３．２．７　バリアフリーに関する研究

Form of Sidewalk-Roadway Boundaries Considering Their Use by Wheelchair Users and Visually Impaired Persons

By

Susumu TAKAMIYA
Senior Researcher, Advanced Road Design and Safety Division, Road Department, National Institute for Land and Infrastructure Management (NILIM), Ministry of Land, Infrastructure and Transport (MLIT)
Address: Asahi-1, Tsukuba-shi, Ibaraki-ken, 3050804, Japan
Phone Number: +81-29-864-4539
Fax Number: +81-29-864-2873
E-mail Address: takamiya-s92gi@nilim.go.jp

Hideto HATAKENAKA
Head, Road Construction Division, Civil Engineering Department, Nara Prefecture
Address: Noborioji-cho 30, Nara-shi, Nara-ken, 6308501, Japan
Phone Number: +81-742-22-1101

Toshiyuki MONMA
Attached to the International Policy Unit for Infrastructure, Policy Bureau, Ministry of Land, Infrastructure and Transport (MLIT)
Address: Kasumigaseki 2-1-3, Chiyoda-ku, Tokyo-to, 1008918, Japan
Phone Number: +81-3-5253-8111

Nozomu MORI
Director, Advanced Road Design and Safety Division, Road Department, National Institute for Land and Infrastructure Management (NILIM), Ministry of Land, Infrastructure and Transport (MLIT)
Address: Asahi-1, Tsukuba-shi, Ibaraki-ken, 3050804, Japan
Phone Number: +81-29-864-2510
Fax Number: +81-29-864-2873

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ABSTRACT
In Japan, at the boundaries of mount-up type sidewalks and pedestrian crosswalks, the level difference between the sidewalk and crosswalk surface is 2cm and a gentle slope links the sidewalk and crosswalk surfaces so that wheelchair users and visually impaired persons can cross the boundary. But in recent years, there have been cases where the level differences and the gradient of the surface of curbs have been lowered excessively. This solution makes it more difficult for visually impaired persons to recognize the sidewalk-roadway boundary, causing them anxiety. So experiments were done to study a form of sidewalk-roadway boundary that contributes to safer road use by both wheelchair users and visually impaired persons.
The experiments were performed by having experimental subjects cross 16 types of sidewalk-roadway boundary made by varying the shape of curbs installed on the boundary. The curb shapes were created by varying the shape of the edge, the level difference of the edge, height of the back surface, and surface gradient. The experimental subjects consisted of wheelchair users and visually impaired persons, all of whom normally go out alone. The experiments showed that wheelchair users found that the higher the level difference of the edge, the more difficult it was for them to cross the boundary. The visually impaired persons reported that when the backs of the curbs were high, it was easier for them to recognize the boundary.

1. INTRODUCTION

Two types of sidewalks have been used in Japan and these are either mount-up type or flat type. The mount-up type sidewalk is a level higher than the roadway and is divided from it by curbs. The flat type sidewalk is the same level as the roadway although it is also divided by curbs. The boundary between a mount-up type sidewalk and the roadway is clear because of the level difference between their surfaces, so it is easy for a visually impaired person to distinguish between the sidewalk and roadway. But because of this level difference or gradient at the sidewalk-roadway boundary of a mount-up sidewalk, it is not convenient for wheelchair users who want to cross the boundary.

In Japan, at the boundaries of mount-up type sidewalks and pedestrian crosswalks, the level difference between the sidewalk and crosswalk surface is 2cm and a gentle slope links the sidewalk and crosswalk surfaces so that wheelchair users and visually impaired persons can cross the boundary. Figure 1 shows an example of this structure. But in recent years, the aging of society has increased the number of elderly people using wheelchairs, resulting in cases where the level differences and the gradient of the surface of curbs have been lowered excessively. If this is done, it is more difficult for visually impaired persons to recognize the sidewalk-roadway boundary, making them anxious. So experiments were done to study a form of sidewalk-roadway boundary that contributes to safer road use by both wheelchair users and visually impaired persons.

2. BACKGROUND AND PURPOSE OF THE STUDY

2.1 The Law Concerning the Promotion of Accessibility of Public Transport Systems to the Aged and the Physically Disabled (Transport Accessibility Improvement Law)

Japanese society is aging at a pace faster than any other country in the world. It is predicted that the population aged 65 or older will reach 26.0% of the total population in 2015 *(1)* and Japanese society will become a society in which one fourth of its members is elderly. To prepare for a society of this kind, it is necessary to provide social infrastructure that will allow everyone including the elderly and the physically disabled to lead independent lives according to each person's desires. So in 2000, the Law concerning the Promotion of Accessibility of Public Transport Systems to the Aged and the Physically Disabled (usually called the Transport Accessibility Improvement Law) was enacted, and road space has been provided in line with its provisions.

The Transport Accessibility Improvement Law was enacted to encourage the more convenient and safer movement of people by removing all barriers to accessibility in railway stations, bus terminals, airports, passenger ship terminals, etc. and removing all barriers to movement on roads in districts surrounding these facilities out of consideration for the movement of the elderly, physically disabled people, pregnant women, and others who use public transportation systems. Under this law, municipal governments designate relatively unified areas centered on specified passenger transportation facilities as "Priority Improvement Areas", and sidewalks constructed in Priority Improvement Areas must comply with "the Standards for Road Structure Required for the Smooth Movement of People in Priority Improvement Areas".

