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

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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"

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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.

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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.

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."

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.

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 (≥ 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 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.

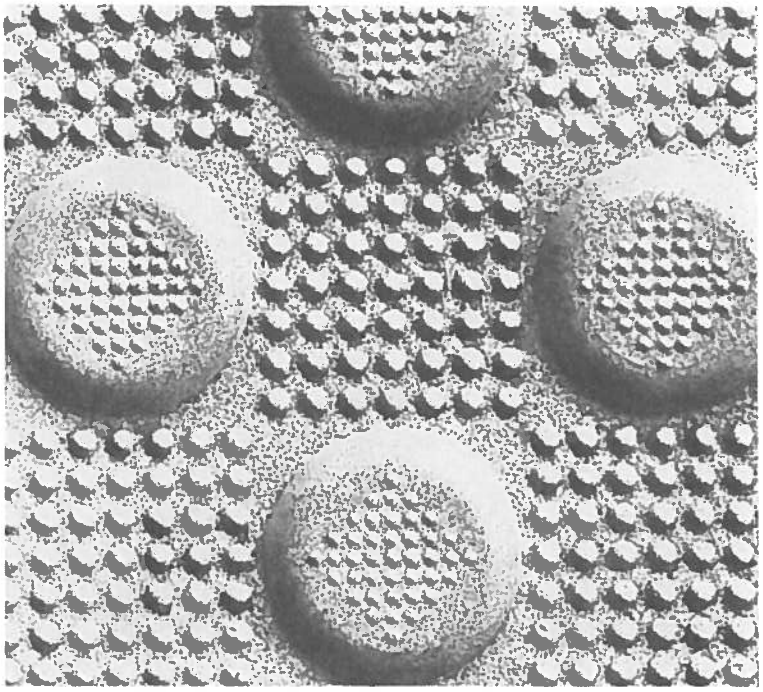
In Phase V, 40 persons varying considerably in their physical disabilities, travel aids and amount of loss of sensation negotiated on 4-ft.-wide-by-6-ft.-long ramps, having a slope of 1:12, the steepest slopes normally permitted for ramps. Persons with physical disabilities were videotaped as they negotiated 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.

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



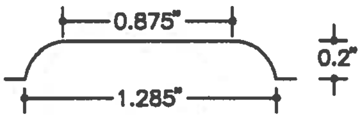


Figure 1-2. **Product C:** Vitrified polymer composite, "Armortile;" consistent spacing across adjacent tiles. Product C is the same as Product D, except was installed using tiles having consistent dome height. Engineered Plastics, Inc., Buffalo, New York

