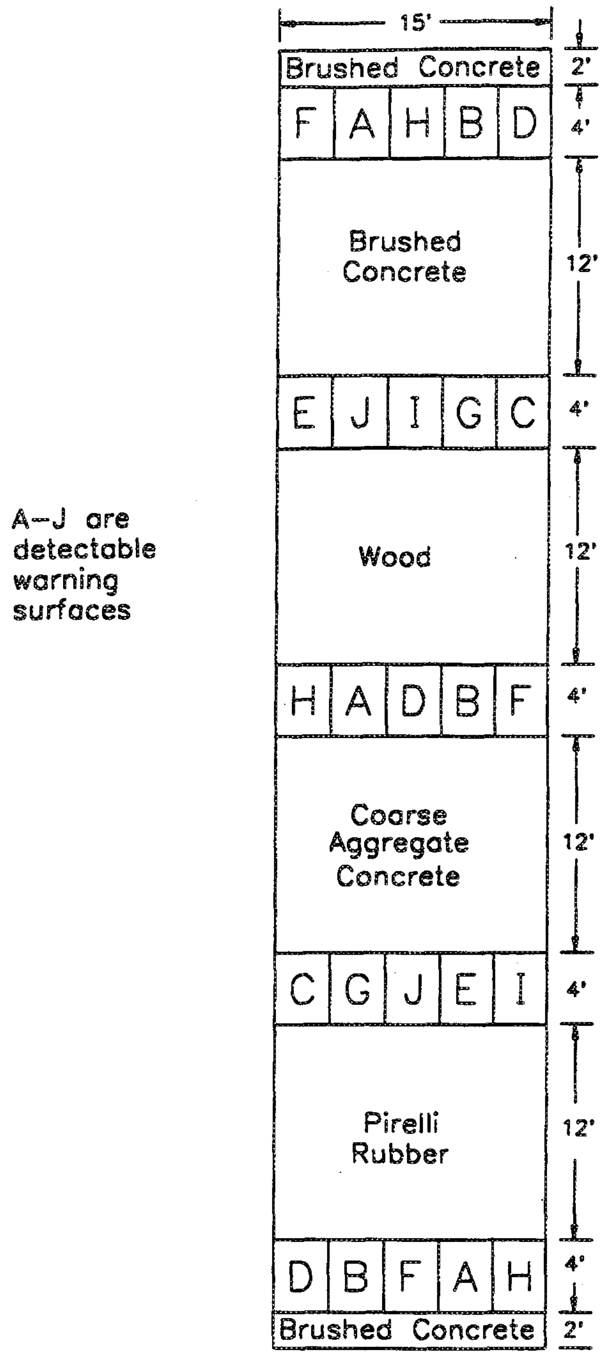



**Figure 2-1.** Laboratory platform for testing detectability of ten detectable warning surfaces in association with four platform surfaces; Phase I (modified for Phase II). Located at old Broadway Station, MBTA.

varied from one another in dimensions. They all, however, represented truncated dome patterns. For Phase II, three of the original ten warning surfaces were replaced with three new warning surfaces. Dimensions and materials of each of the 13 detectable warnings (10 + 3) are depicted on pages 1-10 through 1-16.

Because tactile (underfoot) detection was of primary interest, participants were guided by a 20 ft. rope, approximately waist high, which was secured at one end to a post which could be wheeled over the platforms to each test site. The other end of the rope was held by an experimenter who stood with the warning surface between the subject and herself. (Thus, participants did not use their customary travel aid such as a long cane or dog guide, which could have provided additional information.)

Distance traveled on the warning surfaces was measured using a standard measuring tape, and recorded in inches.

Sounds made by walking on different surfaces can also aid in the detection of detectable warnings. However, sound cues are frequently masked by ambient noise on transit platforms making it difficult to use this information. Therefore, the likelihood of participants detecting changes in surfaces on the basis of sound was minimized by having them listen to a tape recording of white noise at an average volume of 80 dB using a portable Walkman and headset, while walking toward each warning.

### 2.1.3 Procedure

Participants were tested individually in one-hour sessions. They were told that they would be walking on a large level platform having four surface materials likely to be used for platforms in a transit station, and 10 (Phase I) or four (Phase II) other surfaces which might be used as detectable warning surfaces on a transit platform edge. The four warning surfaces in Phase II included three new surfaces plus Surface A', which was tested again to provide a common measure across both phases to aid in the interpretation of results.

Participants were familiarized with the laboratory platform and procedure by having an experimenter serve as a sighted guide. Once familiarized with platform and procedure, participants were tested in the following way on each combination of platform surface and detectable warning surface.

In Phase I, Experimenter 1 guided the participant to a predetermined and randomly assigned start position (varying from 4 to 12 ft. from the warning surface) directly in front of the warning surface to be tested. Experimenter 1 positioned the guide rope by the participant's preferred hand, while Experimenter 2, positioned 20 ft. in front of the participant and holding the other end of the rope, asked the participant to "Start", signaling the start of the trial.

The participant then walked forward using the rope as a guide to assure straight line travel onto the warning surface. Participants stopped when they thought they had detected the warning. Experimenter 2 then measured the distance from the beginning of the warning surface to the toe of the participant's shoe which had progressed farthest onto the warning.

If a participant walked onto a warning surface and off the other end, traversing a distance of 49 in. or more, their performance on that trial was coded as a "failure to detect." For purposes of computing mean stopping distances only, such trials were assigned a stopping distance of 48 in. This procedure was repeated by each participant until all 40 platform surface x warning surface combinations were tested.

Following their last approach to each warning surface, participants were asked to rate each of the warning surfaces on a five-point scale, ranging from -2 to +2, for both detectability and safety—e.g., whether they felt they might slip or trip on the surface. A score of -2 meant that the surface was very difficult to detect or very unsafe. A score of +2 meant that the surface was very easy to detect or very safe to travel over. A score of 0 meant that the surface was not particularly easy or difficult to detect or that the surface was not particularly safe or unsafe.

For Phase II, participants were positioned a random distance (4 to 12 ft.) from each warning surface to be tested. An Experimenter, positioned 20 ft. in front of the participant, asked the participant to "Start," indicating the start of the trial. The participant then walked toward the remembered direction of the Experimenter's voice, until detecting a surface change. Participants stopped, and measurements were made as in Phase I. The procedure was repeated until participants approached each warning surface a total of three times from each platform surface. In this way, the same number of approaches to the warning surfaces (i.e., 24) were made as in Phase I (i.e., more replications of each surface but with fewer participants being tested). The order of testing platform surfaces was randomized, as was the order of testing warning surfaces within each platform surface.

## 2.2 RESULTS AND DISCUSSION

Data on detection rates and stopping distances were analyzed using Analysis of Variance (ANOVA), a statistical test which is used to determine whether differences in means are probably attributable to the research variables (in this case, the warning surfaces or platform surfaces), or whether they may be due to chance. Differences which are found to have less than a 5% probability of occurring by chance are said to be **significant** differences.

Detailed results of these statistical analyses are available in Appendix B. The results will be presented in this text in a more narrative form for the assistance of readers who are not familiar with statistical procedures and reporting. Only **significant differences** are reported in the text.

### 2.2.1 Detection Rates

Detection rates for all but one warning surface from Phases 1 and 2 were above 95%. (See "totals" column of Table 2-2). Surface J was the only surface to have a detection rate below 95%. It was detected on 85 of the 96 approaches (trials) for a detection rate of 88.5%. Failure to detect Surface J occurred primarily on trials when Surface J was approached from coarse aggregate concrete.

**Table 2-2. Detection Rates of Detectable Warning Surfaces—Phases I and II**

| Warning Surface | Number of Trials Detected | Percentage of Trials Detected |
|---|---|---|
| **Phase I** | | |
| A' | 92/96 | 95.8% |
| B | 92/96 | 95.8% |
| C | 94/96 | 97.9% |
| D | 96/96 | 100.0% |
| E | 95/96 | 99.0% |
| F | 94/96 | 97.9% |
| G | 94/96 | 97.9% |
| H | 94/96 | 97.9% |
| I | 92/96 | 95.8% |
| J | 85/96 | 88.5% |
| Totals | 928/960 | 96.7% |
| **Phase II** | | |
| A' | 92/96 | 95.8% |
| K | 93/96 | 96.9% |
| L | 94/96 | 97.9% |
| M | 93/96 | 96.9% |
| Totals | 372/384 | 96.9% |

* The total number of approaches to each warning surface was always 24.

In terms of detectability underfoot, with the exception of Surface J when approached from the coarse aggregate platform, there were no significant differences in detectability of the warning surfaces. From the standpoint of specifications then, there is considerable tolerance for variations in the dimensions for detectable warning surfaces.

Surface J was characterized by truncated domes which were perfectly smooth on top, and somewhat large in top diameter. The coarse aggregate platform was the "bumpiest" platform surface, i.e., the platform surface most closely resembling the texture of the truncated dome detectable warnings.

Dome base diameters from .80 in. to 1.285 in. were highly detectable, as were dome top diameters from .451 to .875 in. The closest distance between adjacent domes of highly detectable surfaces was 1.66 in., and the farthest distance was 2.85 in. Dome heights from .15 in. to .22 in. were equally detectable. In addition, highly detectable warnings were made in resilient rubber, rigid composites, glazed and unglazed tiles, stamped concrete, stamped metal, applied resilient coating, and polymer concrete. However, while tested surfaces varied along these dimensions, not all combinations of all dimensions were tested. Thus, it is possible that a surface falling within these specifications might not be highly detectable. For example, it is not known whether a surface having particularly large domes, placed particularly close together would be highly detectable.

Detection rates from the four platform surfaces are shown for Phases I and II in Table 2-3. Detection rates when warning surfaces were approached from brushed concrete, wood, and Pirelli tile were all better than 95% for both phases. Detection rates when warning surfaces were approached from coarse aggregate concrete, however, were 90.4% for Phase I* and 91.6% for Phase II. This suggests that use of a coarse aggregate surface adjoining a detectable warning may impair the detectability of some detectable warning surfaces which would otherwise be highly detectable.

**Table 2-3. Detectability Rates from Platform Surfaces—Phases I and II**

| | Phase I | | Phase II | |
|---|---|---|---|---|
| **Platform Surface** | **Number of Detections When Approaching from Platform** | **Percentage of Detections When Approaching From Platform** | **Number of Detections When Approaching From Platform** | **Percentage of Detections When Approaching From Platform** |
| Brushed Concrete | 240/240 | 100% | 93/96 | 96.9% |
| Wood | 236/240 | 98.3% | 95/96 | 99.0% |
| Coarse Aggregate | 217/240 | 90.4% | 88/96 | 91.6% |
| Pirelli Tile | 235/240 | 97.9% | 96/96 | 100% |

* In Phase I, the total number of approaches from each platform was 240, while in Phase II, the total number of approaches from each platform was 96.

### 2.2.2 Mean Stopping Distance

For both Phases I and II, results of analyses of mean stopping distances on each warning surface from each platform surface were in the same direction as results of analyses of detection rates. That is, mean stopping distances were similar for all surfaces except Surface J, and the stopping distance for Surface J was longer when Surface J was approached from the coarse aggregate platform.

In addition, with the exception of Surfaces D and K, mean stopping distances on all warning surfaces were longest when those warning surfaces were approached from coarse aggregate concrete. Thus, both detectability and stopping distance are adversely affected when detectable warnings are used in association with coarse aggregate.

### 2.2.3 Cumulative Stopping Distance

Cumulative stopping distance indicates how much of a warning surface is required to enable a given percentage of the target population (i.e., persons with visual impairments) to detect the warning surface and come to a stop without stepping beyond the warning. To determine the width of detectable warning required to enable detection and stopping, an analysis of cumulative stopping distance was performed.

In this analysis, the width of warning is presented in six-inch intervals. This reflects the tendency to recommend or require detectable warnings that are 24 in., 30 in., or 36 in. wide. These recommended widths are based on research, as well as being multiples of widths commonly used in the tile and paving industries. Table 2-4 (Cumulative Stoppping Distances [in %] as a Function of Platform Surface—Phases I and II), presents the percentage of trials on which participants stopped after traversing each width of each surface.

When travel was from the brushed concrete, wood, or Pirelli tile platform surface, 24 in. were required for participants to stop on at least 90% of the trials. However, when travel was from coarse aggregate, 36 in. were required for participants to stop on at least 90% of the trials.

Inspection of cumulative stopping distances within each platform surface again reveals that cumulative stopping distances from coarse aggregate were somewhat longer at each level than from any of the other surfaces.

**Table 2-4. Cumulative Stopping Distances (in %) as a Function of Platform Surface—Phases I and II**

| Distance (inches) | PLATFORM SURFACE | | | | Total |
|---|---|---|---|---|---|
| | Brushed Concrete | Wood | Pirelli Tile | Coarse Aggregate | |
| 48 | 100 | 100 | 100 | 100 | 100 |
| 42 | 99.0 | 99.8 | 100 | 97.4 | 99.1 |
| 36 | 97.0 | 99.6 | 98.7 | 92.5 | 97.0 |
| 30 | 94.4 | 97.4 | 97.0 | 84.3 | 93.3 |
| 24 | 90.8 | 92.5 | 92.2 | 75.5 | 87.8 |
| 18 | 79.8 | 79.7 | 81.4 | 56.1 | 74.25 |
| 12 | 59.2 | 66.0 | 59.3 | 37.5 | 55.5 |
| 6 | 25.5 | 41.2 | 29.2 | 22.4 | 29.6 |
| 0 | 4.5 | 8.4 | 6.9 | 8.8 | 7.15 |

* Combining data across all 13 detectable warning surfaces. Only Phase I data for tests on Surface A' were used in these calculations. Analysis of the cumulative stopping distances was performed for those trials in which warnings were detected (928 out of 960 approaches, or 96.7% of the trials in Phase I, and 280 out of 288 approaches, or 97.2% of the trials in Phase II).

This analysis shows that 24 to 36 in. of a detectable warning surface are typically required to enable stopping on 90-95% of trials on which the surfaces are detected. The width of detectable warnings to be required must be based on an acceptable level of risk. Determination of this level, however, is beyond the scope of this research.

ADAAG requires 24 in. of a detectable warning at transit platforms, 36 in. at hazardous vehicular ways, and at curb ramps, the full surface (typically about 6 ft.). Consistency in environmental cues greatly facilitates travel for blind travelers. It is recommended that the width of a detectable warning be consistent across all three of the above-mentioned applications. While research on stopping distances on detectable warnings has not been conducted on slopes, such as curb ramps, it seems improbable that stopping distances would be significantly greater than on level surfaces, particularly given the additional cues such as slope and traffic which are often available at curb ramps. A requirement for detectable warnings on the full surface of curb ramps does not seem justifiable on the basis of the amount of warning surface required to enable detection and stopping.

### 2.2.4 Subjective Rating of Ease of Detection and Safety on Warning Surfaces

It would be useful to know whether the detectability results could have been predicted on the basis of subjective ratings alone; if this were possible, it would simplify and reduce the cost of future evaluations of new surfaces. Specifically, would it have been possible to identify Surface J as significantly less detectable than the other surfaces when approached from a coarse aggregate base surface?

In fact, Surface J was rated as not easy to detect by those who rated it from a coarse aggregate base surface; indeed, Surface J received the lowest detectability rating of the ten surfaces rated. This suggests that the subjective ratings may have objective validity. Unfortunately, as Table 2-5 shows, Surface J was not alone in receiving a poor rating. Surfaces B and F received comparable low ratings, yet neither had a comparable low detectability in the coarse aggregate base condition. Therefore, although these ratings would allow us to identify J as a poor warning surface, they might also cause us to falsely reject surfaces with no objective detectability faults.

In addition, there are several general factors that would complicate the use of subjective ratings for detectability evaluations. First, it is important to remember that subjective ratings depend on context. Rating a particular surface in the context of one set of different surfaces is not equivalent to rating it in the context of a second set of surfaces, and even less would it be equivalent to rating it in isolation from other surfaces. It might, however, be possible to establish a standard reference surface for comparative rating purposes. Second, because of the demonstrated differences in detectability as a function of base surface, it is essential to collect subjective data for all types of base surface.

**Table 2-5. Mean Ratings for Ease of Detection, Approach from Coarse Aggregate—Phase I**

| Surface | Mean |
|---|---|
| A' | 0.43 |
| B | -0.43 |
| C | 0.71 |
| D | 1.29 |
| E | 0.29 |
| F | -0.29 |
| G | 1.43 |
| H | 0.29 |
| I | 0.71 |
| J | -0.57 |

### 2.2.5 Effect of Gradually Increasing Dome Height

Among the 10 warning surfaces tested in Phase I, there were two (Surfaces C and D) which varied only in consistency of dome height.. The height of the domes of Surface D increases gradually, reaching full height 3 in. from the leading edge, as one approaches the warning. Surface C is identical to Surface D, except that it was installed in such a manner as to result in domes of consistent height. Therefore, a comparison of the data relative to these two surfaces could shed light on any differences in detectability or amount of warning surface required to enable detection and stopping, which could be attributed to gradually increasing dome height.

It was not possible to determine from the data in this experiment whether there was any effect on detectability or stopping distance, of gradually increasing dome height.