In Japan, at the boundaries of mount-up type sidewalks and pedestrian crosswalks, the level difference between the sidewalk and crosswalk surface is 2cm and a gentle slope links the sidewalk and crosswalk surface so that wheelchair users and visually impaired persons can cross the boundary. Measures for sidewalk-roadway boundaries are similarly stipulated in the above

Standards. But in recent years, the aging of society has increased the number of elderly people using wheelchairs, resulting in cases where the level differences and the gradient of the surface of curbs have been lowered excessively. If this is done, it is more difficult for visually impaired persons to recognize the sidewalk-roadway boundary, making them anxious. It is, therefore, necessary to develop a sidewalk-roadway boundary form that wheelchair users can cross easily and that permits visually impaired persons to easily recognize the sidewalk-roadway boundary.

2.2 Past Studies of Sidewalk-Roadway Boundaries

A sidewalk-roadway boundary should be shaped so that wheelchair users can cross it easily and visually impaired persons can easily recognize the boundary. Past studies of sidewalk-roadway boundaries undertaken to provide such a form include that by FUJII et al *(2)* and by ISHIZUKA et al *(3)*. Both studies were conducted by preparing sidewalk-roadway boundaries by varying the shape of the curb installed on the boundary and performing experiments to evaluate how easily this boundary could be crossed. A curb shape consisted of the following elements.

Shape of the edge: Refers to the shape of the roadway side edge of the curb, and it can be rounded or sloped.

Level difference of the edge: Refers to the level difference on the roadway side edge of the curb.

Height of the back surface: Refers to the level difference between the surface of the sidewalk side edge of the curb and the roadway.

Surface gradient: Refers to the gradient from the sidewalk side to the roadway side formed by the surface of the curb.

FUJII et al *(2)* used 14 kinds of sidewalk-roadway boundaries created by varying the shape of the edge, the level difference of the edge, and surface gradient, then had wheelchair users, visually impaired persons, and elderly people cross the boundaries as an experiment to evaluate how easily they could cross the boundary and how easily they recognized it. The results showed that wheelchair users gave good evaluations to shapes with low level difference of the edge, and visually impaired persons gave good evaluations to those with a relatively steep surface gradient. And ISHIZUKA et al *(3)* similarly prepared 10 types of sidewalk-roadway boundaries by varying the level difference of the edge and the surface gradient, then had wheelchair users and visually impaired persons perform the experiment, obtaining almost identical results.

But both of these studies used curbs with the height of the back surface lowered to about 2cm and the level differences between the sidewalk and roadway were smaller than those with the curbs that have been used in Japan in the past. So these studies obtained the result that wheelchair users evaluated the sidewalk-roadway boundaries as easy to cross, but the results of evaluations by visually impaired persons show that they may be difficult for them to recognize.

2.3 Purpose of This Study

This study was conducted with reference to the above circumstances by considering the following points.

(1) In addition to a variety of new curb shapes, the experiments evaluated curb shapes that have been used in Japan in the past. It also evaluated these curb shapes comparatively.

(2) Under the above Standards for Road Structure Required for the Smooth Movement of People in Priority Improvement Areas, the mount-up and flat type sidewalks traditionally used in Japan were to be replaced with a semi-flat type sidewalk with a

level difference of 5cm between sidewalk and roadway. Therefore an evaluation of curb shapes with a height of the back surface of 5cm was also performed.

(3) In Japan, Tactile Ground Surface Indicators (TGSI) for visually impaired persons have been installed extensively at boundaries between sidewalks and roadways in order to make the boundaries easier for visually impaired persons to identify. Figure 2 shows the TGSI and a sample installation pattern *(5)*. However, TGSI have not been installed at every sidewalk-roadway boundary throughout the country, and it is unlikely that they ever will be. For this reason, a case in which TGSI were not installed was assumed in this study, and the characteristics of the curb shape only were evaluated.

3. STUDY METHOD

3.1 Sidewalk-Roadway Boundary

The experiments were performed by, as in the case of the past studies, having experimental subjects cross 16 types of sidewalk-roadway boundary made by varying the shape of curbs installed on the boundary. The experiments were performed at an outdoor test site at the National Institute for Land and Infrastructure Management (NILIM). The shapes of the curbs consisted of the following elements (See Figure 3), and the details of each element of the 16 curbs are shown in Table 1 and Figure 4.

Shape of the edge: Refers to the shape of the roadway side edge of the curb. There are two types: rounded or sloped. The sloped type uses a 100% gradient over the edge height differential, up to 2 cm. This is both higher and steeper than the slope required under the Americans with Disabilities Act (ADA) *(6)*.

Level difference of the edge: Refers to the level difference on the roadway side edge of the curb.

Height of the back surface: Refers to the level difference between the surface of the sidewalk side edge of the curb and the roadway.

Surface gradient: Refers to the gradient from the sidewalk side to the roadway side formed by the surface of the curb.

So the level differences of the edge that were tested were, in addition to the 2cm that is the level used on curbs in the past, 0cm and 1cm cases included to make them easier for wheelchair users to cross. The heights of the back surface included in the experiment were 1cm, 2cm, and 5cm in order to compare how easy it is for visually impaired persons to recognize each boundary. Setting the height of the back surface of some curbs at 5cm was done for reasons explained in 2.3 (2).