Tested for Detectability Only

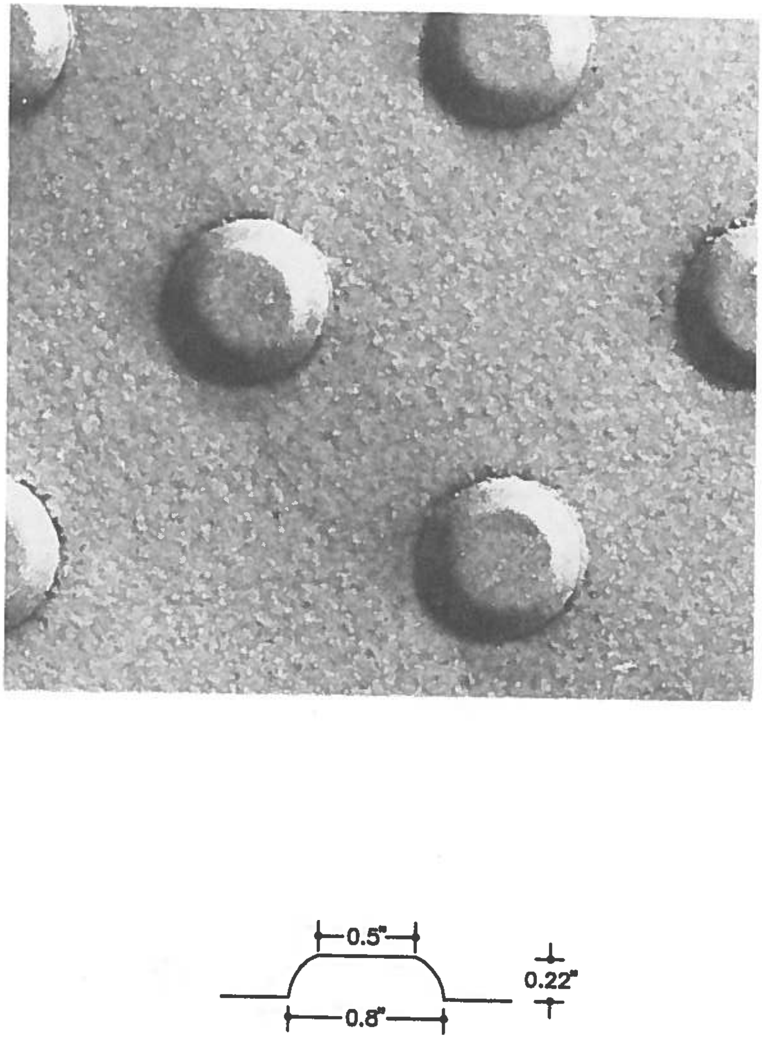
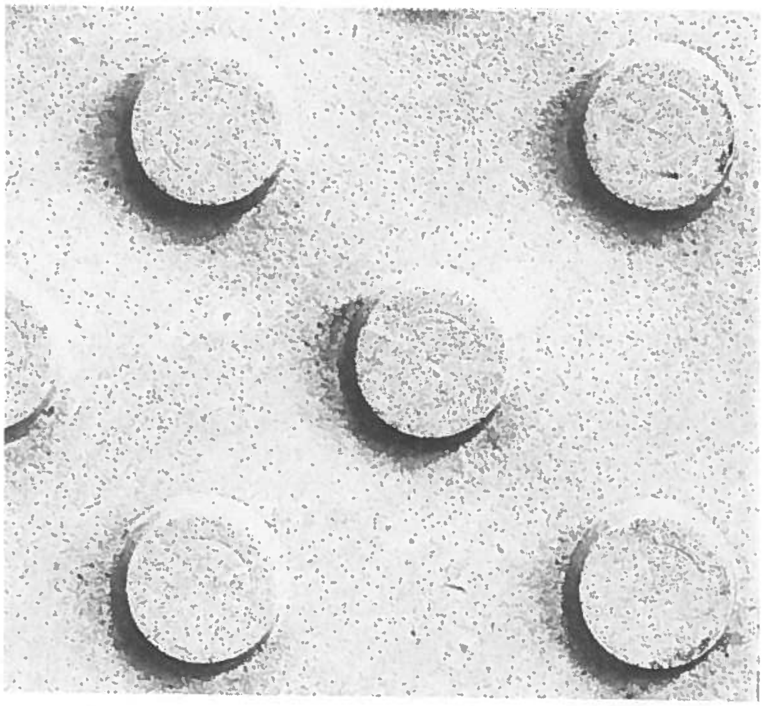


Figure 1-4. **Product G:** Porcelain body ceramic tile, skid-resistant matte glaze, "ADAPT Tile #100." Consistent spacing across adjacent tiles. Terra Clay Products, Roanoake, Alabama