### 2.2.6 Effect of Differences in Resiliency between Platform Surface and Warning Surface

Both the warning and platform surfaces used in this research varied in their resiliency. While it was not a primary goal of this research, these variations in resiliency, nonetheless, provided an opportunity to obtain additional information regarding the potential contribution to warning detection, of differences in resiliency between platform and warning surfaces. No physical measurement of resiliency was obtained, but, for the purposes of this analysis, warnings which were composed of rubber were considered to be resilient (A and L), and those which were composed of concrete, tile, metal or composite were considered to be non-resilient (C, D, E, F, J, M and K).

Mean stopping distances on resilient and non-resilient warnings were examined for trials in which the approach was from a resilient (Pirelli tile) and from a non-resilient (brushed concrete) surface. Pirelli tile and brushed concrete were chosen as the platform surfaces which were most clearly representative of resilient vs. non-resilient platform surfaces. If differences in resiliency between a warning and an adjoining platform surface enhance detectability, then resilient warning Surfaces A and L would be expected to result in lower mean stopping distances when approached from brushed concrete than from Pirelli tile. Conversely, non-resilient warning Surfaces B, D, F, I, K, M, and O would be expected to result in lower mean stopping distances when approached from Pirelli tile than from brushed concrete.

Comparing the mean stopping distances for warning surfaces approached from brushed concrete with those approached from Pirelli tile for each of the 13 warnings tested (one of which, A', was tested in both Phase I and Phase II, for a total of 14 warnings tests), we find that of 14 tests (see Appendix B, Table B-2), in four cases resiliency contrast appears to result in shorter stopping distances (the expected direction), while in eight cases resiliency contrast appears to result in longer stopping distances. In two cases, Surfaces A and E were equivocal.

Therefore, while it is probably true that considerable differences in resiliency enhance warning detection, for the limited range of differences in resiliency currently being considered for detectable warnings as well as for platforms or paving surfaces, differences in resiliency do not appear to significantly increase underfoot detectability.

# 3. PHASE III—DETECTION OF WARNING SURFACES BY USE OF A LONG CANE

This phase was undertaken to partially replicate Phase I in order to determine whether surfaces which were highly detectable underfoot were also highly detectable using a long cane.

## 3.1 METHOD

### 3.1.1 Subjects

Eight blind travelers (totally blind or having no more vision than light projection) who normally travel with a cane participated in Phase III. Three of the participants were males and five were females, the mean age of the group was 44.7 years, and the age range was 38 to 58 years. Participants were obtained in the same manner as for Phases I and II.

### 3.1.2 Materials

The materials were the same as those used in Phase I with the following exceptions. The rope guide was not used; instead, participants used their long canes to detect the warning surfaces. Also, the number of surfaces tested was reduced to four – Surfaces A, C, D, and J. These surfaces were chosen based on the results of Phase I. They represented surfaces with extremes of detectability and mean stopping distances.

### 3.1.3 Procedure

Participants were tested individually in a one-hour session. Procedure and instructions were the same as those described for Phases I and II with the following exceptions. Participants used their long canes to detect the warnings, rather than their feet. Straight line travel towards the appropriate warning was achieved by having participants walk towards the voice of the experimenter, stopping as soon as they detected the presence of the warning with their cane. If a participant walked onto a warning surface and traversed the 48 in. width of the surface without stopping, their performance on that trial was coded as a "failure to detect." For purposes of computing mean stopping distances only, the trials were assigned a stopping distance of 48 in. Participants made three approaches to each of the four warning surfaces from each platform surface. In this way, the same number of approaches to the warning surfaces were made as in Phase I, but with fewer participants needing to be tested. Order of warning surfaces, as well as distances from warnings, was randomized within platform surfaces, which were counterbalanced.

## 3.2 RESULTS AND DISCUSSION

As for Phases I and II, detailed results of the statistical analyses will be presented in Appendix B. Results will be described briefly in this section.

### 3.2.1 Detection Rates

Three of the four detectable warning surfaces were detected on 100% of the trials (Surfaces A, C, D), while Surface J was detected on 98% of the trials. Surface J, approached from the coarse aggregate platform surface, yielded significantly lower detection rates than any other surface approached from any other platform. These results are consistent with those found in testing underfoot detection; both identify Surface J and coarse aggregate as being associated with lower detectability.

Thus, in this research, as in previous research (Peck and Bentzen 1987) in which both detectability underfoot and detectability using a long cane were measured, surfaces which are readily detectable underfoot are readily detected using a long cane.

### 3.2.2 Mean Stopping Distance

There were no significant differences in mean stopping distances attributable to different warning surfaces, (unlike for Phase I, in which Surface J was found to be associated with longer stopping distances), but approach from coarse aggregate was again shown to be associated with greater stopping distances. Thus, in general, the results of underfoot testing were confirmed.

### 3.2.3 Cumulative Stopping Distance

An analysis of the cumulative stopping distance on each surface, combining data from all subjects, all trials, all warning surfaces and all platform surfaces, showed that participants stopped before actually stepping onto the surface on 90% of trials, and subjects stopped after traversing no more than 6 in. onto the surface on almost 100% of trials. This differs markedly, but in an expected direction, from cumulative stopping distances based on underfoot detection. That is, persons traveling without a long cane (a large majority of persons who are visually impaired) have no advance information about changes in surface (e.g., textures) until they encounter them underfoot, while persons traveling with the aid of a long cane are able to perceive and react to surface changes before encountering them underfoot.

### 3.2.4 Subjective Rating of Ease of Detection and Safety on Warning Surfaces

As in underfoot detection, on the last set of trials, after each trial, subjects who completed the trials using their long canes were asked to rate that warning surface for both ease of detection and how secure they felt traveling over the surface (i.e., did they feel any potential for injury—tripping, slipping, turning an ankle, etc.). Ratings for ease of detection were made on a Likert scale with +2 being "very easy to detect" and -2 being "very difficult to detect." A score of "0" on ease of detection meant that the surface was neither easy nor difficult to detect. Ratings for security were also made on a Likert scale with +2 being "very safe" and -2 being "very unsafe." A score of "0" on safety meant that the surface was neither safe nor unsafe to travel over.

The mean subjective ratings for ease of detection and security using a long cane, for each of the four surfaces are shown in Table 3-1. These ratings are not analyzed by platform surface, as were the ratings for the underfoot tests, because the smaller number of participants would be likely to make such an analysis meaningless (Phase I, 24 participants; Phase III, 8 participants).

Once again, it can be seen that subjective ratings of detectability have a relatively wide range (+ 0.38 to +1.25), while it will be recalled that the four warning surfaces were statistically equal in mean stopping distance. Furthermore, Surface J, which was less detectable than the other surfaces when approached from the coarse aggregate platform surface, was subjectively rated as more detectable overall than either Surface C or Surface D. This further confirms that subjective judgment of detectability does not capture all of the variability which can be demonstrated in human performance, nor does human performance capture all the variability which can be seen in the subjective judgments. A combination of human performance testing and subjective judgments made under situations similar to those in which the warnings will be used appear to be necessary to obtain a complete picture of detectability of detectable warning surfaces.

**Table 3-1. Mean Ratings for Detectability and Safety—Phase III**

| Surface | Mean Detectability Rating | Mean Safety Rating |
|---|---|---|
| A | 1.25 | 1.38 |
| C | 0.50 | 0.62 |
| D | 0.38 | 1.12 |
| J | 0.75 | 1.12 |

# 4. PHASE IV—PILOT STUDY: NEGOTIABILITY AND SAFETY OF DETECTABLE WARNING SURFACES ON A LEVEL PLATFORM

This pilot study was undertaken to facilitate the choice of the most "useful" surfaces to be tested for safety and negotiability on ramps. It was desirable, overall, to test surfaces which had been shown to be high in detectability and which were also anticipated to be relatively safe and easy to negotiate. However, it was also desired to include surfaces which differed in specific ways, in order to begin to understand the contributions to safety and negotiability of various warning surface attributes. Furthermore, it was desired to test several warning surfaces which appeared to be particularly appropriate for retrofit situations.

In this pilot test, subjective information on perceived safety and ease of negotiability for 13 warning surfaces known to be highly detectable (Bentzen, et al. 1994) was obtained from 11 participants having physical disabilities.

## 4.1 METHOD

### 4.1.1 Subjects

Eleven persons with various mobility impairments participated in the study; information concerning participant attributes was obtained during an initial telephone interview and is presented in Table 4-1. Participants were recruited through the help of three private and public agencies who serve the needs of persons with disabilities, and also through mailings to paratransit users of the MBTA.

Participants were sought who represented a range of mobility impairments and degrees of loss of sensation, as well as a range of mobility aids (e.g., wheelchairs, canes, walkers, orthotics). It was desirable to use this non-probability sample to learn whether individuals having particular attributes would have specific difficulties in negotiating easily and safely over warning surfaces which have been shown to be highly detectable by persons with visual impairments.

Table 4-1. Matrix of Participant Attributes—Phase IV: Pilot Study

| Aid | Age | Sex | Onset<br>Early<br>Late | Sensation<br>Full<br>Minimal Loss<br>Moderate Loss<br>Severe Loss | Orthotics* | Etiology | Comment |
|---|---|---|---|---|---|---|---|
| Wheel-chairs | 24 | M | Early | Full | | Cerebral Palsy | Power Chair |
| | 39 | F | Early | Full | | Multiple Sclerosis | Manual Chair |
| | 41 | F | Early | Full | | Polio | Power Chair |
| | 58 | F | Late | Full | | Multiple Sclerosis | Scooter |
| Canes Crutches Walkers | 22 | M | Late | Severe | HKAFO | Spinal Cord Injury | Standard Walker |
| | 34 | F | Early | Minimal | Shoe Orthotics | Spina Bifida | One Underarm Crutch |
| | 49 | F | Early | Full | | Cerebral Palsy | Heavy (15 lb.) Rollator Walker |
| | 50 | F | Early | Full | KAFO | Cerebral Palsy | Quad Cane (wide) |
| | 55 | F | Late | Full | | Unknown | Cane |

* KAFO = Knee-ankle-foot orthotic
HKAFO = Hip-knee-ankle-foot orthotic

### 4.1.2 Materials

Human performance testing was conducted on a portion of the laboratory platform constructed by the MBTA for detectability testing. Specifically, testing was conducted on that portion of the level platform having a brushed concrete platform surface adjoined by ten different detectable warning surfaces. (See Figure 4-1.) In addition, samples of five other warning surfaces which had been installed in the area of the original test platform were also rated for negotiability and safety.

### 4.1.3 Procedure

Participants were tested individually in approximately one-hour sessions. They were told that they would be traveling over a large brushed concrete platform and 10 other surfaces which might be used as detectable warning surfaces on transit

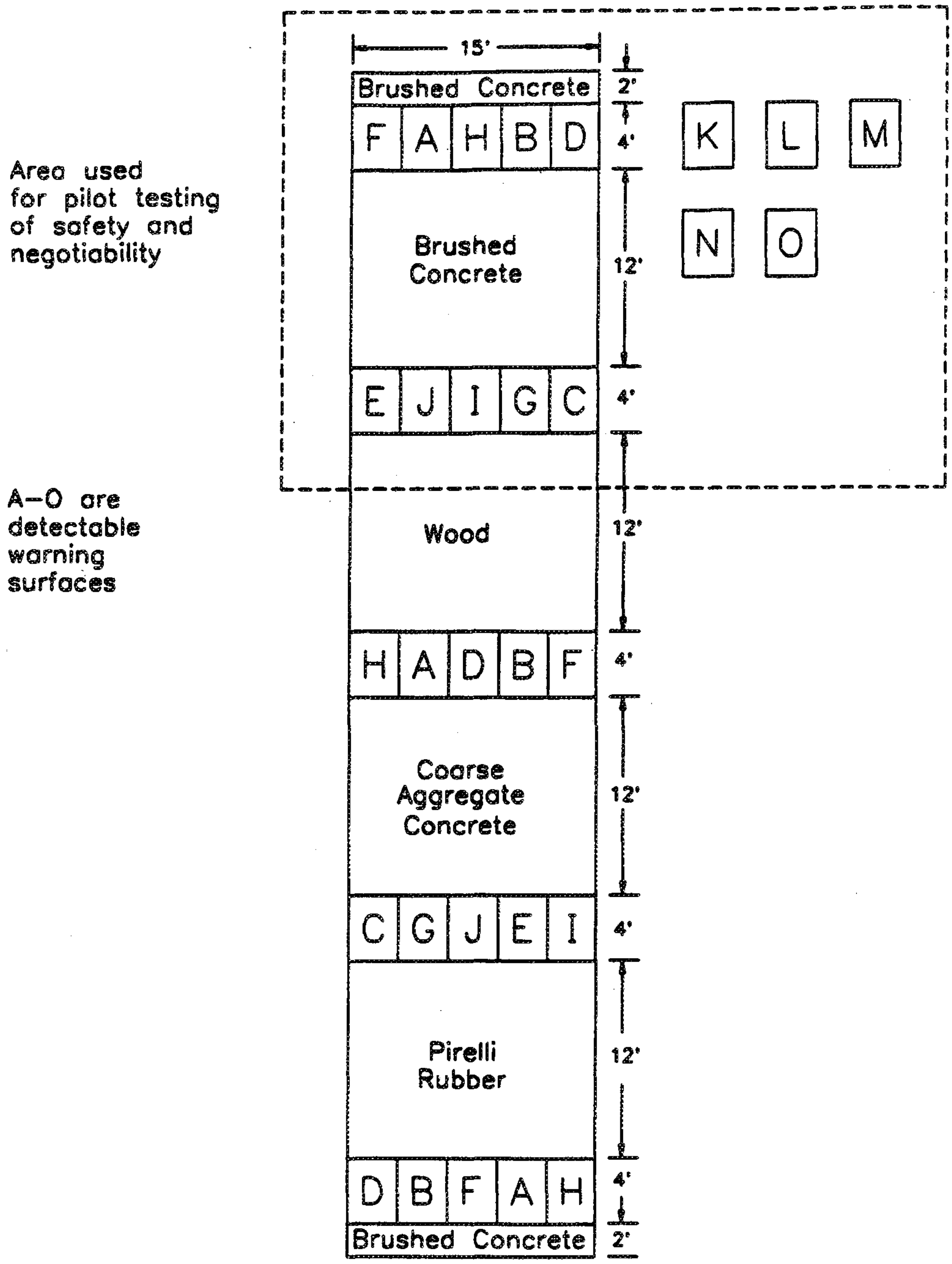



Figure 4-1. Laboratory platform for testing detectability of ten detectable warning surfaces when approached from four platform surfaces. Figure shows portion of platform and adjoining level floor used for pilot testing of safety and negotiability. Constructed at old Broadway Station, MBTA.

platform edges and curb ramps. Participants started approximately four feet from each surface and were told that they were free to maneuver on these surfaces in any way that they wished to, but including starting, stopping and turning on each surface. They were given as much time as desired to complete this task. After maneuvering on each of the 10 surfaces adjoining the brushed concrete platform, participants maneuvered on each of the five detectable warning surfaces installed on the floor near the platform.

After maneuvering over each warning surface, participants were asked to rate that surface relative to travel on brushed concrete for negotiability (ease of travel) and safety. Ratings were made on a five-point scale, ranging from 1 to 5, for both negotiability and safety. A score of 1 for negotiability meant that the surface was as easy to travel over as a brushed concrete surface; a score of 5 meant that the surface was much <u>more</u> difficult to travel over than a brushed concrete surface. Similarly, a score of 1 for safety meant that participants felt as safe traveling over the warning surface as they felt traveling over a brushed concrete surface, and a score of 5 meant that they felt much <u>less</u> safe on the warning surface than on a brushed concrete surface.

Along with their ratings, participants were asked several open-ended questions concerning their ease of travel and safety on the warning surfaces on the level platform, as well as on a hypothetical sloped surface.

At the end of the testing session participants were asked to choose the "three best" warning surfaces for curb ramps, and also to choose the single one they thought would be "best" on a curb ramp. Additionally, they were asked if they thought that any of the warning surfaces should definitely <u>not</u> be used on a curb ramp.

## 4.2 RESULTS AND DISCUSSION

Data from Phase IV were analyzed for the purpose of providing information regarding subjective judgments of safety and negotiability which could be used to facilitate the choice of the most "useful" surfaces for further testing on ramps. The actual data from this pilot test were but one element used to decide which surfaces would be tested on ramps. Descriptive analyses were carried out in the following manner. Participants' "first choices", "top three choices" and "worst choices" were examined for trends. Ratings for negotiability and safety were averaged and rank ordered, as were the number of rankings of 1 or 2 (most like brushed concrete in terms of negotiability and safety) versus ranks of 3, 4, or 5 (moderately to much more difficult or unsafe than brushed concrete) for each surface. These data were then compared along similar lines with the data from Phases I through III.

The general conclusion, which can be drawn from the analysis of this pilot data (i.e., participants ratings and recommendations regarding the negotiability and safety on the warning surfaces) in comparison with the performance and ratings of detectability and safety (Phases I through III), is that those surfaces which were most detectable by participants with visual impairments tended to be those that were least preferred by persons with mobility impairments.

The final choice of nine detectable warnings to be tested on curb ramps was made based on results of Phase IV in comparison with Phases I and III (Phase II had not been conducted, so objective detectability data on some surfaces was not yet available), appropriateness of some surfaces to retro-fit applications, and with input from the project's Steering Committee. A ninth surface was also chosen for testing on ramps because it was descriptively the same as one other surface, and also looked the same. At issue here was whether surfaces which "seem to be the same" can be assumed to be equal in safety and negotiability.

The nine detectable warnings were chosen as follows:

Surface A. Research on this surface was the basis for the ADAAG specifications. In addition, there has been more research on this surface because it has been in use at two properties for several years. It was highly detectable in Phase I testing and subjective judgments in this pilot test rated it intermediate in safety and negotiability.