The curb shape that was used most often in the past in Japan is curb shape 15 in Table 1 and Figure 4, and the second most commonly used curb shape is curb shape 3.

3.2 Experimental Subjects

The experimental subjects were 32 manually operated wheelchair users and 34 visually impaired persons, and all were people who regularly go out alone. The following shows the degree of disability of the experimental subjects.

Wheelchair users: 32

Breakdown by type of injury
- Spinal cord injuries: 17
- Cervical vertebrae injury: 6
- Cerebral paralysis: 3
- Others: 6

Breakdown by age	20 - 29: 5 30 - 39: 4 40 - 49: 9 50 - 59: 11 60+: 2 Unknown: 1
Visually impaired persons: 34	
Breakdown by condition	Profound blindness: 23 Weak eyesight: 11 (visual acuity 0.001 to 0.04)
Breakdown by age	Up to 19: 2 20 - 29: 2 30 - 39: 3 40 - 49: 7 50 - 59: 11 60+: 8 Unknown: 1

3.3 Study Method

The experiment was performed by having the experimental subjects cross the curb, then afterwards, answer questions about how difficult it was to cross or how difficult it was to recognize the sidewalk-roadway boundary. The contents of the questions are shown in Table 2.

Each subject was asked to cross each curb four times, descending from the sidewalk to the roadway (below called "descent") twice and ascending from the roadway to the sidewalk (below called "ascent") twice. Subjects were asked to attempt the curb crossings as they normally would, and without assistance. When each visually impaired person crossed curb, the subject's starting position and the distance to the curb were varied on each repetition to prevent the subject's memory of the distance to the curb from helping them to recognize the boundary. The different curbs were presented in random order. Each subject was asked Q1 and Q2 immediately after each crossing. They responded to these questions with evaluations in five levels. The following points were given for each level.

Not difficult:	2 points
Not very difficult:	1 point
Cannot say:	0 points
A little difficult:	-1 point
Difficult:	-2 points

Then each was interviewed to obtain their other impressions.

3.4 State of the Study

A state of the study is shown in Figure 5 and Figure 6.

4. RESULTS AND CONSIDERATIONS

4.1 Handling the Data

The data was handled as shown in a) to c) according to the state of the experimental subjects during the experiment and the answers they provided. Beginning in part 4.2, the results of handling them in this way are treated as the evaluations of the sidewalk-roadway boundaries.

a) Handling Data that Considers the Characteristics of Wheelchair Users

During the experiment, about half of the wheelchair users raised the front wheels of their wheelchairs higher than the curb and let them down after they crossed the curb so that the front wheels did not touch the curb. Doing this reduced the difficulty caused by the sidewalk-roadway boundary, and the experimental subjects who did this during the experiment normally cross this way. But not all the wheelchair users are able to cross the boundary this way. So evaluation results were obtained using data for 14 other subjects who did not use this technique.

Breakdown of 14 subjects by type of injury

- Spinal cord injuries: 7
- Cervical vertebrae injury: 2
- Cerebral paralysis: 2
- Others: 3

Breakdown by age

- 20 - 29: 2
- 30 - 39: 2
- 40 - 49: 4
- 50 - 59: 5
- Unknown: 1

Wheelchairs were subject to far more resistance by the sidewalk-roadway boundary during “ascent” than during “descent.” So the average of the answers concerning “ascent” after the experimental subjects had already crossed the boundary once, or in other words, the answer about the “second ascent” was treated as the evaluation result.

b) Handling Data Considering the Characteristics of Visually Impaired Persons

This experiment was conducted by having visually impaired persons cross the curbs, but some of visually impaired persons with weak eyesight could visually recognize the sidewalk-roadway boundary. And data for 23 visually impaired persons with profound blindness were treated as the evaluation results.

Breakdown of 23 subjects by condition

- Profound blindness: 23 (all subjects)

Breakdown by age

- Up to 19: 2
- 20 - 29: 1
- 30 - 39: 1
- 40 - 49: 3
- 50 - 59: 8
- 60+: 7
- Unknown: 1

The experimental subjects ascended twice and descended twice, and the average of all answers obtained was the evaluation results.

c) Handling of Data Concerning the Shape of the Edge

Two edge shapes were used for the experiments: rounded edges and sloped edges. But there were few differences between the evaluations of curbs with identical level difference of the edge, height of the back surface, and surface gradient, even if the shape of their edges differed (for example, shape 10 and shape 11, shape 13 and shape 14, etc.). So in a case where the level

difference of the edge, height of the back surface, and surface gradient are identical, the answers concerning the curbs with rounded edges were used as the evaluation results.

4.2 Evaluations by Wheelchair Users

Figure 7 shows the results of the evaluation by wheelchair users of how easy it was to cross the curbs. The following can be concluded from the evaluation results.

- The evaluations vary widely according to differences in the level difference of the edge. The lower the level difference of the edge, the more easily they crossed the curb.
- If the level difference of the edge was 0cm, it was evaluated as easy to cross even if the height of the back surface was 5cm (shape 6, shape 7).
- Differences in the height of the back surface and surface gradient had no direct impact on how easily wheelchair users crossed the curbs.
- Evaluations of shape 15 and shape 3 that have been used in Japan in the past were low and more desirable shapes were obtained.