Tested for Detectability Only



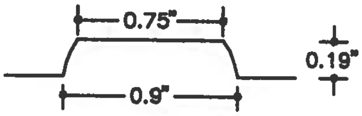
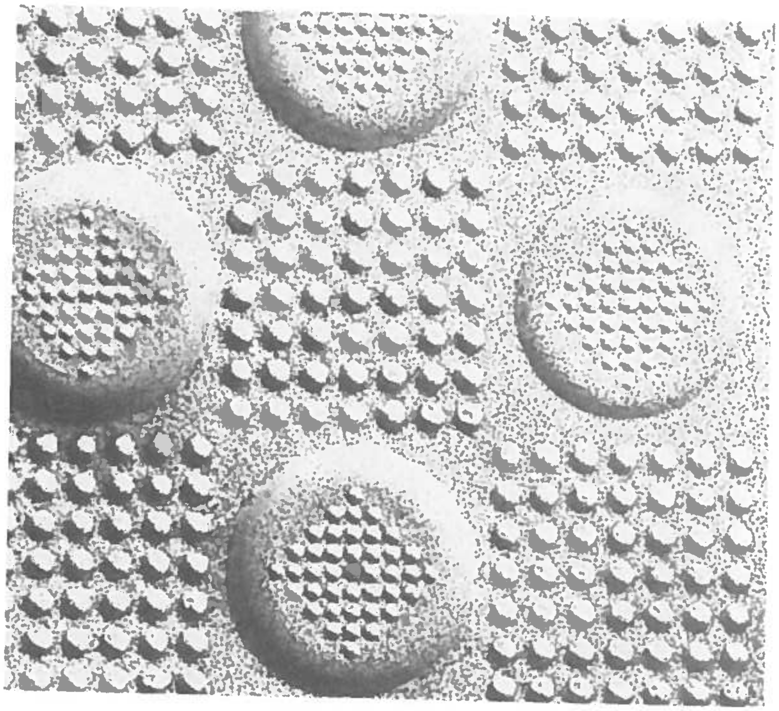


Figure 1-6. **Product J:** Precast polymer concrete. Consistent spacing across adjacent tiles. Prototype product never marketed. Transpo Industries, Inc., New Rochelle, New York



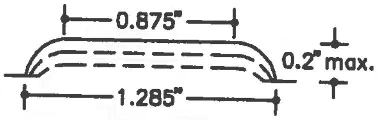
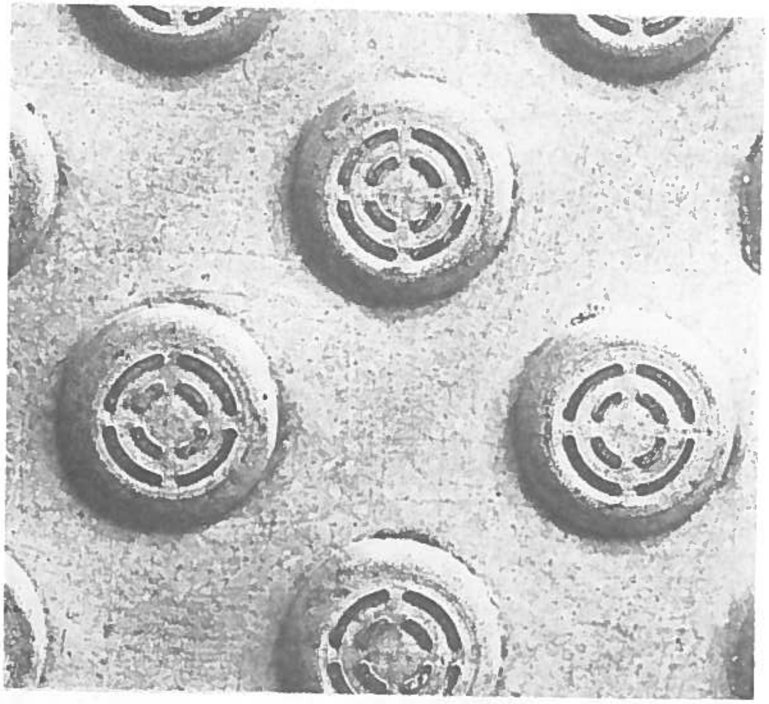


Figure 1-8. **Product D:** Vitrified polymer composite, "Armortile;" consistent spacing across adjacent tiles. Domes gradually increase in height and diameter in first 3 inches of leading edge of tile. Engineered Plastics, Inc., Buffalo, New York

Tested for Detectability, and for Safety and Negotiability



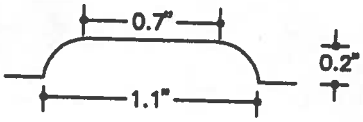


Figure 1-10. **Product I:** Precast polymer concrete, "Step-safe;" consistent spacing across adjacent tiles. Transpo Industries, Inc., New Rochelle, New York

Tested for Detectability, and for Safety and Negotiability

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 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.