Surface B. The surface configuration of this surface is identical to that of Surface A, but Surface A was resilient and Surface B was non-resilient. Some differences between the two surfaces could be observed in both objective testing and subjective ratings. Subjective data on negotiability and safety from participants who have physical impairments showed that Surface B placed in the top five of surfaces easiest and safest to negotiate, while Surface A did not rate quite as highly. Analysis of the detectability data, collected from participants who are visually impaired, showed that there was no significant difference between these two materials in terms of detectability and stopping distance. However, subjective ratings from participants who are visually impaired, suggested that people found the resilient surface to be much more detectable than the non-resilient.

Inclusion of both of these surfaces (A and B) in testing safety and negotiability was needed to determine whether differences in resiliency of otherwise similar surfaces affect human performance. If human performance is affected, this implies that products having similar dimensions, but differing in resiliency, cannot be assumed to be equal in detectability, safety, and negotiability, but must be subjected to independent testing.

Surface D. Analysis of the objective ratings from participants with physical impairments showed this surface, having relatively large domes with additional texture elements, to be one of the least negotiable and least safe. However, both objective detectability and stopping distance data, and subjective ratings by participants with visual impairments in Phase I showed this surface to be very good. It was important to subject this surface to performance testing on ramps because of this discrepancy with one group objectively and subjectively rating it so highly and the other so low. It was considered necessary to attempt to corroborate, by more objective testing, the subjective judgments that this surface would cause difficulties in negotiability and safety from people with physical impairments.

Surface F. This tile surface was the only one tested for detectability on which the domes were aligned horizontally and vertically and not diagonally. It was highly detectable. This dome alignment might or might not have particular advantages for persons with physical impairments. For example, wheels may either ride more smoothly, or they might get trapped between the domes, making wheelchair control more difficult. Based on the analysis of subjective data from participants with physical impairments, and the objective and subjective data from participants with visual impairments, this tile was shown to be negotiable and safe as well as detectable.

Surface I. This polymer concrete surface, having relatively large domes was judged by participants with physical impairments to be the easiest to negotiate as well as the safest. Objectively, participants with visual impairments found it to be detectable and its stopping distances were comparable to most others. Analysis of the subjective data from participants with visual impairments showed that this surface made it into the top five for detectability.

Surface K. This is a stamped concrete surface designed for retrofitting over concrete, on which neither detectability data nor subjective ratings were available at the time the surfaces were chosen for testing on ramps. However, the concept of concrete stamping appeared to have considerable appeal from the aspects of cost and anticipated ease of installation. Therefore, it was desired to obtain objective measures of safety and negotiability. (Subsequent detectability testing in Phase II indicated that Surface K was highly detectable).

Surface L. This applied resilient surface was selected primarily because of its ease of installation and its applicability in retrofit situations. Participants with physical impairments did not judge this surface to be very negotiable or safe. Subjectively, it was judged to be moderately detectable and safe by participants with visual impairments. (Subsequent detectability testing in Phase II indicated that Surface L was highly detectable).

Surface M. This abrasive-coated steel surface was judged as one of the most negotiable and safe surfaces by participants having physical impairments. It was subjectively judged as moderately detectable and safe by participants with visual impairments. (Subsequent detectability testing in Phase II found Surface M to be highly detectable). Surface M was of interest particularly for retrofit situations, because it is quite thin, and for application over bases which are not totally flat, because it is somewhat flexible.

Surface O. This surface was descriptively and visually the same as Surface M, but the subjective ratings of safety, negotiability and detectability were different. Surface O was judged as less negotiable and less safe than Surface M by participants with physical impairments, and as less detectable and less safe by participants with visual impairments. No detectability testing was done on this surface.

# 5. PHASE V—NEGOTIABILITY AND SAFETY OF DETECTABLE WARNINGS ON SLOPES

In this phase, both objective and subjective measures of negotiability and safety of detectable warnings on slopes were obtained from 40 persons with physical disabilities.

## 5.1 METHOD

### 5.1.1 Subjects

Forty persons with physical impairments participated in this study. They were recruited through six public and private agencies which serve the needs of persons with physical impairments, and also through mailings to MBTA paratransit riders.

Participants were purposefully sought who represented a wide range of attributes of persons who are physically disabled and who travel regularly and independently in the environment. It was desirable to use this non-probability sample to learn whether individuals having particular attributes are affected in their ability to negotiate easily and safely over detectable warning surfaces applied to ramps. The variables of most interest and concern were mobility aid used, amount of sensation, and cause of impairment. Table 5-1 is a matrix of participant attributes. Over-represented in the group were participants who were severely impaired or who were anticipated to be particularly likely to experience difficulty traveling over the bumpy detectable warning surface.

**Table 5-1. Matrix of Participant Attributes—Phase V**

| Aid | Age | Sex | Onset<br>Early<br>Late | Sensation<br>Full<br>Minimal Loss<br>Moderate Loss<br>Severe Loss | Orthotics* | Prosthetics | Etiology | Comment |
|---|---|---|---|---|---|---|---|---|
| "Wheels" | 20 | F | Early | Full | | | Cerebral Palsy | Zippy Chair (mother pushed) |
| Wheel-chairs; Scooters | 26 | M | Late | Severe | | | Spinal Cord Injury | Quickie GPV (quadriplegic) |

## Table 5-1. Matrix of Participant Attributes—Phase V (continued)

| Aid | Age | Sex | Onset<br>Early<br>Late | Sensation<br>Full<br>Minimal Loss<br>Moderate Loss<br>Severe Loss | Orthotics* | Prosthetics | Etiology | Comment |
|---|---|---|---|---|---|---|---|---|
| "Wheels"<br><br>Wheel-chairs; Scooters | 29 | F | Late | Full | | | Multiple Sclerosis | Standard Manual Chair |
| | 36 | M | Early | Full | | | Arthritis; Scoliosis | Quickie Chair |
| | 56 | M | Late | Minimal | | | Spinal Cord Injury | Quickie II Chair (paraplegic) |
| | 37 | M | Late | Full | | | Spino-Muscular Atrophy | Power Chair |
| | 41 | F | Early | Minimal | | | Polio | Power Chair |
| | 45 | F | Early | Full | | | Spinal Cord Injury | Power Chair |
| | 48 | M | Early | Full | | | Centro-Nuclear Myopathy | Power Chair |
| | 52 | M | Late | Severe | | | Spinal Cord Injury | Power Chair |
| | 56 | F | Late | Full | | | Bilateral Amputee | Power Chair |
| | 47 | M | Early | Full | | | Cerebral Palsy | Power Chair/ Foot Control |
| | 41 | M | Late | Moderate | | | Multiple Sclerosis | 4-Wheel Scooter |
| | 52 | M | Late | Full | | | Spinal Cord Injury | 3-Wheel, Rear Drive Scooter |
| | 58 | F | Late | Full | | | Multiple Sclerosis | 3-Wheel, Rear Drive Scooter |
| "Tips"<br><br>Canes; Crutches; Walkers | 37 | M | Late | Severe | | Below Knee | Accident | Cane |
| | 47 | F | Late | Full | AFO (right foot) | | Stroke | Cane |
| | 51 | F | Late | Full | AFO (right foot) | | Stroke | Cane |
| | 53 | F | Late | Severe | | Bilateral Below Knee | Accident | 2 Canes |
| | 68 | F | Late | Full | | | Arthritis | Cane |
| | 70 | F | Late | Moderate | In Shoes | | Arthritis | Cane |
| | 70 | F | Late | Moderate | | | Spinal Stenosis; Stroke | Cane |

## Table 5-1. Matrix of Participant Attributes—Phase V (continued)

| Aid | Age | Sex | Onset<br>Early<br>Late | Sensation<br>Full<br>Minimal Loss<br>Moderate Loss<br>Severe Loss | Orthotics* | Prosthetics | Etiology | Comment |
|---|---|---|---|---|---|---|---|---|
| "Tips"<br><br>Canes; Crutches; Walkers | 50 | F | Early | Full | KAFO (both legs) | | Cerebral Palsy | Narrow-Based Quad Cane |
| | 34 | F | Early | Minimal | Molded Shoe Braces | | Spina Bifida | 1 Under-Arm Crutch |
| | 43 | F | Late | Full | | | Accident | 2 Under-Arm Crutches |
| | 55 | M | Early | Full | | | Muscular Dystrophy | 2 Under-Arm Crutches |
| | 56 | M | Early | Full | | | Cerebral Palsy | 2 Under-Arm Crutches |
| | 26 | M | Early | Full | | | Cerebral Palsy | Canadian Crutches |
| | 29 | M | Late | Full | | | Spinal Cord Injury | Canadian Crutches |
| | 46 | M | Early | Moderate | | | Charcot Marie Tooth Disease | Canadian Crutches |
| | 28 | M | Late | Severe | HKAFO | | Spinal Cord Injury | Standard Walker |
| | 49 | F | Early | Full | | | Cerebral Palsy | Heavy Rollator Walker |
| | 80 | F | Late | Full | | | Stroke | Light Rollator Walker |
| "No Aid" | 32 | M | Late | Minimal | AFO | | Accident | |
| | 32 | M | Late | Severe | AFO | | Gunshot Wound | |
| | 45 | M | Late | Severe | | Below Knee | Land Mine | |
| | 51 | M | Late | Severe | | Ankle-Foot | Gunshot Wound | |
| | 19 | F | Early | Full | | | Unknown | |
| | 38 | F | Early | Full | | | Cerebral Palsy | |
| | 71 | F | Late | Moderate | | | Poor Circulation | |

* AFO = Ankle-foot orthotic
KAFO = Knee-ankle-foot orthotic
HKAFO = Hip-knee-ankle-foot orthotic

Steering Committee members, Project ACTION staff, and the physical therapist consultant (L. Desmarais, RPT) to this project all considered that the range of participants adequately represented most persons with physical disabilities who traveled on public transit, as well as a number of other persons whose travel was likely to be more limited. Twenty participants were male and twenty were female; the mean age was 46 years, and the range of ages was 20 to 80 years.

### 5.1.2 Materials

Human performance testing was conducted on ten adjoining laboratory ramps constructed by the MBTA in an unused portion of a rail rapid transit station (the same as that used for Phases I through IV). (See Figure 5-1.) Each ramp was 6-feet-long by 4-feet-wide with a 1:12 slope. Each of nine ramps had a different detectable warning surface applied over the entire 6-foot-by-4-foot ramp area, and one ramp had a brushed concrete surface. Each of these detectable warning surfaces is depicted on pages

Selection of the nine detectable warning surfaces was based on a number of criteria:

- pilot test of safety and negotiability (subjective judgment)
- detectability (Bentzen, et al. 1984)
- input from the Steering Committee
- appropriateness of some surfaces for retrofit applications

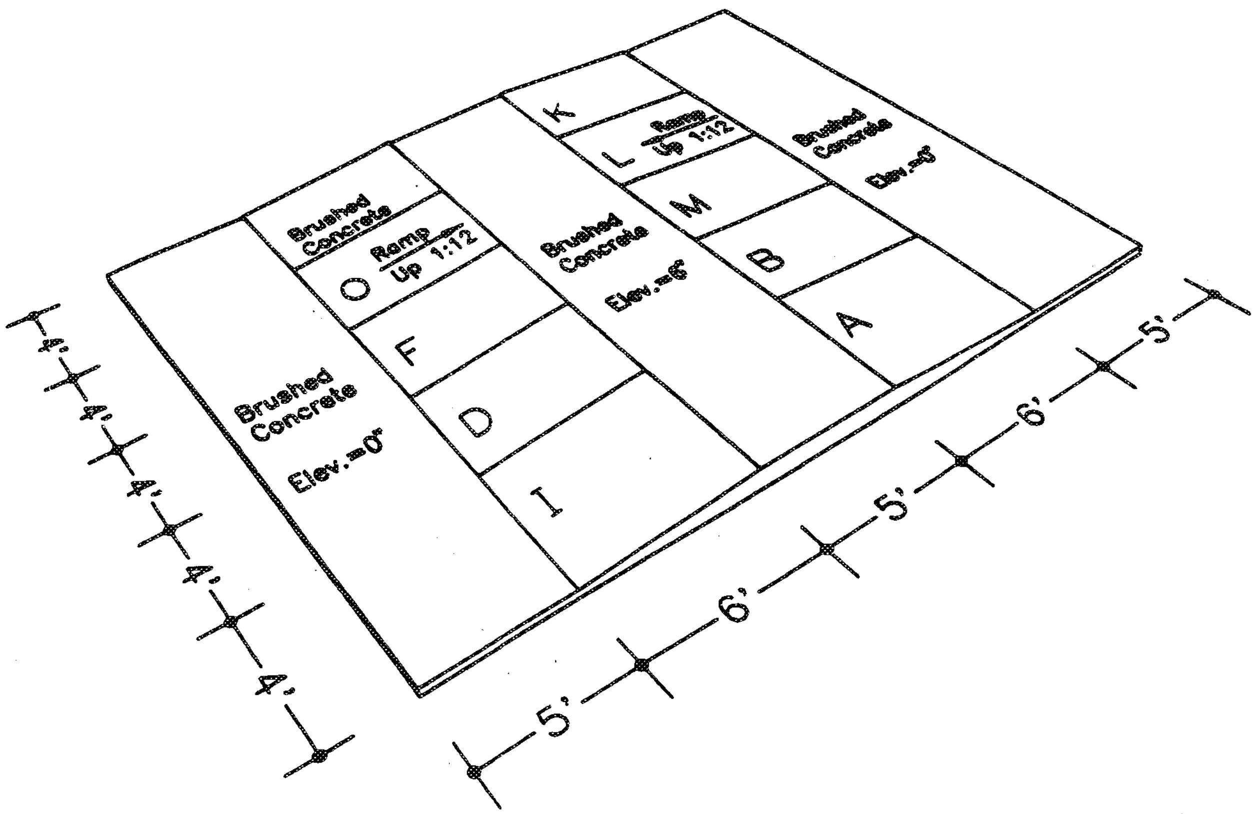



Figure 5-1. Laboratory ramps for testing safety and negotiability of nine detectable warnings on slopes (1:12). Constructed at old Broadway Station, MBTA.

In this study, subjective measures (i.e., participants' ratings) of negotiability and safety were obtained, and participants' actual performances negotiating these surfaces were videotaped for analysis.* Video analysis was based on an objective rating procedure designed to assess safety and ease of travel over these surfaces.

As no rating scale could be located in the literature, a major undertaking of this project was the development of a rating scale which captured differences in performance which were indicative of ease of negotiation and of safety, both between participants and between surfaces. This task was accomplished with input from Linda Desmarais, R.P.T., consultant to this project, and was piloted with the assistance of persons with physical disabilities at Boston College, on ramps at Boston College.

The rating scale varied for each category of aid ("No Aid," "Wheels," and "Tips"), taking into account the different issues that arise with different aids. The "No Aid" group consisted of people who had balance problems, and/or who wore orthotics or prostheses. The "Wheels" group consisted of people who used power wheelchairs, manual wheelchairs, or scooters. The "Tips" group consisted of people who used canes, crutches, or walkers, including rollator walkers. A copy of the rating scale is shown in Appendix C. The various aids used were as follows:

**"Wheels"**

| | |
|---|---|
| Power wheelchair: | (5) non-pneumatic tires |
| | (1) pneumatic tires |
| | (1) non-pneumatic tires, foot control |
| Manual wheelchairs: | (1) standard, non-pneumatic tires |
| | (3) light weight (Quickie II) |
| | (1) sport (Quickie GPV) |
| Scooters: | (2) 3-wheeled scooters—rear wheel drive |
| | (1) 4-wheeled scooter—rear wheel drive |

* Videotaping was done by MBTA personnel.

"**Tips**"

| | |
|---|---|
| Crutches: | (1) single underarm<br>(3) double underarm<br>(3) Canadian |
| Canes: | (6) single, standard canes<br>(1) double canes (person used 1 in each hand)<br>(1) quad cane |
| Walkers: | (1) standard aluminum<br>(2) rollator (one heavy [14 lbs.]; one light) |

"**No Aid**"

| | |
|---|---|
| None: | (3) |
| Orthotics: | (2) ankle-foot |
| Prostheses: | (1) right, below knee, Betello weight-bearing with a flex-walk foot<br>(1) left AK, Silesian belt, Seattle foot |

### 5.1.3 Procedure

Participants were tested individually in sessions lasting approximately one hour. Participants were told that they would be traveling up and down 10 ramps, one of which had a brushed concrete surface and nine of which had different detectable warning surfaces. The procedure for testing negotiability and safety on the ramps was as follows.

The brushed concrete ramp, which served as a control surface, was traveled over at the beginning and again halfway through the session, so that participants could rate the warning surfaces relative to the brushed concrete. This also provided video raters with more than one sample of performance on brushed concrete for comparison with performance on the detectable warnings. The procedure was explained and demonstrated to each participant, using the first trial on the brushed concrete ramp.

Participants began on a level concrete platform five feet from the bottom of each ramp. They traveled straight ahead onto the ramp, and when they had traversed two feet onto the ramp surface (denoted by a black line going the full width of each surface) they stopped, waited approximately three seconds and then continued up the ramp. After traversing four feet onto the ramp surface (again, denoted by a black line going the full width of each surface) participants began to initiate a turn, which they completed at the top of the ramp, on a brushed concrete landing. They waited approximately five seconds at the top of the ramp (longer if they requested a slower pace), then descended, stopping briefly after traveling four feet down the ramp, then continuing straight down to the level concrete platform at the bottom of the ramp. Each participant completed a minimum of two initial practice trials on the brushed concrete ramp, to be sure that all instructions were understood, before beginning the experimental trials. Each trial was videotaped, including all trials on the brushed concrete ramp.