The above results show that the level difference of the edge should be as small as possible for the benefit of wheelchair users, and that the sidewalk-roadway boundary with a level difference of the edge of 2cm that has been used in Japan is given a low evaluation by wheelchair users. This is assumed to be a result of the fact that road surfaces should have no level differences so that they could be used by wheelchair users, and even if the level difference of the edge was 2cm, this level difference would represent a considerable obstruction to wheelchair users.

The results also show that differences in the height of the back surface and the surface gradient make little difference to the ease of crossing by wheelchair users. This can be attributed to the fact that the curbs used in the experiment were no greater than 5cm in height, with a surface gradient length of around 20cm, which is easily enough to eliminate difficulties for wheelchair users.

4.3 Evaluations by Visually Impaired Persons

Figure 8 shows the results of evaluations by visually impaired persons of how easily they recognized the sidewalk-roadway boundaries. The following can be concluded from the evaluation results.

- The evaluations vary greatly according to differences in the height of the back surface. The higher the height of the back surface, the easier it was for visually impaired persons to recognize the sidewalk-roadway boundary.
- At a height of the back surface of 5cm, it was evaluated as easy to recognize even if the level difference of the edge was 0cm (shape 6, shape 7).
- A height of the back surface of 5cm obviously required a larger surface gradient, which meant that the boundary was easily recognized even with the larger surface gradient.
- In a case where the level difference of the edge was 2cm but the height of the back surface was low, the evaluation was low (shape 3). The surface gradient was 0% in this case.
- The higher the level difference of the edge, the easier it seemed to be to recognize the boundary, but only slightly easier.
- Evaluations of shape 15 and shape 3 that have been used in Japan in the past were high for shape 15 but low for shape 3.

The above results indicate that visually impaired persons can more easily recognize a sidewalk-roadway boundary if the height of the back surface is about 5cm than if the level difference of the edge is simply 2cm (shape 3). This is assumed to be a result of the fact that visually impaired persons can recognize the existence of a sidewalk-roadway boundary by contact with the ground by their feet or by their white cane most easily when, because of the height of the back surface, there is a level difference between the sidewalk and roadway of about 5cm. Not only should the policy of guaranteeing a level difference of the edge of 2cm that is stipulated by Japanese standards be followed, but a high height of the back surface should be high so that visually impaired persons can easily recognize sidewalk-roadway boundaries.

The results also indicate that visually impaired persons can easily recognize the sidewalk-roadway boundary at larger surface gradients. Based on a curb width of approximately 20cm, as commonly employed in Japan, and a height of the back surface of 5cm as stipulated in "the Standards for Road Structure Required for the Smooth Movement of People in Priority Improvement Areas", the surface gradient would be in the range 20% – 25%. Thus, the surface gradient is correlated with the height of the back surface, so above results were obtained. The validity of surface gradients greater than 25% was not able to be confirmed in this experiment.

4.4 Overall Evaluations

Figure 9 shows the overall evaluation results obtained using evaluations by both wheelchair users and visually impaired persons. The following can be concluded from the evaluation results.

- There are sidewalk-roadway boundaries that were evaluated highly by both wheelchair users and visually impaired persons (shape 6, shape 7, shape 8, and shape 10).
- These shapes have a low level difference of the edge of 0cm and 1cm, and the height of their back surfaces is 5cm.
- A comparison of evaluations of shape 15 and shape 3 that are shapes used in the past in Japan shows that shape 15 received high evaluations by visually impaired persons but low evaluations from wheelchair users, while shape 3 was given low evaluations by both wheelchair users and by visually impaired persons.

Based on the above results, it is possible to propose that the sidewalk-roadway boundary desirable for both wheelchair users and visually impaired persons is a level difference of the edge of 0cm or 1cm with a height of back surface of 5cm. These shapes are more highly evaluated than the sidewalk-roadway boundaries used in the past in Japan.

5. CONCLUSIONS

The following conclusions can be made based on a summarization of the above study results.

(1) For wheelchair users, the lower the level difference of edge, the easier it is to cross a sidewalk-roadway boundary.
(2) Under Japan's standards, "the level difference of the edge shall be 2cm," but for visually impaired persons, even if the level difference of the edge is 2cm, if the height of the back surface is low, it is not very easy for them to recognize the sidewalk-roadway boundary.
(3) For both wheelchair users and visually impaired persons, the desirable sidewalk-roadway boundary that can be proposed is a shape with level difference of the edge of 0cm or 1cm and a height of the back surface of 5cm. These shapes were evaluated highly because they are more easily crossed and more easily recognized than the sidewalk-roadway boundary that had been used in Japan.

This study succeeded in collecting information about sidewalk-roadway boundaries desirable for both wheelchair users and visually impaired persons. But the study obtained results at an outdoor test site at the National Institute for Land and Infrastructure Management (NILIM); not evaluations that comply with conditions of actual roads. The environments surrounding the test site and actual roads differ somewhat. For example, the boundary between a sidewalk and a roadway on an actual road is not necessarily linear, which means that wheelchair users encounter new obstacles to crossing this boundary. Visually impaired persons recognize sidewalk-roadway boundaries not only from the shape of the sidewalk-roadway boundary, but from the situations of other pedestrians or vehicles. In the future, it will be necessary to conduct studies and evaluations considering the state of actual roads, and ultimately, to include standards stipulating desirable sidewalk-roadway boundaries in Japan's standards.