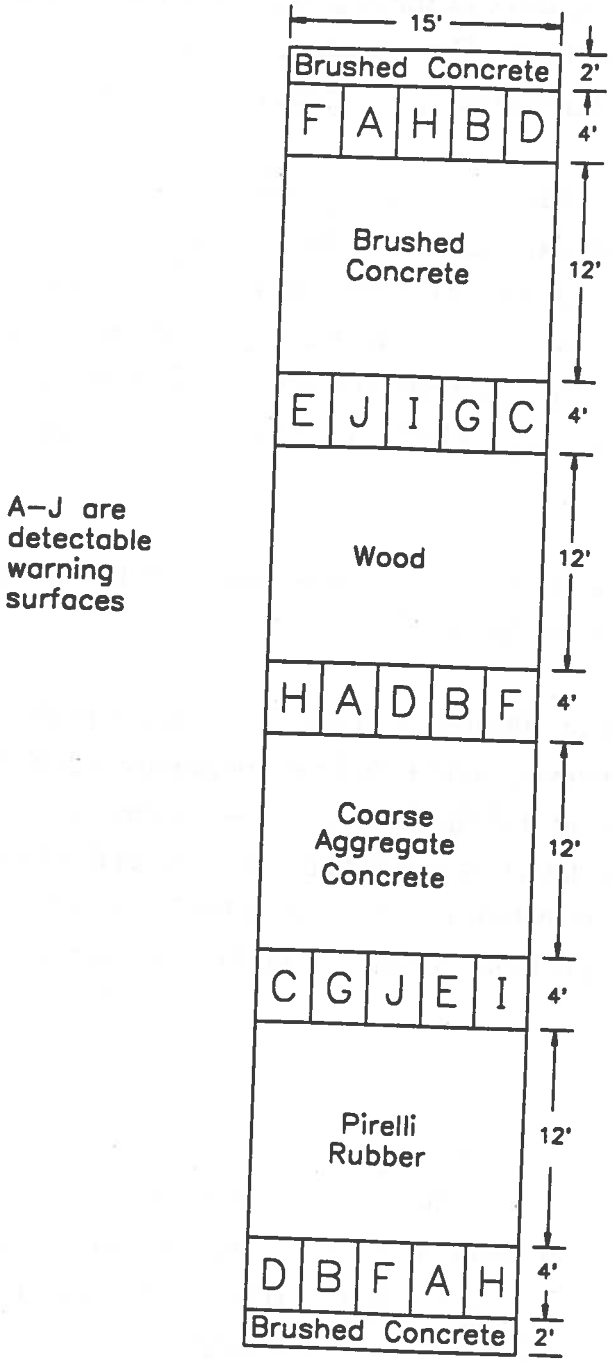


Figure 2-1. Laboratory platform for testing detectability of ten detectable warning surfaces in association with four platform surfaces; Phase I (modified for Phase II). Located at old Broadway Station, MBTA.

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

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

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.

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.

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

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

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.