The order of testing of the nine different warning surfaces was randomized within the two sets of ramps, one set on each side of the central concrete aisle. (See Figure 5-1.) The order of these two sets was counterbalanced.

Following travel up and down each ramp, participants rated that ramp for ease of negotiability and safety relative to the brushed concrete ramp. Ease of negotiability was defined as, "the effort required to travel over the surface—starting, stopping, going up, going down, and turning on the surface material." Safety was defined as, "whether you feel insecure—like you may fall, slip, tip over, trip, or otherwise become harmed while traveling over the surface." Participants were periodically reminded to make each rating relative to their ease of travel and safety while traveling up and down the brushed concrete ramp. Ratings were made on a five point scale, ranging from 1 to 5 for both negotiability and safety. A score of 1 for negotiability meant that the warning ramp was as easy to negotiate as the brushed concrete ramp, and a score of 5 meant that the warning ramp was much <u>more</u> difficult to negotiate than the brushed concrete ramp. For safety, a 1 meant that the warning ramp was as safe to travel over as the brushed concrete ramp, and a 5 meant that the warning surface was perceived as much <u>less</u> safe to travel over than was the brushed concrete ramp.

After completing the entire session, participants were asked which three surfaces, of the nine warning surfaces over which they had traveled, they would choose for use on curb ramps, which surface they liked "best" for use on curb ramps, and which surface or surfaces "should not be used on curb ramps."

A Registered Physical Therapy Assistant was present at all times and shadowed participants throughout the entire experiment to ensure the safety of participants against the danger of falling. Participants were encouraged to rest as often as they desired, and given the option of not negotiating ramps that looked "too difficult or unsafe" to them. In addition, if participants appeared excessively tired, they were encouraged not to negotiate all the ramps. If they were too tired, they were not required to negotiate all ramps. Despite these options given to participants, only two participants did not complete all the ramps; these persons each failed to complete the negotiation of just two ramps having detectable warning surfaces.

## 5.2 RESULTS AND DISCUSSION

### 5.2.1 Objective Measures of Safety and Negotiability

Each videotaped trial (in which an individual traveled up and down one ramp, starting, stopping and turning on the warning surface) was viewed and rated by three independent raters, using a scoring sheet developed for the purpose. Depending on which travel aid was used, "no aid," "wheels" (power and manual wheelchairs and scooters), or "tips" (canes, crutches and walkers, including rollator walkers), the scoring sheet required observation and rating of three to seven behaviors, such as "effort required to start from stop," "stability," and "wheels slip." (See Appendix C). Some behaviors were rated separately for the trip up the ramp and the trip down. Each behavior received either a "0" or a "-1", depending on whether the rater judged that the participant had difficulty equal to that when traveling on a brushed concrete ramp (0), or greater difficulty (-1).

With 40 participants, nine ramps with detectable warning surfaces, and either three or seven observed behaviors per ramp per participant (depending on type of aid), there were a total of 2,268 behaviors observed and rated by each rater. Overall reliability was excellent: all three raters agreed on 89.5% of all ratings, and at least two out of three raters agreed on 92.9% of all ratings.

It was not possible to separate safety and negotiability in analyzing the data obtained, as a majority of the behaviors observed could be reflective of either or both decreased negotiability and decreased safety. For example, if wheels or tips became entrapped in domes, greater effort might be required to control the direction of travel (decreased negotiability), and a decrease in ability to control direction could result in decreased safety. The distinction between negotiability and safety impacts of wheel or tip entrapment would have been too subjective to be reliable. Therefore, raters observed only whether wheels or tips became entrapped. They did not speculate further on whether this resulted in decreased negotiability or decreased safety. All ratings of -1 are therefore simply reported as observed difficulties.

Of the 2,268 rated behaviors, raters were unanimous in observing no difficulties for 88.5% of all rated behaviors. However, on 258 rated behaviors (11.5%) difficulties were observed by one or more raters, indicating some degree of difficulty in negotiability or safety, which was greater than that observed for travel on brushed concrete.

Agreement on observed difficulties was not as good as for observations of no difficulty. Of 262 observed difficulties, 160 (61%) were observed by only one out of three raters, and only 20 (8%) were observed by all three raters. The low agreement on observed difficulties can be accounted for in two ways. First, there were relatively few observed difficulties overall, and the fewer the observations or ratings (of any sort) the more difficult it is to achieve high levels of inter-rater reliability.

Second, and perhaps more important to understanding the implications of this research, for many participants, travel under any circumstances is a challenge. The sample was deliberately biased toward inclusion of participants who were expected to have difficulties with detectable warnings. Persons with minimal physical disabilities, who comprise the largest group of persons who are physically impaired, were represented by only a few individuals in this project. It was difficult to standardize the determination of what constituted **additional** difficulties beyond what were normal for an individual participant who might, for example, be observed to travel on the brushed concrete ramp with great effort and instability.

Because of the difficulty of achieving agreement on observed difficulties, they were counted in two different ways. When the "number of observed difficulties" is reported for a given participant on a given surface, that number does not reflect interrater agreement; it is simply a count of any difficulties that any (or all) of the raters observed. In order to provide a measure that does reflect agreement (and thus perhaps extent of difficulty), we also report a "score"; the "score" for a given participant on a given surface is the sum of all observed difficulties added across all raters. For example, suppose a participant was observed to have two difficulties (e.g. wheels slip, and increased effort) on Surface A, by only one rater. The "number of observed difficulties" would then be two, and the "score" would also be two. If all three raters observed those same difficulties, however, the "number of observed difficulties" would still be two, but the "score" would be six.

Because of obvious differences in travel difficulty and types of problems, data were analyzed in groups according to type of travel aid ("no aid", "wheels", or "tips"). Furthermore, participants fell roughly into three categories: those with no scored travel difficulty, those with relatively few travel difficulties (average score per surface ranged from 0.2 to 1.3), and those with numerous difficulties (average score per surface ranged from 2.3 to 6.8, with the exception of one borderline case averaging 1.8). These data are summarized in Table 5-2.

**Table 5-2. Participants Grouped by Travel Aid and Amount of Difficulty**

| | Number of Subjects | Mean Score Per Surface |
|---|---|---|
| "No Aid" (7 participants) | | |
| No Difficulty | 4 | - |
| Few Difficulties | 3 | 0.6 |
| Numerous Difficulties | 0 | - |
| "Wheels" (15 participants) | | |
| No Difficulty | 5 | - |
| Few Difficulties | 6 | 0.5 |
| Numerous Difficulties | 4 | 3.6 |
| "Tips" (18 participants) | | |
| No Difficulty | 5 | - |
| Few Difficulties | 10 | 0.9 |
| Numerous Difficulties | 3 | 4.7 |

Fourteen of 40 participants (35%) showed no difficulties. Nineteen participants (47.5%) showed few difficulties, and seven (17.5%) were observed to have numerous difficulties across most or all of the surfaces. These seven participants accounted for 153 (59%) of the total 262 observed difficulties. Not surprisingly, interrater agreement on observed difficulties was best for those participants who had numerous difficulties, indicating that these participants represent the unambiguous cases.

Of the seven participants described below, who accounted for 59% of all observed difficulties, and on whom there was good interrater agreement, four traveled using manual wheelchairs, two used rollator walkers, and one used a quad cane. Three of those four participants who used manual wheelchairs had Quickie chairs, characterized by very small diameter front wheels. All three were very strong, active travelers, used to negotiating bumpy surfaces. While the detectable warnings caused some wheel slippage and entrapment, as well as apparently increased effort relative to brushed concrete, all of these three travelers appeared to compensate well for the effects of the detectable warnings.

One participant used a standard manual wheelchair, and finds most ramps (without detectable warnings) to be moderately difficult, primarily as a result of upper body weakness. He also appeared to compensate well for the effects of the detectable warnings, although they required increased effort, which tired him.

The two participants who used rollator walkers use wheelchairs for most outdoor travel. One mentioned that she finds curbs easier to negotiate than curb ramps when using her rollator walker. Both of these participants were too fatigued to complete all ramps having detectable warnings—each one failed to complete performance on two ramps.

The participant who completed the test using a quad cane uses a motorized wheelchair for all outdoor travel. He has knee, ankle and foot orthotics, and coordination difficulties, but was able to complete all travel on all test ramps.

The different kinds of difficulties encountered are presented in detail in Table 5-3, by travel aid, by surface, and by numbers of participants. For users of "wheels," the most common problem was increased effort starting on the up ramp; less commonly, wheels were occasionally trapped in domes or slipped. For users of "tips," not surprisingly, the most common problem was decreased stability, a problem for which many are already at risk. A number of these participants also showed increased effort starting up ramps, and a few participants showed trapped or slipping tips.

**Table 5-3. Number and Type of Observed Participant Difficulty for Each Detectable Warning Surface**

| Type of Difficulty | SURFACE | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | D | F | I | K | L | M | O | |
| **"No Aid"** | | | | | | | | | | |
| UP: Effort | - | - | - | - | - | - | 1 | - | - | 1 |
| Stability | 1 | - | - | - | - | 1 | 2 | - | - | 4 |
| DOWN: Stability | - | - | - | 1 | - | - | 2 | - | 1 | 4 |
| **"Wheels"** | | | | | | | | | | |
| UP: Effort | 4 | 5 | 4 | 1 | 4 | 4 | 3 | 5 | 3 | 33 |
| Stability | - | 1 | - | - | 1 | - | 1 | 2 | 1 | 6 |
| Wheels Slip | 2 | 4 | 4 | - | 1 | 1 | 2 | 2 | 1 | 17 |
| Wheels Trapped | 1 | 2 | 3 | - | 2 | 2 | 2 | 3 | 1 | 16 |
| DOWN: Stability | - | - | - | - | 1 | - | - | 1 | - | 2 |
| Wheels Slip | - | 3 | 6 | - | 2 | 1 | - | 1 | 1 | 14 |
| Wheels Trapped | 1 | 3 | 3 | - | 1 | 1 | 1 | 1 | 1 | 12 |
| **"Tips"** | | | | | | | | | | |
| UP: Effort | 2 | 4 | 5 | 1 | 5 | 3 | 4 | 4 | 4 | 32 |
| Stability | 5 | 4 | 4 | 3 | 6 | 1 | 8 | 2 | 6 | 39 |
| Aid Slips | - | 1 | 1 | - | 1 | - | - | 1 | - | 4 |
| Aid Trapped | - | 2 | 2 | 1 | 3 | 3 | 2 | 2 | 3 | 18 |
| DOWN: Stability | 5 | 8 | 6 | 3 | 5 | 2 | 6 | 5 | 1 | 41 |
| Aid Slips | - | 1 | - | - | 1 | 2 | - | - | - | 4 |
| Aid Trapped | - | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 15 |

Table 5-4 gives the distribution of ratings by rater, by surface and by participant. In the main body of the table, each entry consists of three numbers: # difficulties observed by rater 1/# difficulties observed by rater 2/# difficulties observed by rater 3. There are substantial differences according to total score per surface. Chi-square tests confirmed that, for users of "wheels", Surface F had a significantly lower score (1X9 chi-square = 38.06, $p<0.01$). When Surface F is excluded from the analysis, Surface K also had a significantly lower score (1X8 chi-square = 18.34, $p<0.05$) than the other surfaces, and Surfaces D and B had significantly higher scores (1X8 chi-square = 18.34, $p<0.05$). For users of "tips", Surfaces F and A had significantly lower scores, and I and B had significantly higher scores (1X9 chi-square = 21.21, $p<0.05$).

Excluding from the analysis the seven participants with numerous difficulties across nearly all surfaces, these findings are quite different. Among users of "wheels" the only finding is that Surface D had a significantly higher score (1X9 chi-square = 37.09, $p<0.01$); among users of "tips" there were no significant differences, although the finding that Surface K had a lower score (1X9 chi-square = 14.26, $p<0.09$) is significant.

## Table 5-4. Raters' Scores by Subject and Detectable Warning Surface (Number of Observed Difficulties, Rater 1/Rater 2/Rater 3)*

| | DETECTABLE WARNING SURFACE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Subject #** | A | B | D | F | I | K | L | M | O | **Score** |
| **"No Aid"** | | | | | | | | | | |
| 3 | - | - | - | - | - | - | 2/-/- | - | - | 2 |
| 11 | - | - | - | -/1/1 | - | 3/-/1 | -/1/2 | - | 1/1/1 | 12 |
| 12 | - | - | - | - | - | - | - | - | - | - |
| 20 | -/-/1 | - | - | - | - | - | - | - | - | 1 |
| 28 | - | - | - | - | - | - | - | - | - | - |
| 35 | - | - | - | - | - | - | - | - | - | - |
| 37 | - | - | - | - | - | - | - | - | - | - |
| **Subtotal Score** | 1 | - | - | 2 | - | 4 | 5 | - | 3 | 15 |
| **"Wheels"** | | | | | | | | | | |
| 6 | 1/-/2/ | 4/-/3 | 2/-/1 | -/-/1 | 1/1/1 | 1/-/1 | -/-/1 | -/-/3 | 1/-/1 | 25 |
| 8 | - | -/-/1 | 1/-/- | - | - | - | - | -/-/2 | - | 4 |
| 10 | - | 1/-/- | 4/-/- | - | - | - | - | - | - | 5 |
| 13 | - | - | - | - | - | - | - | - | - | - |
| 22 | - | - | - | - | - | - | - | - | - | - |
| 23 | - | - | - | - | - | - | - | - | - | - |
| 24 | 1/1/- | 1/1/- | 3/1/1 | - | 1/1/- | - | -/1/- | 1/1/1 | 1/-/- | 16 |
| 25 | - | - | - | - | - | - | - | - | - | - |
| 27 | 1/3/2 | 1/3/2 | - | - | 3/4/- | 1/3/- | 4/4/1 | 3/3/2 | 5/4/1 | 50 |
| 29 | - | - | - | - | - | - | - | - | - | - |
| 30 | - | 1/-/- | - | - | 1/-/- | 1/-/- | - | - | - | 3 |
| 33 | -/1/1 | 4/3/2 | 3/3/2 | - | 4/3/3 | 1/1/- | -/1/2 | 3/2/- | - | 39 |
| 36 | - | - | - | - | - | - | 1/-/- | - | 1/-/- | 2 |
| 38 | - | - | 2/-/- | - | - | - | - | - | - | 2 |
| 40 | - | 2/-/- | 5/-/- | - | - | -/-/2 | - | 1/-/2 | - | 12 |
| **Subtotal Score** | 13 | 29 | 28 | 1 | 23 | 11 | 15 | 24 | 14 | 158 |
| **"Tips"** | | | | | | | | | | |
| 1 | - | - | - | - | - | - | - | - | - | - |
| 2 | 1/-/- | -/-/1 | -/-/1 | - | 1/-/1 | 1/-/- | - | 2/1/- | - | 9 |
| 4 | - | - | - | - | - | - | - | - | - | - |
| 5 | - | 1/-/- | - | - | - | - | 1/1/1 | - | 1/-/- | 5 |
| 7 | - | - | 1/-/- | -/-/1 | - | - | 2/-/- | - | - | 4 |
| 9 | - | - | - | - | - | - | - | 1/1/- | -/1/1 | 4 |
| 14 | **/1/1 | 7/2/3 | 6/2/3 | 2/-/1 | 6/2/3 | 5/2/1 | **/2/1 | 3/1/- | 1/3/3 | 61 |
| 15 | 1/-/2 | 1/-/1 | 3/-/2 | -/-/1 | 3/-/- | 1/-/- | 1/-/1 | 1/-/- | 1/-/2 | 21 |
| 16 | - | - | - | - | - | - | - | - | - | - |
| 17 | - | 1/-/- | -/-/1 | -/-/1 | - | - | - | -/2/1 | - | 6 |
| 18 | - | - | - | - | - | - | - | - | - | - |
| 19 | 2/-/1 | 2/-/- | - | 1/-/2 | - | - | 2/-/- | 2/-/- | - | 12 |
| 21 | 2/-/- | 2/-/1 | 2/-/- | - | 2/-/- | - | 2/-/- | - | 1/-/- | 12 |
| 26 | - | - | - | - | 2/-/- | - | - | - | - | 2 |
| 31 | - | - | - | 2/2/- | 3/-/2 | 1/-/- | - | 1/-/- | - | 11 |
| 32 | - | - | - | - | - | - | - | - | - | - |
| 34 | 2/-/- | 1/-/- | 2/-/- | - | 2/-/1 | - | 2/-/- | 2/-/- | - | 12 |
| 39 | ** | 5/-/3 | 3/-/3 | 1/-/- | 4/-/3 | 4/-/3 | 5/-/3 | ** | 4/-/3 | 44 |
| **Subtotal Score** | 13 | 31 | 29 | 14 | 35 | 18 | 24 | 18 | 21 | 203 |

* e.g., S 6 traveled with the aid of wheels. On Surface I, each of 3 raters observed 1 difficulty; on Surface D, Rater 1 observed 2 difficulties, Rater 2 observed no difficulties, and Rater 3 observed 1 difficulty.