ACKNOWLEDGMENTS

The Discussion Group for the Universal Design of Road Space led by Associate Professor Kubota of Saitama University provided us with valuable advice concerning the summarization of the study results. The authors wish to express their deep gratitude to its members for their help.

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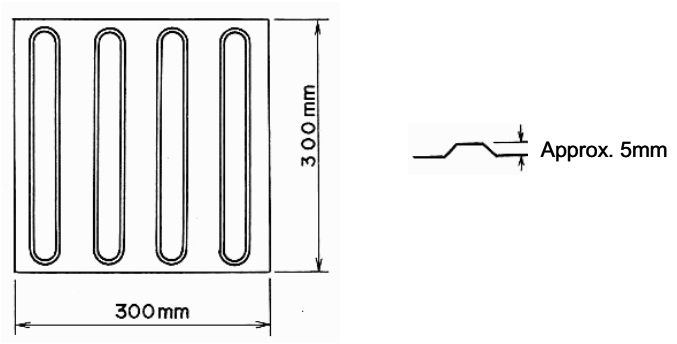
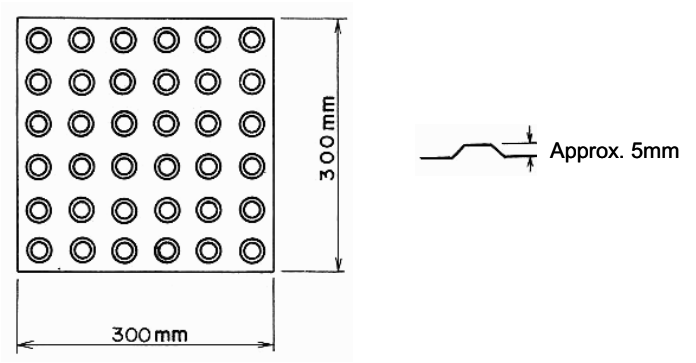
LIST OF TABLES AND FIGURES

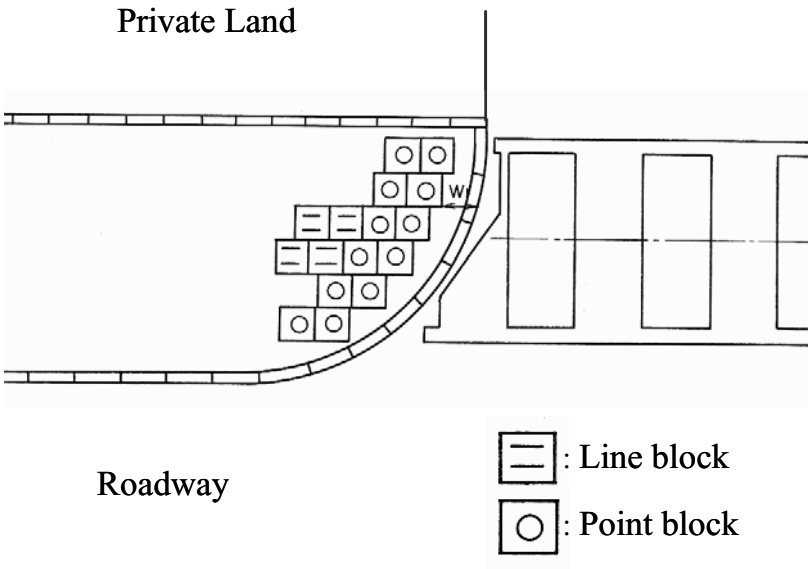
FIGURE 1 Example of a sidewalk-roadway boundary on a mount-up type sidewalk.



(a) Line block



(b) Point block



(c) A sample installation pattern

FIGURE 2 Tactile Ground Surface Indicators (TGSI) and a sample installation pattern.

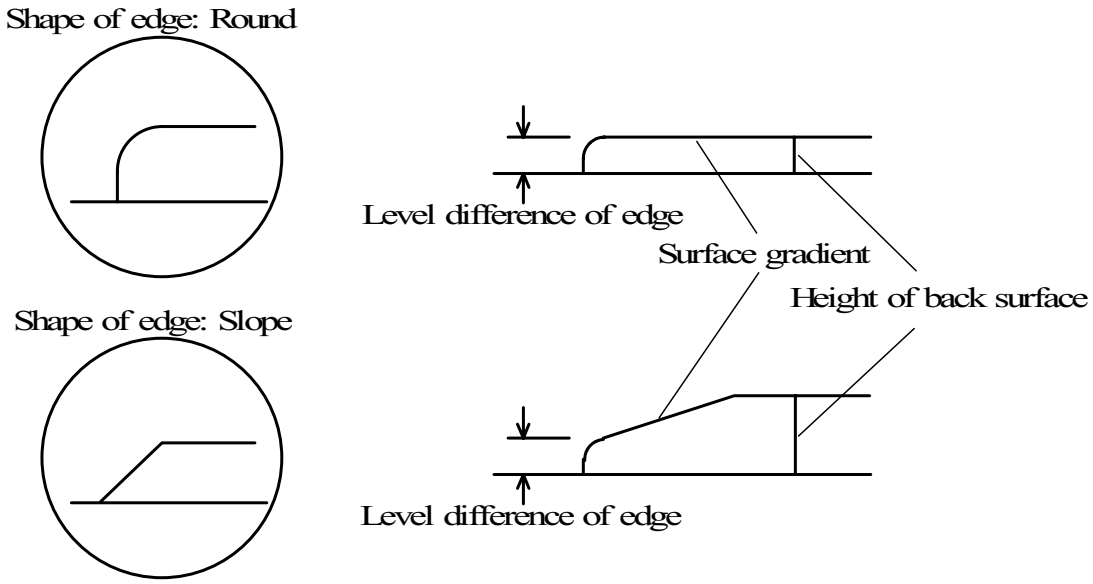


FIGURE 3 Names of elements of curb shape.