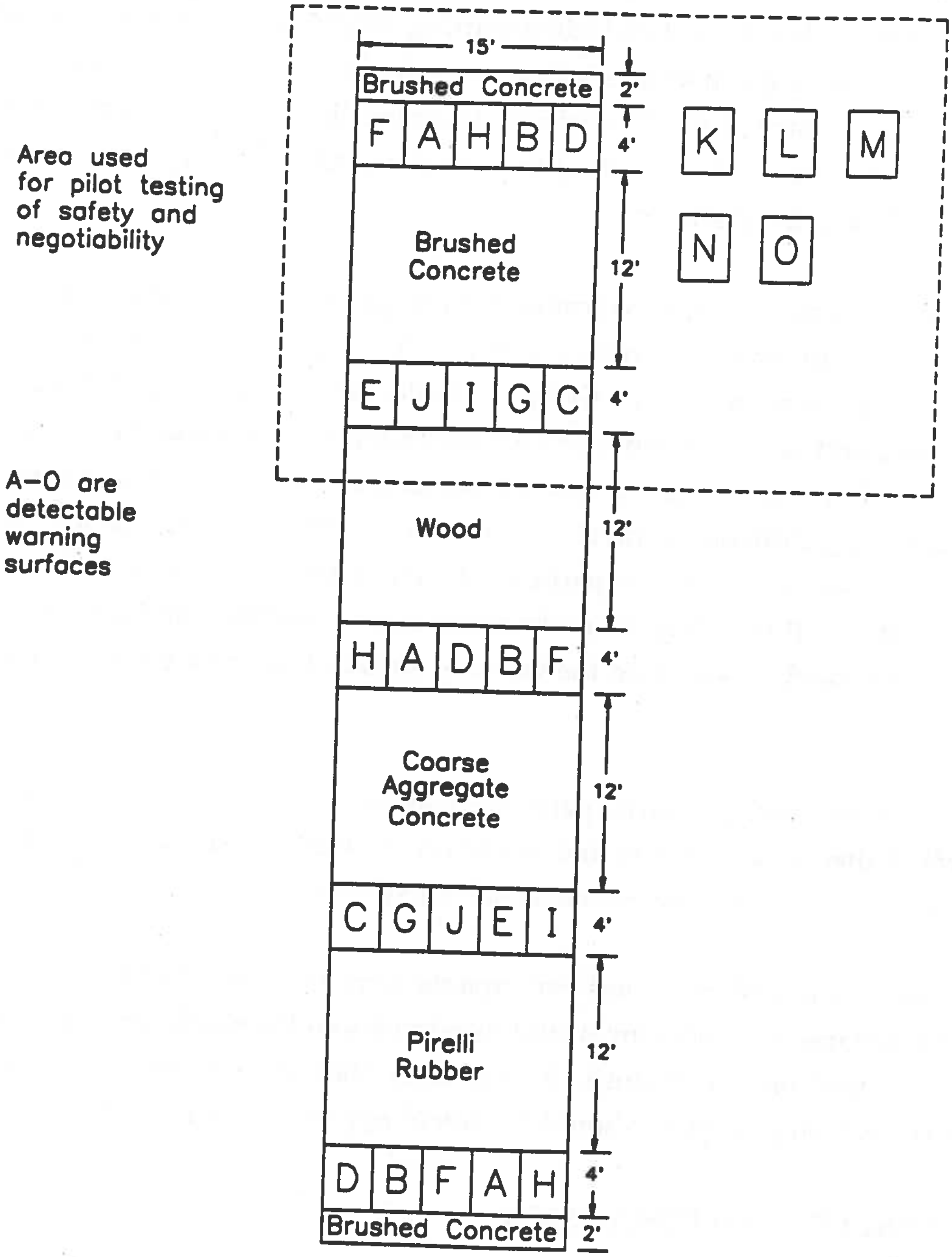


Figure 4-1. Laboratory platform for testing detectability of ten detectable warning surfaces when approached from four platform surfaces. Figure shows portion of platform and adjoining level floor used for pilot testing of safety and negotiability. Constructed at old Broadway Station, MBTA.

