Journal of the Eastern Asia Society for Transportation Studies, Vol.8, 2010

Development of Recessed Pavement Markings That Incorporate Rumble Strips

Masayuki HIRASAWA
Senior Researcher
Traffic Engineering Research Team
Civil Engineering Research Institute for Cold Region, PWRI
1-3 Hiragishi, Toyohira-ku, Sapporo, 062-8602, Japan
Fax: +81-11-841-9747
E-mail: hirasawa@ceri.go.jp

Azuma TAKEMOTO
Researcher
Traffic Engineering Research Team
Civil Engineering Research Institute for Cold Region, PWRI
1-3 Hiragishi, Toyohira-ku, Sapporo, 062-8602, Japan
Fax: +81-11-841-9747
E-mail: a-takemoto@ceri.go.jp

Satoshi KASAI
Team Leader
Traffic Engineering Research Team
Civil Engineering Research Institute for Cold Region, PWRI
1-3 Hiragishi, Toyohira-ku, Sapporo, 062-8602, Japan
Fax: +81-11-841-9747
E-mail: s-kasai@ceri.go.jp

Hisashi AITA
Manager of Equipment
Technical Development Division
Nippo Corporation
6-70, Mihashi, Nishi-ku, Saitama, 331-0052, Japan
Fax: +81- 48-622-3028
E-mail: aita_hisashi@nippo-c.jp

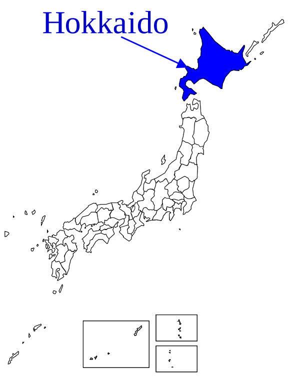
Abstract: In winter in Hokkaido, pavement markings are damaged from snow removal, and every spring, the markings need to be reapplied. The authors propose a system of pavement markings whose recessed design prevents scraping damage from snowplows and whose incorporation of rumble strips increases driving safety. To determine the optimum design for recessed pavement markings, trial installation used two intervals between grooves. Driving tests found that recessed markings with long intervals generate more noise and vibration than recessed markings with short intervals, making the former more noticeable than the latter. It was found that waterborne paints are not durable enough to be used on recessed pavement markings. Spraying of thermoplastic paints were chosen instead. Furthermore, in order to improve of nighttime visibility under rainy conditions by highly reflective beads were used. This paper reports on development of recessed pavement markings that incorporate rumble strips.

Key Words: *pavement markings, road safety, rumble strips*

1. INTRODUCTION

In winter in Hokkaido, northern Japan, pavement markings are damaged from scraping by snowplows and tire chains, and every spring, the markings need to be reapplied. Thermoplastic paints are the standard in Japan. In Hokkaido, thermoplastic markings are often scraped by the blades of snowplows (Figure 1). For this reason, the lowest-priced waterborne paints have mostly been used. Moreover, the cost of such maintenance is particularly onerous in light of current constraints on road budgets in Japan.

The authors propose a system of pavement markings whose recessed design prevents scraping damage from snowplows and whose incorporation of rumble strips increases driving safety. The markings are installed by milling a shallow longitudinal recess into the pavement at the shoulder line while simultaneously milling more deeply recessed transverse grooves (the rumble strips), and then applying marking paint. The recessed design reduces maintenance costs by affording resistance to snowplow damage. To improve cost-effectiveness, the further recessed grooves of the rumble strip achieve accident reduction by producing noise and vibration in vehicles traveling over them to alert drivers who are in danger of leaving the carriageway.



Snow removal in Hokkaido

Damaged markings in the spring

Vehicles

Environment

Snowplows

Factors in pavement marking damage

Figure 1 Damaged markings in Hokkaido

In a past study, Outcalt (2001) measured noise and vibration in vehicles running over rumble strips of various dimensions. He proposed the use of shallower rumble strips in order to achieve safety for bicycle users while maintaining the warning function for vehicle drivers. Hirasawa et al. (2005) measured noise and vibration in vehicles running over rumble strips of three depths (9 mm, 12 mm, and 15 mm) and surveyed test drivers by questionnaire on subjective safety, noise and vibration. They proposed the use of rumble strips 12 mm in depth to maximize safety while maintaining the warning effect. They reported that the noise in vehicles running over such rumble strips is about 80 dB.

Kopf (2004) spent one year measuring the reflection intensity of waterborne and solvent-based paint markings at about 80 locations in Washington State. He developed deterioration curves for road marking performance, but reported that those curves were not accurate. Bahar et al. (2006) reported that California applies frequent maintenance, with pavement markings reapplied on higher-volume highways up to three times a year for waterborne paint markings and every two years for thermoplastic markings.