TABLE 1 Details of Elements of 16 Types of Curbs

Shape	Shape of edge	Level difference of edge (cm)	Height of back surface (cm)	Surface gradient (%)
1	Round	1	1	0
2	Slope	1	1	0
3	Round	2	2	0
4	Slope	2	2	0
5	-----	0	2	12.5
6	-----	0	5	20
7	-----	0	5	25
8	Round	1	5	20
9	Slope	1	5	20
10	Round	1	5	25
11	Slope	1	5	25
12	Round	2	5	12.5
13	Round	2	5	20
14	Slope	2	5	20
15	Round	2	5	25
16	Slope	2	5	25

Note) The shape of the edge defined as “Round” has a rounded edge and the shape of the edge defined as “Slope” is sloped.

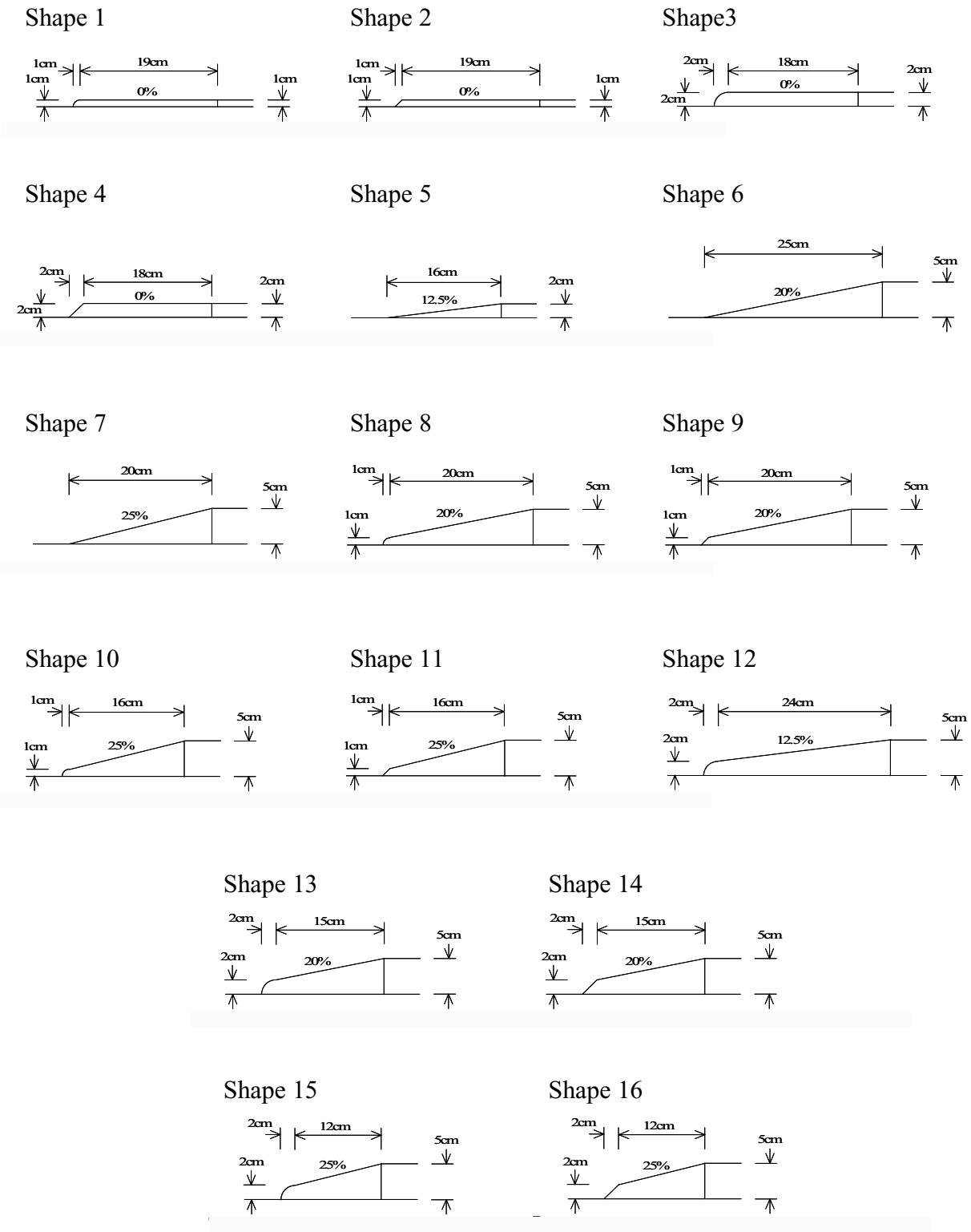


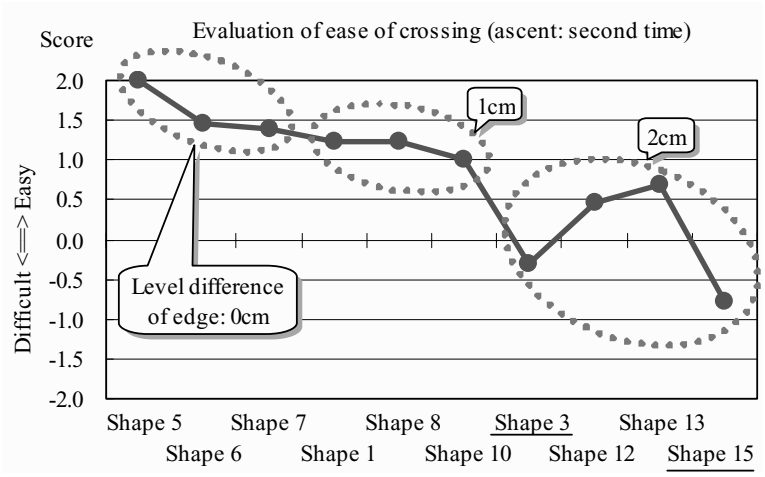
FIGURE 4 Shapes of 16 types of curbs.

TABLE 2 Questions Answered by the Experimental Subjects

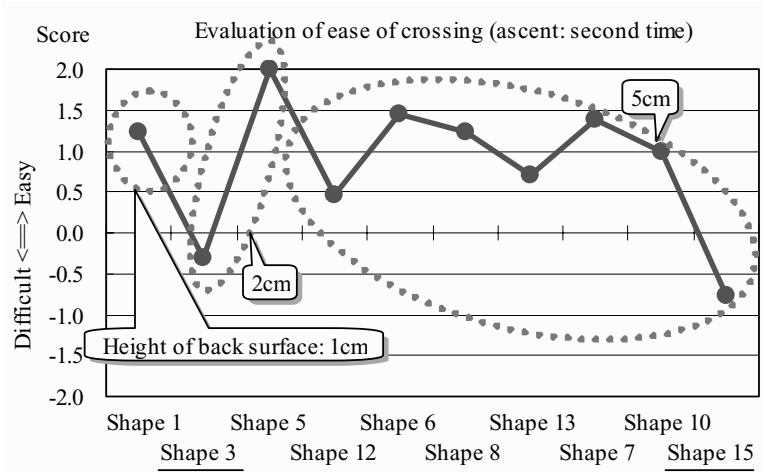
Questions for wheelchair users