** Incomplete.

### 5.2.2 Subjective Measures of Safety and Negotiability

#### 5.2.2.1 Ratings

Participants rated each surface on a 5-point scale, for ease of negotiability and for safety, relative to brushed concrete. (1 = as easy or safe as brushed concrete; 5 = much more difficult or much less safe than brushed concrete.) Ratings were collected and analyzed within each of the three groups of travel aids. Mean ratings are given, with surfaces ranked from best to worst, in Table 5-5. Separate within-subjects ANOVA's for the ratings from each travel aid group were computed.

**Table 5-5. Mean Ratings of Ease of Negotiability and Safety, by Travel Aid (With Surfaces Listed in Left Column and Ratings Listed in Right)**

| "No Aid" | | | | "Wheels" | | | | "Tips" | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ease | | Safety | | Ease | | Safety | | Ease | | Safety | |
| I | 2.0 | I | 2.0 | F | 1.6 | F | 1.6 | I | 2.1 | I | 2.0 |
| K | 2.1 | D | 2.1 | M | 2.3 | A | 1.8 | F | 2.2 | K | 2.1 |
| A | 2.2 | K | 2.3 | A | 2.35 | L | 1.9 | K | 2.3 | F | 2.3 |
| B | 2.35 | A | 2.4 | L | 2.4 | M | 2.0 | M | 2.45 | A | 2.5 |
| D/L | 2.4 | B/L | 2.5 | I | 2.45 | I | 2.1 | O | 2.5 | O | 2.55 |
| D/L | 2.4 | B/L | 2.5 | O | 2.5 | B | 2.3 | A/D | 2.7 | D | 2.6 |
| F/M | 3.1 | F/M | 3.4 | K | 2.7 | D | 2.5 | A/D | 2.7 | B | 2.7 |
| F/M | 3.1 | F/M | 3.4 | B | 3.1 | O | 2.55 | B | 2.75 | M | 2.9 |
| O | 3.6 | O | 3.6 | D | 3.2 | K | 2.6 | L | 2.8 | L | 3.1 |

For the group of participants who traveled with "no aid", ratings differences between surfaces were significant for both ease, ($F(8,48) = 2.16$, $p<0.05$), and for safety, ($F(8,48) = 2.12$, $p<0.05$). On the basis of the Newman-Keuls procedure, the surfaces may be divided into two groups with significantly different ratings: Surfaces I, K, A, B, D, and L were rated relatively easy and safe to negotiate, and Surfaces F, M, and O were rated relatively difficult and unsafe.

For the group of participants who traveled with "wheels", differences in ratings were highly significant for both ease, ($F(8,112) = 5.28$, $p<0.0001$), and for safety, ($F(8,112) = 3.57$, $p<0.001$). On the basis of the Newman-Keuls procedure, the ratings for ease of travel indicate that Surface F was rated significantly better than any of the other surfaces. The ratings for safety were less conclusive, but the Newman-Keuls procedure indicated that Surface F was rated significantly safer than Surfaces D, K, and O.

For the group of participants who traveled with "tips", there were no significant differences in ratings of the surfaces for ease of travel or safety.

To summarize, the surface ratings show different and in some respects contradictory patterns for different groups of participants. In particular, Surface F was rated by users of "wheels" as very nearly equivalent to brushed concrete for ease of travel and safety, and clearly superior to the other surfaces; yet, those participants who use "no aid" rated Surface F as among the worst with respect to both ease and safety. (There was, however, only one observed difficulty on Surface F for all participants using "no aid.")

#### 5.2.2.2 Preferences

In addition to rating the nine surfaces for ease and safety, participants also expressed preferences by selecting the "three best", "single best", and any number of surfaces that "should not be used at all" from among the surfaces. Totals are given in Table 5-6 for each travel aid group. Note that surfaces that received equal preference scores are grouped together and repeated across adjacent rows.

For the group of participants who traveled with "no aid", a chi-square analysis indicated that there were no significant differences among preferences.

For the group of participants who traveled with "wheels", the preference for Surface F in the categories "three best" (1X9 chi-square = 19.27, $p<0.02$) and "single best" (1X9 chi-square = 24.17, $p<0.001$) was significant. The preference against Surface D (1X9 chi-square = 16.63, $p<0.05$) was also significant. These preferences conform well to the group's ease and safety ratings.

For the "tips" group, the preference for Surfaces I and K in the "three best" category (1X9 chi-square = 25.44, $p<0.001$) was significant, as was the preference for Surfaces F, I, and K in the "single best" category (1X9 chi-square = 17.63, $p<0.05$). These preferences mirror the ratings scores from this group, although the ratings differences were not statistically significant. There were no significant choices in the "worst" category.

**Table 5-6. Surface Preferences, Ordered from Highest to Lowest (Number of Subjects Choosing Each Surface)**

| "No Aid" | | | "Wheels" | | | "Tips" | | |
|---|---|---|---|---|---|---|---|---|
| Three Best | Single Best | Un-usable | Three Best | Single Best | Un-usable | Three Best | Single Best | Un-usable |
| K (4)* | K (2) | F (3) | F (12) | F (6) | D (6) | I (11) | I (4) | O (8) |
| A/D/I (3)** | D/L (1) | M/O (2) | D/I (5) | I (2) | B (3) | K (9) | F/K (3) | M (7) |
| A/D/I (3)** | D/L (1) | M/O (2) | D/I (5) | D/L/M (1) | I/K/O (2) | D/F (7) | F/K (3) | B/D/F/ L (4) |
| A/D/I (3)** | - | B/D/K (1) | K (4) | D/L/M (1) | I/K/O (2) | D/F (7) | D (1) | B/D/F/ L (4) |
| B/L (2) | - | B/D/K (1) | A/L/O (3) | D/L/M (1) | I/K/O (2) | B (4) | - | B/D/F/ L (4) |
| B/L (2) | - | B/D/K (1) | A/L/O (3) | - | - | A (3) | - | B/D/F/ L (4) |
| M (1) | - | - | A/L/O (3) | - | - | M/O (1) | - | A (3) |
| - | - | - | M (2) | - | - | M/O (1) | - | I (2) |
| - | - | - | B (1) | - | - | L (0) | - | K (1) |

* 4 participants using "no aid" included Surface K in their selection of the "three best" surfaces.
** 3 participants using "no aids" included Surface A in their "three best," 3 participants included Surface D, and 3 participants included Surface I.

### 5.2.3 Comparison of Objective and Subjective Data

Objective data (ratings of performance observed on videotape) were compared with subjective data (participants' own ratings of, and preferences for, surfaces) to determine whether the subjective data could be used alone to provide an assessment of the safety and negotiability of detectable warning surfaces that would be comparable to actual performance evaluation.

For the "no aid" group, the sparsity of objective data makes the comparison of objective and subjective data meaningless. These participants did express subjective preferences, however, there were not sufficient observable performance difficulties to make the comparison useful.

For the group of participants who traveled with "wheels", the objective data indicated that Surface F, and to a lesser extent Surface K, caused the fewest travel difficulties; Surfaces B and D caused the most difficulties. The ratings for ease and safety corroborate these findings insofar as they unambiguously select Surface F as best; however, they fail to show an advantage for Surface K and do not unambiguously show a disadvantage for Surfaces B and D. The expressed preferences of this group were for Surface F and against Surface D, matching the objective data fairly well.

For the "tips" group, the objective data indicated that Surfaces F and A caused the fewest travel difficulties, while Surfaces I and B caused the most. There were no significant differences in ease or safety ratings. The expressed preferences of this group for Surfaces F, I, and K coincide with the objective data only in the case of Surface F. Note that while Surface I was highly preferred, a relatively high number of difficulties were observed on that surface.

These varying correlations between subjective and objective data are not surprising; however, they are somewhat revealing. They are not surprising for several reasons. First, remember that the objective data only reflect the performance of those participants who were rated as having (one or more) travel difficulties on the surfaces. In the objective data, for those participants with no apparent travel difficulties, all surfaces are equally "good". There is no question, however, that these participants often had clear preferences among surfaces, even though for them there may have been no observable performance differences. Second, note that the objective data, when analyzed by observed difficulty or score, effectively give greater weight to the performance of those participants with the greatest travel difficulty (because they contribute more observed difficulties to the analysis). In contrast, the subjective ratings give equal weight to each participant who gives a response.

For the same reasons, the comparison of these data is revealing. First of all, it is clear that even among those users of "wheels" with no travel difficulty, there is a strong preference for Surface F. This is an important qualification to the finding that, when those with numerous difficulties are excluded from the analysis, the performance advantage for Surface F disappears. For users of "tips", on the other hand, it is the difference between subjective and objective data that is revealing; for instance, Surface I caused the most difficulties (video rating), and yet it was one of the most preferred (subjective judgment). What this difference in objective and subjective data reveals is the fact that the "tips" group was more heterogeneous in terms of performance on and perception of the surfaces. Where no significant differences were found in either objective or subjective data, it does not necessarily mean that the participants experienced no differences; it means only that there was no agreement on what those differences were.

### 5.2.4 Combination of Objective and Subjective Data

It is very difficult to synthesize the results of objective and subjective tests into one simple presentation. However, some kind of synthesis is a necessary aid to understanding the entire body of results. Table 5-7 presents both objective and subjective data in a simplified form.

Objective data are the numbers of observed difficulties by aid and by detectable warning surface, taken from Table 5-3 (in which the types of difficulties, by aid, can be seen). The highest score (-12) for the Subtotal-Objective indicates that Surface F was observed to have the fewest difficulties. The lowest scores (-40) indicate that Surfaces B and D were observed to have the greatest number of difficulties.

Subjective data are preference scores computed from participants' choices of surfaces, with regard to both negotiability and safety, as among "the best," "the three best," and "the worst."

The highest score (+21) for the Subtotal-Subjective indicates that Surfaces F and I were the most preferred surfaces, while the lowest score (-8) indicates that Surface O was least preferred.

**Table 5-7. Observed Difficulties and Participant Judgments About Safety and Negotiability of 9 Detectable Warning Surfaces on Slopes (1:12, in comparison with brushed concrete)**

| SURFACE* | A | B | D | F | I | K | L | M | O |
|---|---|---|---|---|---|---|---|---|---|
| **Objective** ** **Measures** (Observed Difficulties) | | | | | | | | | |
| Persons Using: **"Wheels"** n=15 | -8 | -18 | -20 | -1 | -12 | -9 | -9 | -15 | -8 |
| **"Tips"** n=18 | -12 | -22 | -20 | -10 | -23 | -13 | -21 | -16 | -16 |
| **"No Aid"** n=7 | -1 | 0 | 0 | -1 | 0 | -1 | -5 | 0 | -1 |
| **Subtotal Objective** | **-21** | **-40** | **-40** | **-12** | **-35** | **-23** | **-35** | **-31** | **-25** |
| **Subjective*** Measures** (Preference Score) | | | | | | | | | |
| Persons Using: **"Wheels"** n=15 | +3 | -2 | 0 | +18 | +5 | +2 | +4 | +3 | +1 |
| **"Tips"** n=18 | 0 | 0 | +4 | +6 | +13 | +11 | -4 | -6 | -7 |
| **"No Aid"** n=7 | +3 | +1 | +3 | -3 | +3 | +5 | +3 | -1 | -2 |
| **Subtotal Subjective** | **+6** | **-1** | **+7** | **+21** | **+21** | **+18** | **+3** | **-4** | **-8** |
| **TOTAL SCORE** | **-15** | **-41** | **-33** | **+9** | **-14** | **-5** | **-32** | **-35** | **-33** |

* Letter designations for surfaces are the same as for tests of detectability, and safety and negotiability.

** Negative values of these scores are number of observed difficulties (video ratings of increased effort, instability, wheel or tip slippage, or wheel or tip entrapment) on detectable warning surfaces. Lowest score = most difficulties observed.

*** Preference score computed as follows:
# of times participants included surface in <u>3 best</u>
+ # of times participants mentioned surface as <u>the best</u>
– # of times participants mentioned surface as <u>the worst</u>
Highest total score = surface which objective and subjective measures indicate caused least difficulty relative to brushed concrete.

Table 5-8 presents the detectable warning surfaces in rank order, based on the algebraic sums of objective and subjective scores presented in Table 5-7.

**Table 5-8. Rank Order of 9 Detectable Warning Surfaces Tested for Safety and Negotiability on Slopes**

| Surface (Rank Ordered By Total Score*) | Observed Difficulties** | | Preference Score*** | | Total Score**** |
|---|---|---|---|---|---|
| F | (-12) | + | (+21) | = | +9 |
| K | (-23) | + | (+18) | = | -5 |
| I | (-35) | + | (+21) | = | -14 |
| A | (-21) | + | ( +6 ) | = | -15 |
| L | (-35) | + | ( +3 ) | = | -32 |
| D | (-40) | + | ( +7 ) | = | -33 |
| O | (-25) | + | ( -8 ) | = | -33 |
| M | (-31) | + | ( -4 ) | = | -35 |
| B | (-40) | + | ( -1 ) | = | -41 |

* Letter designations for surfaces are the same as for tests of detectability.

** Negative values of these scores are number of observed difficulties (video ratings) on detectable warning surfaces. Lowest score = most difficulties observed.

*** Preference score computed as follows:
  # of times participants included surface in 3 best
  + # of times participants mentioned surface as the best
  – # of times participants mentioned surface as the worst
  Highest total score = surface which objective and subjective measures indicate caused least difficulty relative to brushed concrete.

**** Observed Difficulties and the Preference Score for each surface were algebraically summed.

### 5.2.5 Specific Surface Comparisons

Several specific comparisons of surfaces are of interest in exploring general design implications of these results.

**Surface A vs. Surface B**: These surfaces employ similar domes of relatively small size. The principle difference between them is the surface material itself, Surface A being made from rubber and Surface B from a hard composite. Surface B clearly caused more problems than did Surface A, mostly attributable to additional slipping and trapping of wheels, among users of "wheels" and also among the two participants in the "tips" group whose aids have wheels (i.e. rollator walkers). Surface D was the only other surface made of a hard composite. It also resulted in slipping and trapping of wheels.

**Surface D vs. Surface I**: Both of these surfaces employ relatively large, flat-topped domes. Surface D is a polymer composite having additional rough texture elements on top of and between the domes. Surface I is a polymer concrete, having lower, more rounded texture elements on top of the truncated domes, and no texture elements between the domes. Surface D was observed to result in significantly more difficulties for users of "wheels," particularly slipping and trapping of wheels, than Surface I.

**Surfaces D and I vs. Surfaces A, F, and K:** The difference between these two groups is that Surfaces D and I have larger domes. Objective data showed that Surfaces A, F, and K caused significantly fewer problems for one or both groups of aid users.

**Surface O vs. Surface M:** These two surfaces are both stamped metal with an abrasive coating; their design specifications are nearly identical. It is of interest to determine whether performance and subjective evaluations indicated any difference between the two surfaces. Objective data indicate no significant differences (although among wheels users there is an apparent difference in scores). Subjective ratings and preferences indicate that these surfaces were perceived as very similar.

**Surface F vs. all other surfaces:** Surface F differed from all other surfaces in three respects. First, it was the only surface included in this test which was comprised of ceramic tile. Second, the spacing between domes, circumference to circumference, was wider than any other surface tested—and, indeed, the center-to-center spacing was greater than specified in ADAAG 4.29.2. And third, Surface F was the only surface tested in which the domes were aligned horizontally and vertically vs. diagonally. (N.B. This horizontal/vertical alignment does fall within the ADAAG specification, although it differs from the figure shown in "Detectable Warning Bulletin #1" available on request from the Architectural and Transportation Barriers Compliance Board.)

Surface F appeared to be better than all other surfaces on most objective and subjective measures. However, because it differed from all other surfaces in three different ways, it is not possible to say whether this superiority was attributable to the surface material (ceramic tile), to the wide inter-dome spacing, or to the horizontal/vertical alignment of the truncated domes. It seems clear, however, that none of these three characteristics contributes importantly to difficulty or lack of safety in negotiation. Indeed, while persons with physical disabilities had previously anticipated that wheels would become trapped, and negotiation thus more difficult as well as somewhat less safe, on surfaces having domes aligned horizontally and vertically, this does not seem to be the case.

Furthermore, the wide spacing, as well as the horizontal/vertical alignment of the domes on this surface enabled users of "wheels" to deliberately place one or more wheels between the domes. This appeared to reduce the effort required for persons using "wheels" to negotiate this surface. Similar effects were observed for persons using "tips."

### 5.2.6 Professional Summary (Report of Linda Desmarais, Registered Physical Therapist)*

#### 5.2.6.1 Descriptions of Observable Performance by Aid

"No Aid": Not surprisingly, disabled participants requiring no aid performed consistently well on all surfaces. Even those with prostheses or braces showed good negotiability and few threats to safety. Although some of these participants presented with diminished sensation in their legs, their skill at moving about on uneven terrain or bumpy surfaces appeared to be sufficient to allow them safe travel on these surfaces. Unlike those who rely on the small area of a crutch or cane tip, or the moving area of a wheel on a walker, these participants have only to contend with extensions of their own bodies, in prostheses or shoe braces or such. The diminished sensation apparent in some participants' legs did not generally appear to affect the safety or negotiability of travel on detectable warnings.

"Wheels": Clearly, many of the participants using power and manual wheelchairs and three- and four-wheeled scooters are excellent candidates for using their equipment in general public areas; some, however, are not. Power wheelchair users demonstrated few, if any, difficulties on any surfaces, relative to brushed concrete. Those who were proficient in using their manual chairs usually demonstrated strength and confidence on all surfaces. One person, who used a standard manual wheelchair and had multiple sclerosis, demonstrated consistent difficulty on many surfaces. This participant is typically transported in his wheelchair by an assistant when he is traveling outdoors.