In this study, test installation of recessed pavement markings incorporating rumble strips was first conducted to evaluate their performance through measurements of noise and vibration in vehicles using noise and vibration meters. Next, a driving experiment involving road users was conducted on a test road, and levels of safety as well as the effects provided by the markings were evaluated through subjective assessment by the participants to confirm the safety of passing vehicles. Installation of recessed pavement markings with rumble strips on

National Route 230 in Sapporo based on the results obtained revealed that the durability of waterborne paint was insufficient. Accordingly, thermoplastic paint was adopted despite the higher material costs involved. In addition, since visibility decreases at night and in rainy conditions if markings are positioned lower than the pavement surface, highly refractive glass beads were adopted to improve visibility, and a visibility evaluation experiment was conducted. The results indicated that it was possible to create markings that are resistant to scraping by snowplows in winter, capable of alerting drivers and highly visible at night and in rainy conditions. This paper reports on the development of these recessed pavement markings that incorporate rumble strips.

2. INSTALLATION METHOD

In Japan, waterborne paints, solvent-based paints and thermoplastic paints are used for markings, with thermoplastic paints as the standard. But in Hokkaido, thermoplastic marking is often scraped by the blades of snow removal machinery. Therefore, the lowest-priced waterborne paint has been mostly used in Hokkaido. The recessed pavement marking system is expected to reduce repair and maintenance costs by affording greater durability than conventional pavement markings. However, since the cost of applying a waterborne pavement marking is about JPY100/m (about $0.9/m) and the recessing method entails the extra cost of milling the pavement surface, it may be difficult to achieve a satisfactory cost-benefit. To remedy this, the system incorporates a rumble strip.

A milling machine is used to cut the longitudinal recess for the markings while simultaneously cutting the transverse grooves for the rumble strips. The milling drum is mounted at the rear left of the milling machine, making it convenient for use even on narrow road shoulders.

In the proposed pavement marking system, the longitudinal recess is shallow, and it is important to maintain a constant depth for that recess. Also, because the rumble strips are milled into the recess, they are shallower than conventional rumble strips. The most important factor in milling grooves of a consistent depth is the precision of the cam wheels.

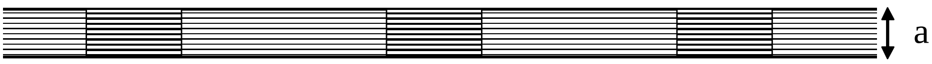
The proposed pavement marking system is to be installed at the road shoulder. It should not adversely affect the stability of bicycles and motorbikes. To produce shallow grooves for minimum bumpiness, the vertical movement of the milling drum needs to be small. Therefore, the cam wheel is closer to round than it would be for deeper rumble strips. In this study, two types of cam wheels were tested (Figure 2). The two types produce longitudinal recesses and transverse grooves with the same transverse width, but one produces the grooves at long intervals and the other produces them at short intervals. Figure 3 shows the dimensions of the cam wheels, the upper surface of recessed pavement markings that incorporate rumble strips and a longitudinal section of those markings.

Figure 2 Installation of recessed pavement markings

(a) Dimensions (mm)

Type	Cam wheel	Recess width: a	Groove width: b	Distance between grooves: c	Pitch of grooves: b+c	Milling depth: d	Milling depth: e
Long-interval markings		150	80	160	240	6	3
Short-interval markings		150	100	100	200	6	3

(b) View of upper surface



(c) Cross section view

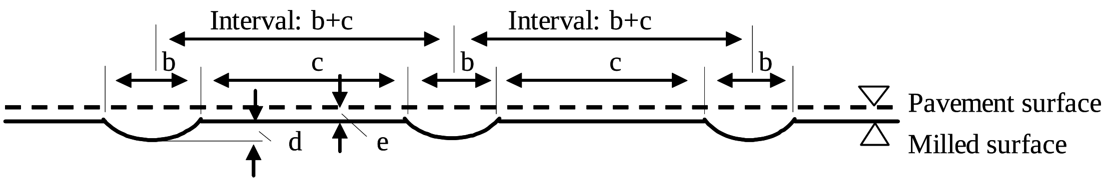
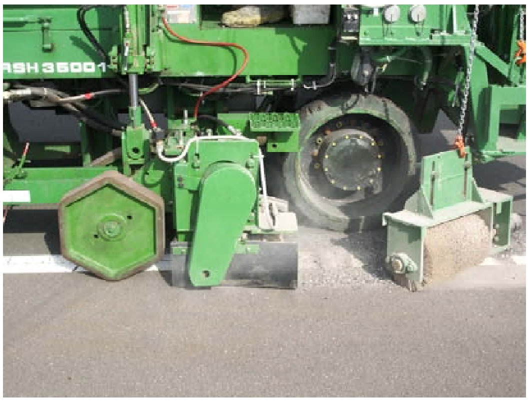


Figure 3 Dimensions (mm) and Schematic

3. TRIAL INSTALLATION AT THE TOMAKOMAI WINTER TEST TRACK

At the Tomakomai Winter Test Track, the two types of recessed pavement markings were installed (100 m for each type) on October 25, 2005. The installation rate was about 4 m per minute, and the markings were installed as designed.