Q1: Degree of difficulty of crossing (5-level evaluation) Q2: Degree of difficulty when the curb that you crossed is used as a sidewalk-roadway boundary (5-level evaluation) Q3: Others, impressions etc.
Questions for visually impaired persons
Q1: Degree of difficulty of recognizing the sidewalk-roadway boundary (5-level evaluation) Q2: Degree of difficulty when the curb that you crossed is used as a sidewalk-roadway boundary (5-level evaluation) Q3: Others, impressions etc.

FIGURE 5 State of the study (experiment by wheelchair users).

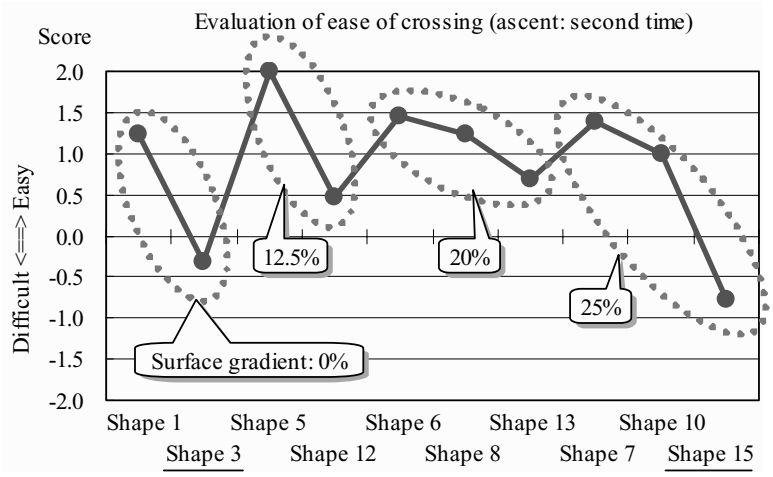
FIGURE 6 State of the study (experiment by visually impaired persons).



(a) Differences in evaluations according to the level difference of the edge.

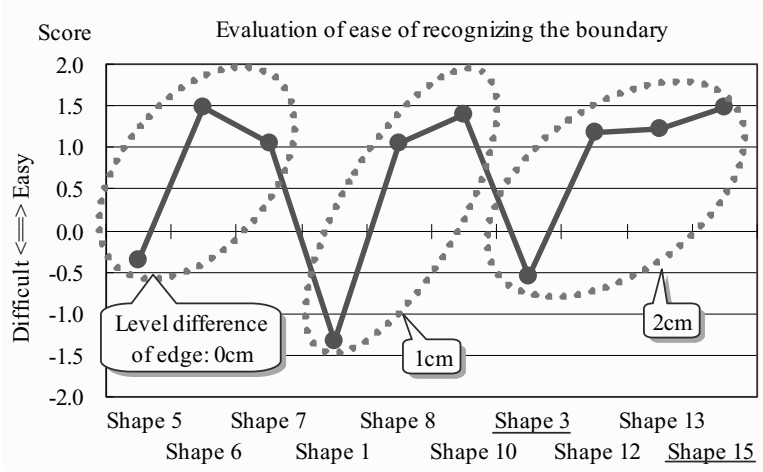


(b) Differences in evaluations according to the height of the back surface.