Users of wheelchairs with small and narrow front wheels exhibited more difficulty than those who had standard front wheels. On several surfaces, these smaller wheels appeared to get caught in the space between domes. Similarly, weight distribution appeared to be a problem in one case, where the participant was paraplegic and his legs were rather atrophied. Hence, his center of gravity was

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* Linda Desmarais, R.P.T., had significant input to the design of the video rating scales. She also was one of the three video raters. She was asked to report from a clinical perspective on the observed travel difficulties associated with warning surfaces, especially with regard to safety, and also with regard to participant population characteristics, particularly degree of mobility.

placed slightly more to the rear than other wheelchair users. His front wheels demonstrated a wobbliness which may have been attributable to the lack of substantial weight over them.

Performance of wheelchair users also appeared to be affected by fatigue, and it was difficult to judge whether it was truly the specific surface that presented challenges, or the surface's placement in the testing order. [Retesting on brushed concrete, halfway through the trials, helped the raters determine whether an effect was due to fatigue or to specific surfaces, but this judgment was always difficult, as reflected in the variability across raters—B.L.B.]. Clearly, some surfaces early in their trials appeared to present more difficulties than others later in the trial, leading us to conclude that some surfaces were truly better and others worse for safety and negotiability.

"<u>Tips</u>": In general, those participants using canes, crutches, or walkers present with the most threats to stability among the three groups of participants. As the aid is a totally separate piece of equipment from the body, it is at risk for slipping, making uneven contact with the ground (and hence, giving the participant inconsistent feedback, thus producing more instability), or becoming trapped in the domes. In any of these cases, the participant relies on the consistent contact of the aid with the ground in order to proceed safely. If this is denied, their sense of security, stability, and safety is threatened. These conditions make canes, crutches and walkers the most risky of assistive equipment, generally, and it is not surprising that participants using "tips" were observed to have the most difficulties on detectable warnings.

The size of cane/crutch tips or walker wheels also appears to relate to safety and negotiability. The smaller the tips or wheels, the greater the tendency for difficulties with safety and negotiability. The smaller tips and wheels appear to get caught between the domes or lay on an angle between the base and the dome, thus causing the participant to appear less stable. Wheeled walkers performed similarly to wheelchairs, creating a bumpy and less safe trip on those surfaces which had more closely spaced domes. Those participants with four-wheel walkers had great difficulty negotiating, and exhibited safety concerns, most likely from their lack of solid traction or stopping ability with the four wheels.

As with some of the users of wheelchairs (above), persons with wheeled walkers of any kind would be less likely to travel in public areas or to use public transit. They would be more likely to use paratransit for shopping trips and other such public excursions. Those cane users who are more apt to go out in public would—and should—be using large cane tips. Those participants tested with crutches performed more like those with no aids than like those with canes or walkers; participants using crutches appeared safer and generally negotiated all warning surfaces better than other members of the group using tips.

### 5.2.6.2 Descriptions of Observable Performance by Disability

Spasticity: A number of participants presented with disabilities that are a consequence of central nervous system impairments, such as cerebral palsy, paraparesis, or hemiparesis. Many of these participants presented with spasticity, which under normal mobility conditions was controlled by a brace or resting position in a wheelchair. Negotiating on a bumpy surface elicited an increase in spasticity for two participants, evidenced as clonus responses, but in no case did the increased spasticity cause observable safety or negotiability difficulties.

Fatigue: Some neuromuscular conditions, such as multiple sclerosis, manifested difficulties through the presentation of fatigue and compensatory patterns of movement. For some of these participants, negotiating on a brushed concrete surface was quite difficult; maneuvering up and down a bumpy surface with varying amounts of traction appeared to be exhausting. In addition to being a bar to negotiability, fatigue represents a potential safety risk because persons with such fatiguing conditions are likely to be limited in their ability to stop quickly. As mentioned above, because such participants are vulnerable to fatigue, it was difficult to ascertain whether it was a particular surface that was more challenging than the others, or whether it was its placement in the order of trials. Again, such persons are also less likely to be active, independent travelers in the community.

Gait disability: Some participants presented with disabilities that manifested themselves with a shuffling gait. These participants are more inclined to require the assistance of an aid such as a cane, crutch or walker. Because of their disability, such persons frequently resort to over-anticipation of ground-level obstacles. They may take smaller steps or shuffle their feet more as they anticipate an uneven or bumpy surface, as a means of protecting themselves from a potential threat to stability. This common tendency was observed in participants' negotiation of the various surfaces, making it difficult to assess through observation alone whether a change in gait indicated that a particular surface in fact posed a threat to stability, or rather reflected only an anticipated threat based on visual appearance.

#### 5.2.6.3 Discussion

Generally speaking, persons with disabling conditions that do not require an aid, but might include a brace or prosthesis, exhibited few if any difficulties in safety and negotiability on slopes with detectable warning surfaces. Persons using power wheelchairs or scooters, likewise exhibited little difficulty. On the other hand, some persons with disabling conditions requiring manual wheelchair use or assistance of cane or walker did exhibit difficulty on these slopes.

Of the seven participants identified in the quantitative analysis as having numerous difficulties, four were users of wheelchairs, two used rollator walkers and one was equipped with leg braces and a quad cane. Note that all four users of wheelchairs were users of manual chairs; not surprisingly, most or all were rated as exerting additional effort on up ramps, across all surfaces (except Surface F). One of the four (discussed above), has a displaced center of gravity that apparently puts him at risk for slipping and entrapment of his extremely small front wheels. Another one of the four, with multiple sclerosis, has limited upper body strength and was at high risk for fatigue; she had negotiability difficulties only on up ramps. Importantly, three of the four are strong, active travelers and are unlikely to be significantly impeded or placed at risk by any of the warning surfaces. They appeared to compensate well for the various difficulties observed.

The three participants in the "tips" group with numerous travel difficulties present a different issue. None are active travelers; in fact, rollator walkers and quad canes are typically used in the home, not as wide-ranging mobility aids. The two persons using rollator walkers encountered wheel entrapment across many or all of the surfaces. All three individuals were at risk for stability across many or all of the surfaces, as they are in general. Thus, unlike the four users of wheelchairs discussed above, these three participants are unlikely to be candidates for independent travel in public areas.

Finally, it is important to consider safety issues related to those participants who exhibited only few travel difficulties. One cannot assume that the infrequency of difficulties insures that those difficulties do not pose any safety risk to those individuals. Observation shows, however, that in no case were participants at grave safety risk on any of the surfaces. In fact, nearly all showed the ability to compensate well for the travel difficulties imposed by the warning surfaces.

# 6. SUMMARY AND CONCLUSIONS

## 6.1 DETECTABILITY

Twelve commercially available detectable warning surfaces plus one prototype surface were tested for detectability by persons having a wide range of attributes found in the visually impaired population. All 13 warning surfaces tested were paired with four platform surfaces representing extremes of roughness and resiliency which are in common use on transit platforms. Both objective measures (detectability and stopping distance) and subjective measures (ratings of perceived detectability and comfort) were obtained.

Objective measures of detectability revealed that all 12 of the commercially available surfaces were detected underfoot on at least 95% of (96) trials, and they were essentially equal in detectability. The prototype warning surface was somewhat less detectable, especially when approached from a coarse aggregate platform. Therefore, detectable warning surfaces can vary somewhat from the specification provided in ADAAG, and nonetheless be high in detectability. Highly detectable warnings varied in truncated dome height between .15 and .22 inches, in dome base diameter between .90 and 1.285 inches, in dome top diameter between .45 and .875 inches, and in the distance between adjacent truncated domes, between 1.66 and 2.85 inches.

Highly detectable warnings also varied from one another in other attributes which appeared to have little or no effect on detectability. These included 1) resiliency differences, 2) horizontal and vertical versus diagonal alignment of domes, 3) the presence, and nature, of additional small textural elements incorporated into some products to increase slip resistance, 4) irregularities in spacing, where the spacing of domes across adjoining tiles was more or less than the spacing between domes within each tile, and 5) consistency in dome height.

The fact that 12 surfaces having such variability in spacing, as well as other attributes, were equal in detectability should not be taken to indicate that **any** surface whose dimensions fall within any of the above ranges would be highly detectable, however, as the one surface which was somewhat less detectable was approximately in the mid-range of all but one of these dimensions. Characteristics which may have accounted for the lower rate of detectability of this surface were the very smooth top surface of the truncated domes, and that the sides of the domes were less rounded (in fact, they looked more like cylinders than truncated domes). Thus, we are unable on the basis of this research, to recommend dimensional specifications that will assure high detectability.

On the other hand, both objective and subjective measures of detectability confirm that truncated dome patterns are highly detectable. Any consideration of permitting or requiring other (non-truncated dome) surfaces as detectable warnings must recognize the considerable research prior to this project, which tested a great variety of surfaces and configurations, and typically did not find them to be detectable, underfoot, at rates of at least 95%, when approached from surfaces varying in resiliency and roughness. At this time, a performance standard of equal to or greater than 95% detectability, underfoot, when approached from surfaces varying in resiliency and roughness, appears to be the only way of being certain that surfaces will be highly detectable.

Subjective ratings of detectability bore only moderate relationship to objective measures of detectability. While the one surface which objective measures of detectability indicated was less detectable was also identified as least detectable in subjective ratings, in general, more surfaces were subjectively rated somewhat low in detectability than were identified in objective testing.

Across all of the different tests of detectability, participants were somewhat less likely to detect warning surfaces approached from coarse aggregate concrete than from less "bumpy" surfaces, and they tended to travel greater distances before stopping.

Anecdotal information from an experienced orientation and mobility specialist and researcher in Japan (O. Shimizu, personal communication, April 1993) indicates that as pavers having various patterns in relief are being increasingly used in Japan for aesthetic reasons, blind pedestrians in Japan are experiencing increasing difficulty in detecting detectable warnings. This information, coupled with the adverse effect of coarse aggregate on detection and stopping distance observed in this research, suggests that a cautious approach should be taken in choosing any surface which will be adjoined by detectable warnings. In general, relatively smooth adjoining surfaces are to be preferred over "bumpy" surfaces such as coarse aggregate concrete or pavement having a texture with relatively high relief.

## 6.2 SAFETY AND NEGOTIABILITY

There are two major issues that can be addressed in the findings of the tests of safety and negotiability of detectable warnings on slopes, for persons having physical impairments:

- Are there major safety concerns for persons having physical impairments?
- Are there differences between surfaces or surface characteristics which result in differences in safety and negotiability?

Before presenting conclusions regarding these two issues, the reader is reminded that although the tests of safety and negotiability in this project were quite stringent in some respects such as the steepness of slope, the amount of warning material to be traversed, and the deliberate inclusion in the sample of those persons who were considered most likely to experience difficulties as a result of detectable warnings, nonetheless, all were completed under dry conditions.

Regarding safety, none of the 40 participants were considered by the consultant physical therapist to be at serious risk as a result of the addition of detectable warning surfaces to slopes. Four participants exhibited serious difficulty negotiating these surfaces, but their difficulties were indicative of general mobility limitations, and not necessarily related to the surfaces themselves. These were individuals who would probably be very limited in the extent of their independent travel—at least using the aids with which they completed this testing. Three of these four used rollator walkers or quad canes for the testing, but would probably use a wheelchair for extended travel because it offers greater security. An additional three participants, who used manual wheelchairs, and who were severely impaired, showed substantial difficulty in negotiating the warning surfaces, but they did not appear to be at risk. These three were very active travelers despite the severity of their disabilities and the difficulties they encounter as a result of any bumpy surface. The remaining 33 participants appeared to compensate quite well for difficulties they experienced as a result of the detectable warnings.

With regard to differences between surfaces, or characteristics of surfaces, there are important trends, although the variability of both objective and subjective measures as a result of individual differences in travel aid and disability make it difficult to conclude unambiguously that particular surfaces are outstandingly better or worse than others, with regard to ease of negotiability and safety.

The strongest finding was that Surface F appeared to create the least difficulties for any group, and particularly for the group using "wheels." The superiority of Surface F was further confirmed by subjective data from both the "wheels" and the "tips" users. It is not clear what made this surface better, however, as it was the only surface having the following characteristics: horizontal/vertical alignment of truncated domes; the widest inter-dome spacing combined with relatively small domes, thus exposing more of the base level of the surface than was exposed on other surfaces; and it was unglazed ceramic tile.

An additional observation with regard to Surface F is important. Namely, that concern has been expressed by persons with physical disabilities and their advocates that a surface with horizontal/vertical alignment would be more likely to result in wheel entrapment, and consequent loss of control for wheelchairs than would surfaces having diagonal alignment. This definitely does not seem to be the case. Persons with visual impairments have also expressed the opinion that domes aligned diagonally are easier to detect than domes aligned horizontally/vertically. This also does not seem to be the case, as detectability of Surface F has been demonstrated to be statistically equal to detectability of surfaces having diagonal alignment.

More generally, Surfaces A, F, and K seemed to promote few difficulties and to be well liked. The common characteristic of these three surfaces is relatively small domes.

Surfaces which caused the most difficulties differed somewhat across groups. Among users of "wheels," Surfaces B and D were troublesome, as reflected by both objective and subjective measures. Among users of "tips," Surfaces B and I were observed to cause the most difficulties, but clearly, many "tips" users rated Surface I highly.

Both "tips" users and participants who used "no aid" were in agreement with a subjective dislike of Surfaces O and M, possibly because of perceived slipperiness. This was not confirmed by especially poor performance by these groups on these surfaces, however.

It should be noted that the fact that a surface is perceived as difficult or unsafe, while it may not accurately reflect performance on such a surface, is nonetheless important. All persons tend to dislike or avoid surfaces which they perceive to be hazardous; this is no less true for persons with physical disabilities. It is important that detectable warnings surfaces that persons with physical disabilities would wish to avoid, not be used—making some otherwise accessible routes inaccessible to certain individuals.

Resilient surfaces may provide better slip resistance than comparable non-resilient surfaces, as can be seen in comparing data for slipping on Surfaces A and B.

Larger domes do not appear to result in fewer difficulties than smaller domes, as can be seen in comparing the relatively good performance on Surfaces A, F, and K versus Surfaces D and I.

# 7. RECOMMENDATIONS

- Most detectable warning surfaces complying with ADAAG 4.29.2 are likely to be detectable underfoot on at least 95% of encounters.

- Human performance testing of detectable warning surfaces in association with the variety of surface textures and resiliencies with which they will be used, using the paradigm developed by Peck and Bentzen (1987), could be a standard procedure for determining human performance for detectable warnings.

- When subjective judgment is used to determine underfoot detectability of warning surfaces, it is important that this judgment is based on actual approach and travel over detectable warning surfaces, from the variety of surface textures and resiliencies with which they will be used. Subjective judgment is always relative; therefore any new surface should be rated in relationship to a surface or surfaces whose detectability has previously been determined.

- The use of "bumpy" platform surfaces such as exposed coarse aggregate concrete tends to make detection of warnings more difficult. It is therefore recommended that the appendix to ADAAG (ADAAG A4.29.2) advise that use of exposed aggregate concrete, or other bumpy surfaces, adjoining detectable warnings should be avoided.

- Differences in resiliency between platform and warning surfaces which are appropriate for transit architecture do not significantly increase underfoot detectability or decrease stopping distances. It is recommended that the requirement that detectable warnings on interior surfaces differ from adjoining surfaces in resiliency or sound-on-cane contact be changed to a recommendation, and placed in ADAAG A4.29.2.

- It is recommended that language be added to ADAAG 4.29.2 stating that variations in inter-dome spacing across adjacent tiles are permissible, as such variations do not appear to decrease detectability or increase stopping distance.

- Alignment of truncated domes on detectable warning surfaces in either horizontal/vertical, or diagonal patterns should continue to be permitted. It now appears that safety and negotiability on surfaces having horizontal/vertical alignment of truncated domes may be greater than on surfaces having diagonal alignment.

- Given the moderately increased level of difficulty and decrease in safety which detectable warnings on slopes pose for persons with physical disabilities, it is desirable to limit the width of detectable warnings to no more than that required to provide effective warning for persons with visual impairments. Data on cumulative stopping distance indicate that 24 in. is adequate for stopping on 90% of approaches on level surfaces; 36 in. is required to reach the 95% level.

- Although it is beyond the scope of this project to establish the acceptable level of risk for detectability of warning surfaces, it is our recommendation that a single width standard of 24, 30, or 36 inches be established because consistency in environmental cues contributes importantly to their effectiveness.

## APPENDIX A

## REVIEW OF RELEVANT LITERATURE

Research in the United States to identify floor or paving surfaces which would be used to alert persons with visual impairments to the presence of hazards such as vehicular ways in the circulation path, began in 1980, and has proved to be very complex. (See Figure A-1 for cross-section illustrations of surface textures which have been found to be low in detectability.)