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

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

Aid	Age	Sex	Onset Early Late	Sensation Full Minimal Loss Moderate Loss Severe Loss	Orthotics*	Prosthetics	Etiology	Comment
"Tips" 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

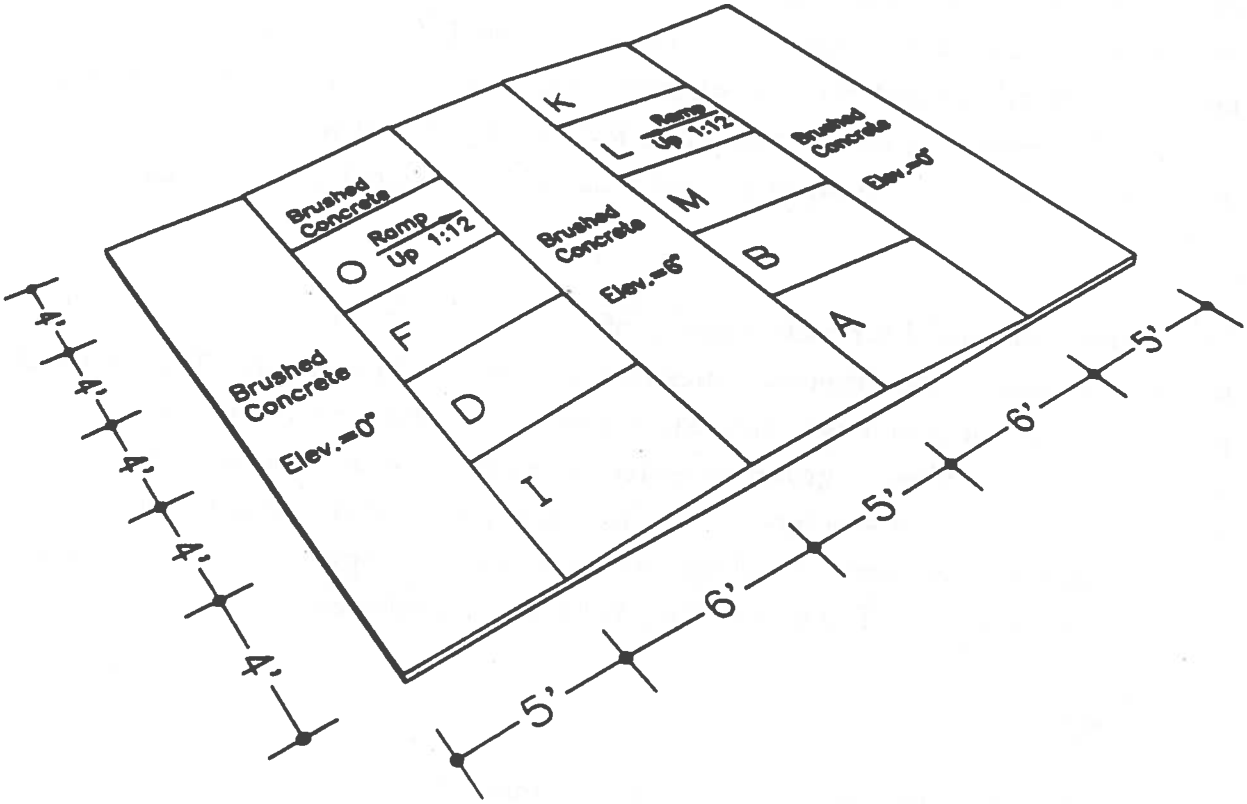


Figure 5-1. Laboratory ramps for testing safety and negotiability of nine detectable warnings on slopes (1:12). Constructed at old Broadway Station, MBTA.

"Tips"

Crutches:	(1) single underarm (3) double underarm (3) Canadian
Canes:	(6) single, standard canes (1) double canes (person used 1 in each hand) (1) quad cane
Walkers:	(1) standard aluminum (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 (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

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.

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

Subject #	DETECTABLE WARNING SURFACE									Score
	A	B	D	F	I	K	L	M	O	
"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.

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

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

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.

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.

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.

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

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-ange of all but one of these dimensions. Characteristics which may have accounted or the lower rate of detectability of this surface were the very smooth top surface of

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.

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.

> 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 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 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

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[1] Pathfinder Warning Tiles manufactured by Carsonite

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

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 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.

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.)

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 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

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