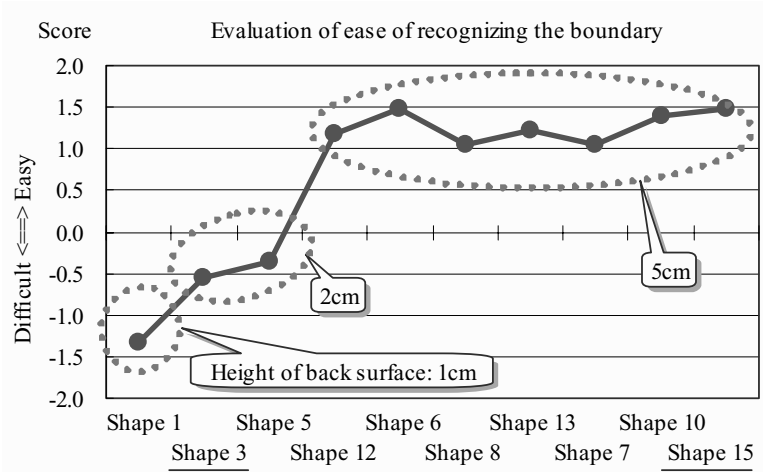


(c) Differences in evaluation according to the surface gradient.

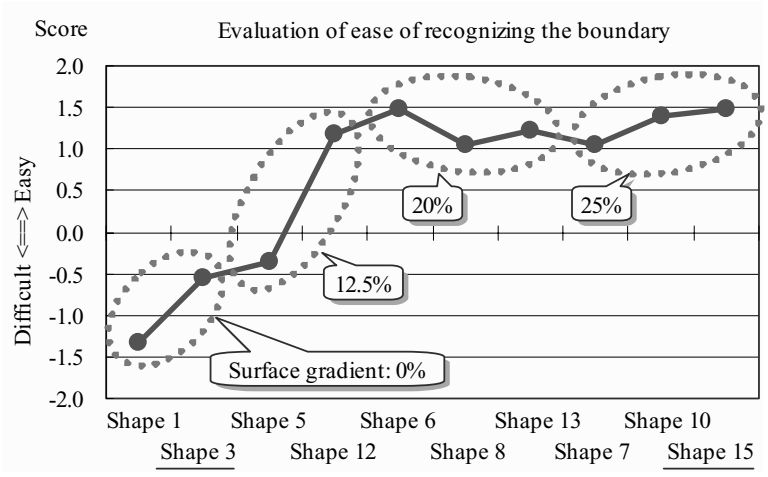
FIGURE 7 Results of evaluation of ease of crossing by wheelchair users.



(a) Differences in evaluation according to the level difference of the edge.



(b) Differences in evaluation according to the height of the back surface.



(c) Differences in evaluation according to the surface gradient.

FIGURE 8 Results of evaluation of ease of recognizing the sidewalk-roadway boundary by visually impaired persons.

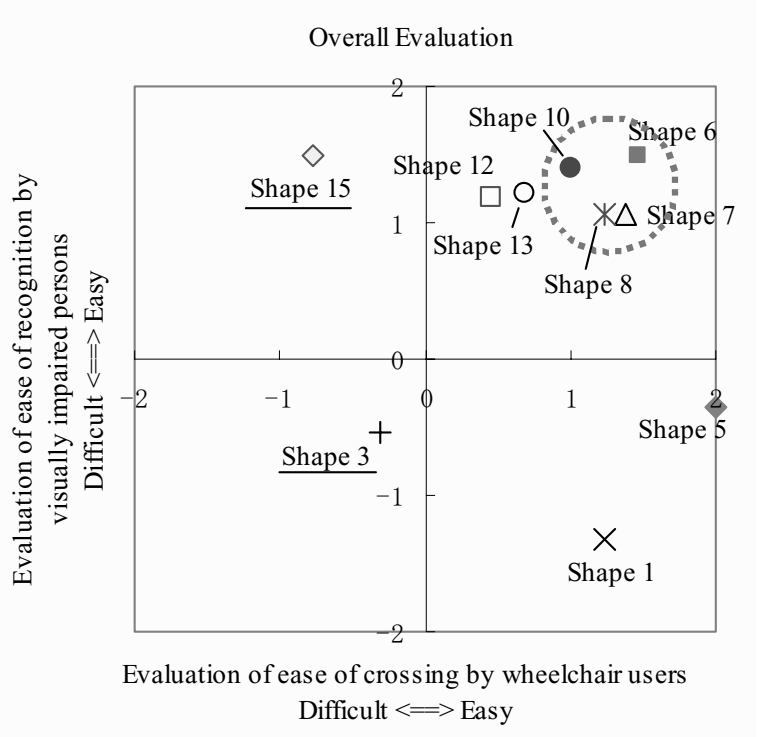


FIGURE 9 Overall evaluations.