In an experiment by Aiello and Steinfeld (1980) using eight subjects who were blind and who traveled with the aid of long canes, the detection rates were compared for two warning materials, applied in two configurations to a concrete interior floor. Materials tested were: an abrasive material raised 1/64 inch, 1/32 inch, or 1/8 inch above the floor and applied either in strips or a solid area; and ribbed rubber matting, applied either in two six-inch-wide strips, or in a solid area. When detection rates for abrasive strips of different heights were compared, it was found that at 1/64 inch no one sensed the warning; at 1/32 inch the detection rate was 72%; and at 1/8 inch the detection rate was 83%. The solid area of ribbed rubber mat (five feet by five feet) was detected in 100% of the approaches by all subjects, regardless of cane technique used. In some approaches, subjects reported sensing the mat first with the cane; in other approaches, the mat was reported to have first been detected underfoot. The mat was detected equally well regardless of the direction of the ribbing, (i.e. parallel or perpendicular to a subject's line of travel). All subjects preferred the large mat above both the abrasive surfaces and the strips of rubber mat because of the size and the changes in texture, resiliency and sound.

The results of Aiello and Steinfeld (1980) were the basis for the following ANSI A117.1-1980 Standards:

> 4.29 Tactile Warnings
>
> 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. Grooves may be used indoors only.

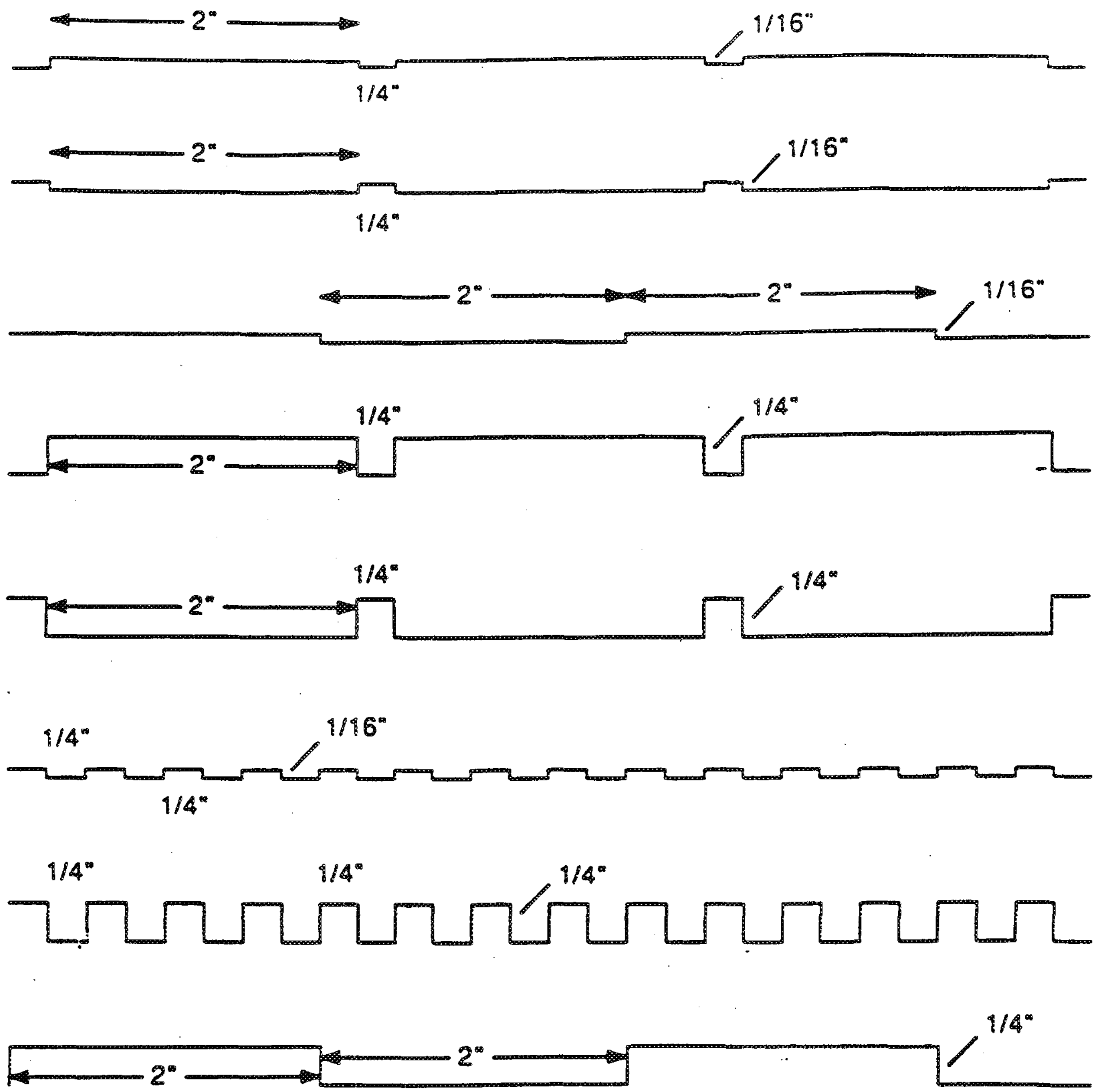


Figure A-1. Cross-sections of surfaces found by other researchers to be low in detectability (Source: Peck & Bentzen, 1987, with permission)

4.29.4 Tactile Warnings on Stairs. All stairs, except those in dwelling units, in enclosed stair towers or set to the side of path travel, shall have a tactile warning at the top of the stair runs.

4.29.5 Tactile Warnings at Hazardous Vehicular Areas. If a walk crosses or adjoins a frequently used vehicular way, and if there are no curbs, railings, or other elements detectable by a person who has a severe visual impairment separating the pedestrian and vehicular areas, then the boundary between the areas shall be defined by a continuous 36 inch (915-mm) wide tactile warning texture complying with 4.29.2.

Subsequent to publication of ANSI A117.1-1980 numerous properties installed surfaces which purported to comply with ANSI, both on transit platforms and on curb ramps. Nonetheless, these surfaces were not sufficiently detectable to prevent accidents.

Further research to identify sufficiently detectable surfaces was conducted at Georgia Institute of Technology. Templer and Wineman (1980) studied the detectability of 11 materials when approached from broom finish concrete. Subjects were legally blind, totally blind, having low residual vision, or high residual vision. Based on both stopping distance and subjects' subjective ratings of ease of detection, Templer and Wineman concluded that either a resilient material such as "Kushionkote," a tennis court surfacing material, or strips of thermoplastic six inches wide, spaced six inches apart, and placed perpendicular to the normal line of travel should be considered for detectable walkway surfaces; and that these surfaces should be at least 48 inches wide, allowing a 48-inch stopping distance.

Further research was reported by Templer, Wineman, and Zimring in 1982. This project attempted to determine the relationship between surface detection and texture (defined as depth, spacing, and width of grooves), impact noise, and rebound (or resiliency). Subjects in Templer and Wineman's previous study, as well as in that of Aiello and Steinfeld (1980), had reported that all of these factors contributed to their ability to detect surface changes. Now it was hoped to quantify the contribution each of these factors made to detection, and to develop regression equations useful in predicting the probability that a particular surface (perhaps an untested one) would, in fact, be detectable. Conceptually, this was a valuable approach, and the investigators did succeed in arriving at regression equations useful where texture can be described in terms of groove width, spacing and depth, and where the contrasting surface is brushed concrete. Thirty-two potential warning surfaces tested in this study were combinations of concrete, plastic (thermoplastic, neoprene, and corrugated plastic), wood, and steel. Additional texture was added to some surfaces with paint. Textures were linear or non-linear (raised lines, circles, or squares). Materials were installed over concrete or above a cavity (varying from 3/4 inch deep to 1-3/4 inches). All subjects used long canes as travel aids.

The regression equations of Templer, et al. (1982) may be useful in choosing tactile warnings that are reliably detectable by blind travelers using long canes, for use in combination with brushed concrete platforms. However, they are not helpful in choosing warnings for use in combination with surface materials which differ from brushed concrete in their texture, impact noise, and rebound.
Of a total of nine steel surfaces (varying in texture and in the presence or absence of a cavity), five were detected on 100% of the trials. Detection rates for the other four surfaces were 95% or better. The next best material was plywood to which various plastics or paint had been applied. Of the five surfaces subjectively rated easiest to detect (mean ratings), three were steel and two were plywood. Templer, et al. (1982) concluded by highly recommending all nine steel surfaces, all seven surfaces for which plywood was the base or underbase, and three other surfaces in which concrete was the base material. The detection rate for each of these recommended surfaces was 95% or better. No one texture appeared better than any other. Sound was subjectively considered to be a major factor in detection of the predominantly steel or plywood surfaces.

Of those subjects who detected a warning surface, 86.4% stopped after traversing 24 inches or less of the surface. A 42-inch depth was necessary to insure stopping by virtually all subjects. Stopping distance could not be predicted on the basis of the surface used.

Pavlos and Steinfeld (1985), in research sponsored by the Access Board, endeavored to find surface materials commonly used in construction which could function as detectable warnings in various settings. They tested the detectability of 37 surfaces when used in juxtaposition with either smooth concrete or carpet. The 52 subjects varied in their preferred travel aid and in their amount of vision. The 37 surfaces were found to vary greatly in their detectability, however no surface was consistently detected at better than a 90% rate across all phases of the research. None was therefore recommended for use as a warning. Participants in this research were asked to report whether their detection of each test surface was based primarily on differences in sound, surface texture, or resiliency. Resiliency appeared to be the most salient cue for detecting the test surfaces included in this project.

Research sponsored by the Urban Mass Transit Administration (UMTA), specifically directed towards rail rapid transit platforms (Bentzen, Jackson, and Peck 1980) concluded that falling or fear of falling from high level transit platforms was a major problem and cause of anxiety amongst visually impaired travelers. Moreover, teachers of orientation and mobility were often hesitant to teach travel in the rapid rail environment to visually impaired clients unless they had excellent long cane skills, superior spatial reasoning, fine use of non-visual sensory information, and no additional impairments. Subsequently, UMTA sponsored research to identify a surface which was sufficiently detectable to be defined as a standard for use on platform edges comprised of various materials.

Peck and Bentzen (1987) tested four potential warning surfaces in juxtaposition with each of four platform surfaces in use in transit stations. The platform surfaces were smooth concrete, heavy wooden decking, hard rubber tile with a pattern of raised circles (Pirelli tile), and concrete with a coarse aggregate finish. If a warning material, or materials, could be identified which were reliably detected in conjunction with all four of these platform flooring materials, recommendations for tactile warning materials might not have to be based on consideration of the platform with which they were used. Instead, a warning surface or surfaces, could be recommended for standard use throughout all systems. Persons who are blind have repeatedly stressed the importance of consistency in design both within systems and between systems.

The four potential warning materials tested were tennis court surfacing ("Kushionkote"), a rough steel plate, a ribbed rubber mat, and a hard "corduroy" pattern. The tennis court surfacing was chosen because of its excellent performance in the first set of experiments conducted by Templer and Wineman (1980). The rough steel plate was chosen because of the excellent performance of all steel surfaces in Templer, et al.'s (1982) second set of experiments. The ribbed rubber mat was similar to the one found to be the best by Aiello and Steinfeld (1980). The "corduroy" surface was chosen for testing because it was hypothesized that a linear pattern in which the lines were dome-shaped in cross-section would be more detectable underfoot than a linear pattern in which the lines were flat-topped. A variety of linear patterns had been previously tested (Aiello and Steinfeld 1980; Templer and Wineman, 1980; Templer, et al. 1982) which were flat-topped. They are not notably detectable (see Fig. A-1). The hypothesis that dome-shaped linear textures would be highly detectable was based on research on finger perception, specifically, perception and legibility of braille, in which the optimal shape was found to be half-spherical or somewhat conical (Burklen 1932). No commercially available product having the desired dimensions and contours could be located; therefore, a prototype surface was constructed of strips of PVC "T" molding with the shafts embedded in parallel grooves in plywood. The protruding dome-shaped top of a cross-section of the molding was 3/4 inch wide and 3/16 inch high. Strips of the "T" molding were embedded in the plywood so that they were two inches apart center-to-center.

While all four potential warning materials were readily detected by 13 participants using long canes as travel aids, only the "corduroy" and the ribbed rubber mat were highly detectable underfoot by the 10 dog guide users. The "corduroy" surface performed best. It was the only surface detected by more than 75% of dog guide users and 100% of long cane users. None of the four platform surfaces, which adjoined the warning surfaces, was associated with poor detection rates. Therefore, it appeared feasible to specify one warning pattern which could be consistently used in association with varied surfaces. Stopping distance was similar to that reported by previous investigations.

Participants were tested in a noisy environment to minimize the likelihood that they were able to use differences in sound as an aid to detection, as sound differences may not be perceptible in a noisy transit environment. Thus, detection had to be based on differences in surface texture and resiliency. Even though Templer, et al. (1982) found sound differences to be salient in detection, Peck and Bentzen were able to identify two surfaces which were highly detectable when sound differences were not perceptible. Those surfaces which were highly detectable differed from adjoining surfaces primarily in surface texture.

Peck and Bentzen (1987) then planned a test of the detectability of two manifestations of a prototype "corduroy," 24 inches wide, placed at the edge of platforms at three BART stations. Prior to beginning the test, however, BART safety manager, Ralph Weule, became aware of another surface which was being informally tested on several curb ramps in Sacramento. This surface was comprised of resilient tiles having a pattern of truncated domes[1] whose dimensions and spacing were similar to those now specified by ADAAG. Because the dimensions of the truncated dome pattern were somewhat similar to the dimensions of the highly detectable "corduroy," it was decided to include this material by placing it on one BART platform, which had a terrazzo surface.

The testing protocol for this experiment differed in one important respect from all previous research on tactile warnings. Emphasis was placed on detection underfoot. In one condition, all 30 participants, who were totally blind, were guided by an experimenter toward the warnings; in another condition they used their long canes or dog guides. The truncated dome tile and "corduroy" were both highly detectable. Participants detected warnings underfoot and were able to stop within the available 24 inches of warning surface on 91.1% of the trials on both warnings combined. Participants using long canes frequently detected the warnings and stopped before stepping on them.

In another part of this experiment, 24 persons who were physically disabled negotiated across or along the warnings, and made turns on them. Ten participants used power wheelchairs, four used manual wheelchairs, and ten others used various walking aids or had gait problems. These participants also rated the surfaces on the extent to which they would be anticipated to impair ease of travel on BART.

All participants were able to perform all experimental tasks on both the tile and "corduroy" surfaces regardless of whether they used electric or manual wheelchairs or walked with difficulty. A total of 20 participants (83.3%) judged that the tile would help, not affect, or would insignificantly affect their travel on BART. A nearly equal total of 21 participants (87.5%) judged that the "corduroy" surface would help, not affect, or would insignificantly affect their travel on BART. No participant anticipated that either surface would seriously impair his or her travel on BART. There were nine spontaneous responses that one or both surfaces would be helpful in travel. Eight of the nine "helpful" responses were from participants in the sub-group who walked with difficulty. There was no basis in either performance data or subjective

[1]Pathfinder Warning Tiles manufactured by Carsonite

judgment of participants with ambulation problems to prefer one surface over the other.

To be certain that the truncated domes were highly detectable in combination with various surfaces, UMTA funded an additional laboratory test (Peck and Bentzen 1987) involving 12 participants who were totally blind. Detectability and stopping distance were compared for "corduroy" and truncated domes, each adjoining coarse aggregate concrete, heavy wood decking, Pirelli tile and brushed concrete. The "corduroy" and the truncated domes were equally and highly detectable in association with all four adjoining surfaces. On 90.6% of trials in which participants used a long cane or dog guide, participants stopped after traversing no more than 24 inches of warning surface.

Following this research, Pathfinder Tile was installed in all platforms of all stations in BART. After approximately five years of continuous use, visually impaired riders are very pleased with the warnings, and no individual or group of riders has expressed dissatisfaction with the truncated dome material (Weule, Personal communication, 1994). The overall incidence of trips, slips and falls at the platform edge appears to have decreased. BART riders tend to stand farther from the platform edge than MUNI riders standing at different tracks in the same stations, but not having detectable warnings (McGean 1991).

Contrasts in several attributes have been shown to influence detectability of a warning surface from an adjoining surface (Aiello and Steinfeld 1980; Templer, et al. 1982). These are contrasts in surface texture, resiliency, and sound-on-cane-contact. Depending on the magnitude of the differences in any of these attributes between a potential warning surface and an adjoining surface, as well as on ambient sound levels, any one of these attribute contrasts may appear to be salient in enabling detection. However, because detectable warnings may be used in noisy areas such as intersections and transit platforms, differences between adjoining surfaces in sound-on-cane-contact may not always be detectable--and not all persons who can benefit from detectable warnings will be using long canes.

The truncated dome surface found by Peck and Bentzen to be highly detectable underfoot, when sound cues were masked, and when used in association with varied platform surfaces including one which was similar in resiliency, is essentially the surface specified in ADAAG. The requirement (ADAAG 4.29.2) that detectable warnings in interior applications should differ in resiliency or sound-on-cane-contact recognizes the contributions these other qualities potentially can make to detectability.

More recent research has confirmed the high detectability of truncated dome patterns. Mitchell (1988) replicated the in-transit testing of Peck and Bentzen (1987) at MetroDade in Miami. Mitchell's project, like that of Peck and Bentzen, also demonstrated that the truncated dome surface was not only highly detectable, enabling detection and stopping within 24 inches or less, when approached from various directions and distances, but it also had minimal impact on travel by persons with physical disabilities. MetroDade subsequently installed Pathfinder Warning Tile on all platforms. Experience to date has documented no adverse impacts of detectable warnings on persons having physical disabilities or the general ridership (A. Hartkorn, personal communication, MetroDade, 1994).

In research sponsored by the Toronto Transit Commission (1990), truncated dome patterns were again demonstrated to be highly detectable, and preferred above other potential warning surfaces. Included in the surfaces tested was one comprised of truncated domes which were larger than those of the tile tested in BART and MetroDade. This surface[2] was also found to be highly detectable to persons who were totally blind or who had low vision.

Detectable warnings have been in wide use in Japan since the 1960's, both on sidewalks and in public transit. Although there has never been a national standard in Japan providing specifications and scoping for detectable warnings, and the design of warnings was not based on empirical research, the most commonly used surfaces are truncated dome patterns similar to those specified in ADAAG (O. Shimizu, personal communication, 1993).

Recent research in Japan and Australia, using one detectable warning surface, the dimensions of which are within the ADAAG specifications, also found this surface to be highly detectable (Murakami, et al. 1991; Peck, et al. 1991). It is important to note that in research in which participants who were totally blind were required to discriminate between the detectable warning tiles and guiding tiles having a linear pattern, there were confusions between these two patterns.

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[2]Designed by S. R. Tanaka, Toronto Transit Commission

Confusion between warning tiles (implying "Stop. Check out this potentially hazardous area."), and guiding tiles (implying "Follow me. I'll keep you out of danger.") may be the cause of train platform accidents in Japan reported by Murakami and Shimizu (1990). Warning tiles on transit platform edges are inconsistently placed in Japan, but a common pattern is to place them 36 inches away from the platform edge, in a 12-inch-wide strip, the length of the platform. Twelve inches of a detectable warning surface has been demonstrated, in research reviewed above, to be insufficient to enable detection and stopping.

Research in England (Transport and Road Research Laboratory 1983; Gallon, et al. 1991; and Department of Transport 1992) to identify surfaces which are sufficiently detectable to function as detectable warnings on curb ramps and at platform edges confirms that a surface similar to that specified in ADAAG is highly detectable. Initially, a surface having rounded domes was recommended for use on curb ramps; subsequently, after some difficulties were reported by persons having physical disabilities, a surface having truncated domes was recommended, as it was found to be more readily negotiated.

# APPENDIX B

# RESULTS OF DETECTABILITY TESTING

## B.1 PHASES I AND II

### B.1.1 Detection Rates

When detection rates from Phase I (10 surfaces) were looked at as a function of warning surface, the rate of detection for all surfaces, except Surface J, was above 95% (see "Totals" column of Table B-1). Surface J was the only surface to have a detection rate below 90%. It was detected on 85 of the 96 approaches for a detection rate of 88%.

When the rate of detection from Phase I was looked at as a function of platform surface, the detection rate of warnings approached from three of the four platform surfaces yielded was above 97% (See "Totals" row of Table B-1). The detection rate from coarse aggregate was 90.4%.

A 2 x 2 within-subjects Analysis of Variance (ANOVA) (platform surface x warning surface) on detection rates of warning surfaces showed a significant main effect of both platform surface, $F(3,69) = 3.765$, $MSe = .116$, $p < .01$, and warning surface, $F(9, 207) = 4.736$, $MSe = .020$, $p < .001$, which were qualified by a significant interaction between platform surface and warning surface, $F(27, 621) = 2.897$, $MSe = .081$, $p < .001$. A simple effects analysis of the interaction confirmed, as suggested by Table B-1, that detection rates from the coarse aggregate platform surface were significantly lower than were the detection rates from any of the other platform surfaces. This effect was primarily attributable to the detectability of Surface J when approached from coarse aggregate. Likewise, the low detectability of Surface J was primarily attributable to approaches from coarse aggregate.

Analysis of the detection rates obtained in Phase II, testing the detectability of three additional warning surfaces (K, L, M) and the rerun of Surface A' (A' [II]), as a function of warning surface showed that detection of all warning surfaces occurred on more than 95% of the trials (see "Totals" column in bottom section of Table B-1). When looked at as a function of platform surface the detection rate from brushed

Table B-1. Detection Rates of Detectable Warning Surfaces - Phases I and II

| | BASE SURFACE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Brushed Concrete | | Wood | | Coarse Aggregate | | Pirelli Tile | | Totals | |
| Detect. warn. surface | number times detect.* | % detect. | number times detect.* | % detect. | number times detect.* | % detect. | number times detect.* | % detect. | number times detect. | % detect. |
| Phase I | | | | | | | | | | |
| A'(I) | 24 | 100% | 24 | 100% | 21 | 87.5% | 23 | 95.8% | 92/96 | 95.8% |
| B | 24 | 100% | 23 | 95.8% | 21 | 87.5% | 24 | 100% | 92/96 | 95.8% |
| C | 24 | 100% | 24 | 100% | 22 | 91.7% | 24 | 100% | 94/96 | 97.9% |
| D | 24 | 100% | 24 | 100% | 24 | 100% | 24 | 100% | 96/96 | 100% |
| E | 24 | 100% | 24 | 100% | 23 | 95.8% | 24 | 100% | 95/96 | 99.0% |
| F | 24 | 100% | 24 | 100% | 22 | 91.7% | 24 | 100% | 94/96 | 97.9% |
| G | 24 | 100% | 23 | 95.8% | 24 | 100% | 23 | 95.8% | 94/96 | 97.9% |
| H | 24 | 100% | 23 | 95.8% | 23 | 95.8% | 24 | 100% | 94/96 | 97.9% |
| I | 24 | 100% | 24 | 100% | 21 | 87.5% | 23 | 95.8% | 92/96 | 95.8% |
| J | 24 | 100% | 23 | 95.8% | 16 | 66.7% | 22 | 91.7% | 85/96 | 88.5% |
| Totals | 240/240 | 100% | 236/240 | 98.3% | 217/240 | 90.4% | 235/240 | 97.9% | 928/960 | 96.7% |
| Phase II | | | | | | | | | | |
| A'(II) | 24 | 100% | 23 | 95.8% | 21 | 87.5% | 24 | 100% | 92/96 | 95.8% |
| K | 22 | 91.7% | 24 | 100% | 23 | 95.8% | 24 | 100% | 93/96 | 96.9% |
| L | 23 | 95.8% | 24 | 100% | 23 | 95.8% | 24 | 100% | 94/96 | 97.9% |
| M | 24 | 100% | 24 | 100% | 21 | 87.5% | 24 | 100% | 93/96 | 96.9% |
| Totals | 93/96 | 96.9% | 95/96 | 99.0% | 88/96 | 91.6% | 96/96 | 100% | 372/384 | 96.9% |

* The total number of approaches to each warning surface was always 24.

concrete was 96.9%, from wood 100%, from Pirelli tile 100% and from coarse aggregate 92.7%.

A 2 x 2 within-subjects ANOVA (platform surface x warning surface) showed a marginally significant main effect of platform surface, $F(3, 21) = 2.652$, $MSe = .038$, $p < .075$. Post hoc contrast between platform means confirmed, as suggested by Table B-1 (see row totals, Phase II), that travel from coarse aggregate concrete yielded significantly lower detection rates than did travel from any of the other platform surfaces. No other significant effects were found. The marginal effect of platform is similar to the platform effects found in Phase I and suggests that coarse aggregate may impair the detectability of some detectable warning surfaces, which are otherwise highly detectable.

Previous research on detectable warnings which utilized four similar platform surfaces (Peck and Bentzen 1987) did not find significant differences in detection rates associated with coarse aggregate concrete. Pebble size and density of the aggregate, and the height of the aggregate revealed in the concrete, were not specified in construction of the two laboratory platforms. The platform used in the 1980's study had smaller pebble size than the current platform. The aggregate concrete used in the present study appears to have a grade of roughness more similar to the warning surfaces participants were asked to detect. This probably accounts for the lower detection rates for some warnings when they were approached from coarse aggregate.

### B.1.2 Mean Stopping Distance

An initial 2 x 2 within-subjects ANOVA (platform surface x warning surface) of the mean stopping distance in Phase I (all 10 surfaces) showed significant main effects of both platform surface, $F(3, 69) = 25.61$, $MSe = 118.02$, $p < .001$, and warning surface, $F(9, 207) = 9.47$, $MSe = 46.57$, $p < .001$, which were qualified by a significant interaction between platform surface and warning surface, $F(27, 621) = 4.10$, $MSe = 48.67$, $p < .001$. A simple effects analysis of the interaction (platform surface x warning surface) confirmed, as suggested by Table B-2, that the mean stopping distance on all warning surfaces, except for Surface D, tended to increase when approached from the coarse aggregate platform.

**Table B-2. Mean Stopping Distance for Each Warning Surface Approached from Each Platform Surface (Phase I and Phase II)**

| | WARNING SURFACES | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Phase I | | | | | | | | | | | Phase II | | | | |
| Base Surface | A′ | B | C | D | E | F | G | H | I | J | All Surfaces | A′ | K | L | M | All Surfaces |
| Concrete | 17.96 | 20.42 | 15.04 | 15.79 | 17.96 | 15.67 | 16.20 | 17.17 | 17.33 | 17.36 | 17.09 | 16.45 | 23.00 | 22.79 | 18.50 | 20.18 |
| Wood | 20.33 | 20.83 | 15.00 | 17.08 | 15.75 | 18.83 | 14.96 | 21.29 | 13.75 | 18.00 | 17.58 | 16.37 | 13.58 | 15.46 | 15.25 | 15.16 |
| Coarse Agggregate | 28.33 | 24.58 | 22.88 | 16.08 | 22.21 | 22.75 | 20.29 | 26.38 | 24.50 | 36.79 | 24.48 | 23.33 | 25.12 | 19.83 | 22.83 | 22.77 |
| Pirelli Tile | 17.96 | 17.08 | 15.96 | 16.33 | 17.83 | 14.88 | 18.08 | 17.54 | 18.33 | 19.21 | 17.32 | 15.25 | 18.20 | 15.20 | 16.83 | 16.37 |
| Total Means | 21.13 | 20.73 | 17.22 | 16.32 | 18.44 | 18.03 | 17.38 | 20.60 | 18.48 | 22.84 | 19.12 | 17.85 | 19.98 | 18.32 | 18.35 | 18.62 |

A two-way within-subjects ANOVA (platform surface x warning surface) on the mean stopping distance for Phase II data, Surfaces K, L, M, and the re-running of Surface A (A II), showed a significant main effect of platform ($F(7, 21) = 10.3$, $MSe = 37.81$, $p < .001$), qualified by a significant interaction between platform surfaces and warning surfaces ($F(9, 63) = 2.209$, $MSe = 18.44$, $p < .033$). An analysis of the simple effects of the interaction confirms, as shown in Table B-2, that in general in Phase II, coarse aggregate leads to longer mean stopping distances on the detectable warning surfaces tested, as it did in Phase I.

### B.1.3 Cumulative Stopping Distance

Analysis of the cumulative stopping distances was performed for those trials in which warnings were detected (928 out of 960 approaches, or 96.7% of the trials in Phase I, and 280 out of 288 approaches, or 97.2% of the trials in Phase II, excluding the replication of tests on Surface A'). See Table 2-4 [text]. When travel was from the brushed concrete, wood, or Pirelli tile platform surface, 24 inches were required for participants to stop on at least 90% of the trials. However, when travel was from coarse aggregate 36 inches were required for participants to stop on at least 90% of the trials. For stopping on at least 95% of the trials, 30 inches of warning surface were needed when approached from wood and Pirelli tile. To reach the 95% level from brushed concrete, 36 inches were required, and to reach this level from coarse aggregate required 42 inches.

When data are collapsed across 13 warning surfaces and all platform surfaces, the "Total" column of Table 2-4 [text] shows that 30 inches of warning surface were required to enable stopping on at least 90% of trials, while 36 inches were required to enable stopping on at least 95% of trials. Inspection of cumulative stopping distances within each platform surface reveals, however, that cumulative stopping distances from coarse aggregate were somewhat longer at each level than from any of the other surfaces. (The reader will recall that the mean stopping distance for warnings preceded by coarse aggregate was also longer.)

## B.2 PHASE III

### B.2.1 Detection Rates

Three of the four detectable warning surfaces were detected on 100% of the trials (Surfaces A, C, D), while Surface J was detected on 98% of the trials. A two-way within subjects ANOVA (platform surface x warning surface) showed marginal significant main effects of both platform surface ($F(3, 21) = 2.333$, $MSe = .003$, $p = .103$) and warning surface ($F(3, 21) = 2.333$, $MSe = .003$, $p = .103$) which were qualified by a significant interaction between platform surface and warning surface ($F(9, 63) = 2.333$, $MSe = .003$, $p = .024$. Simple effects tests of the interaction confirmed that Surface J, approached from the coarse aggregate platform surface, yielded significantly lower detection rates than any other surface approached from any other platform.

### B.2.2 Mean Stopping Distances

A 2 x 2 ANOVA (platform surface x warning surface) of mean stopping distances showed a significant main effect of platform surface, $F(3, 21) = 8.052$, $MSe = 35.39$, $p < .001$. A Tukey's B test conducted on the main effect of platform means showed that detection from coarse aggregate, regardless of the warning surface to be detected, required significantly longer traveling distance than did detection from brushed concrete or wood ($p < .01$). Thus, the results of underfoot testing that use of coarse aggregate as a platform surface is likely to increase the stopping distance, or necessary width of the detectable warning used in association with it are confirmed. There were no other significant differences found.

## APPENDIX C

## RATING SCALES—SAFETY AND NEGOTIABILITY ON SLOPES

Ramp____________ Participant #_________

**Subjects in any kind of wheelchair or scooter**

-1 0

I------------------------I

worse same

**Relative to Performance on brushed concrete**

Going up:

______ 1. **Effort required to start from stop.**
e.g., in a manual chair subject may lean forward more by placing center of gravity forward or show difficulty of transitional movement of wheels

______ 2. **Stability.**

______ 3. **Wheels slip.**
Look for discontinuity in wheel motion, particularly when going up, incongruent with activation of the chair or scooter. Also look for overshooting as a result of slipping when attempting to stop—particularly when going down.

______ 4. **Wheel(s) becomes trapped in domes.**
Look for difficulty turning, if wheels are between domes. Also look for exaggerated oscillation of front wheels.

Going down:

______ 1. **Stability.**

______ 2. **Wheels slip.** (see above)

______ 3. **Wheel(s) become trapped in domes.** (see above)

**Rater's comments:** In this section you should note anything you think wasn't appropriately covered by the scale, that is surface related, i.e., ease and safety of travel over the surface, not individual subject variation in performance such as fatigue or change in foot or body placement in normal anticipation of stopping. Some things to look for in a general sense are subjects' accuracy of stopping, continuance of wheelchair motion during transitional hand lifts and how they relate to safety and ease of travel over the particular surface. **Remember these comments will assist us in our critical discussion of the difficulty or threat to safety that these surfaces present to various handicapping conditions.**

Ramp____________ Participant #__________

**Subjects using any kind of cane, crutches, or walker**

```
    -1                      0
      I-----------------------I

   worse                   same
```

**Relative to Performance on brushed concrete**

<u>Going up:</u>

______ 1 **Effort required to start from stop.**
Evident in body or foot placement.

______ 2. **Stability.**
Evident by change in gait pattern, or body movement indicating that the subject feels less stable on this surface relative to the concrete surface.

______ 3. **Aid slips.**
May be due to decreased slip resistance of warning surface.

______ 4. **Aid becomes trapped in domes.**
Grooves between domes or shape of dome may interfere with ease of travel or subject's normal gait pattern.

<u>Going down</u>:

______ 1. **Stability.** (See above)

______ 2. **Aid slips.** (See above)

______ 3. **Aid becomes trapped in domes.** (See above)

**Rater's Comments:** In this section you should note anything you think wasn't appropriately covered by the scale that is surface related, i.e., ease and safety of travel over the surface, not individual subject variation in performance such as fatigue or change in foot or body placement in normal anticipation of stopping. Some things to look for and keep in mind might be adjustment/change in aid/feet (gait) when starting to go up from a level, i.e., the very first step (please note, if possible, whether it is the feet or the aid that changes), length of time aid is in contact with the surface-dragging of the aid etc., accuracy of stop (if less, note if undershot or overshot). Most of these will be very obvious and extreme in nature if they are present at all. **Remember these comments will assist us in our critical discussion of the difficulty or threat to safety that these surfaces present to various handicapping conditions.**

Ramp__________ Participant #_________

**Subjects who walk without an aid**

-1 0
I-------------------------I
worse same

**Relative to performance on brushed concrete**

Going up:

_____ 1. **Effort required to start from stop.**

_____ 2. **Stability.**
Evident by change in gait pattern, or body movement indicating that the subject feels less stable on this surface than on the concrete surface.

Going down:

_____ 1. **Stability.**

**Rater's Comments:** In this section you should note anything you think wasn't appropriately covered by the scale, that is surface related, i.e., ease and safety of travel over the surface, not individual subject variation in performance, such as fatigue or change in foot or body placement in normal anticipation of stopping. Some things to look for and keep in mind might be any adjustment/change in gait when starting to go up from level, i.e., the very first step. For example, you might note whether the bumpy surface effects balance, making it easier or harder to go up/down the surface, or whether foot or body placement on the bumpy surface indicates relative ease of travel or safety compared to the concrete surface. You would also want to note if a participant has a wider gait, wobbly ankle or any exaggerated changes in the placement of feet, on the warning surface. **Remember these comments will assist us in our critical discussion of the difficulty or threat to safety that these surfaces present to various handicapping conditions.**

## APPENDIX D

## STEERING COMMITTEE

**Roger Cicchese** (has visual impairment)
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*U.S. GOVERNMENT PRINTING OFFICE:1994-502-430/00039