Figure 4 shows the recessed pavement markings after milling and immediately after pavement marking paint application. As shown in the photo, the milling drum cuts a shallow longitudinal recess. This tends to trap asphalt chippings from the milling process. These chippings have to be thoroughly removed, since the marking paint is sprayed directly into this recess.



Installation of recessed pavement markings

Pavement marking paint spraying

Immediately after milling

Immediately after marking paint spraying

Figure 4 Newly milled recessed pavement markings

4. MEASUREMENT OF NOISE AND VIBRATION INSIDE THE CAR

Noise and vibration caused by travel over the rumble strips in the recessed pavement markings were studied using a noise meter (RION NL-22) and vibrometer (RION VM-82). Raised pavement markings were installed for comparison of noise and vibration with the recessed pavement markings. Noise and vibration were measured by installing instruments in a sedan car (1500 cc engine, 185/70R14 tire size) and driving it over the recessed pavement markings and the raised pavement markings. The microphone of the noise meter was installed on the passenger seat headrest, and the vibrometer was installed on the steering column (Figure 5). Noise was measured at travel speeds of 40, 60, 80 and 100 km/h, three times for each speed. The noise was the average of the maximum value for each of the three travels (Figure 6). The long-interval recessed pavement marking produced the most noise, which was roughly the same at all speeds. The noises produced by the long-interval recessed pavement marking were often greater than those of raised pavement markings, and they were about 8 to 16 dB greater than those for normal pavement.

Vibration inside the car was measured in accordance with the JIS method for measuring vibration that changes cyclically and/or intermittently, and the measured vibration per travel was the average of the ten highest values for that travel. The vibration for each travel speed was obtained by averaging the ten greatest vibration values for each of the three travels (Figure 7). Measured vibration did not differ greatly among the long-interval recessed pavement markings, short-interval recessed pavement markings, and raised pavement markings. However, the vibration produced by the three types of markings was greater than that produced by normal asphalt pavement.

Measurement devices | Recessed pavement marking (long interval) | Recessed pavement marking (short interval) | Raised pavement marking

Figure 5 Measurements of noise and vibration inside the car

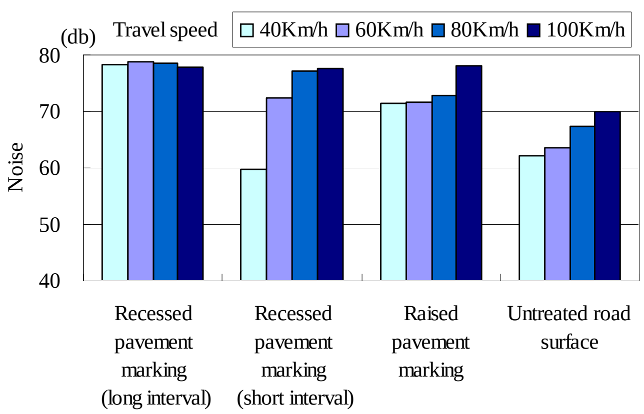


Figure 6 Noise inside the car

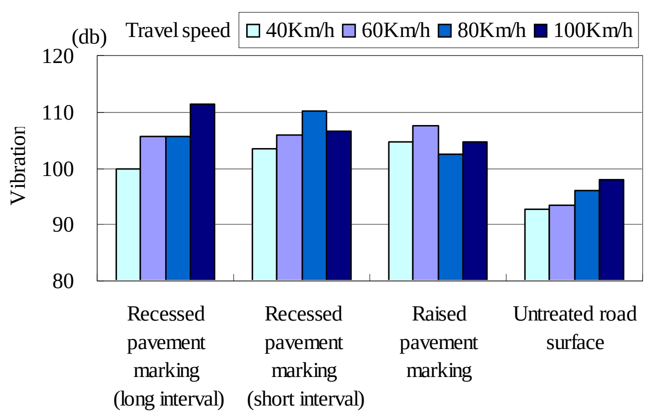


Figure 7 Vibration inside the car

5. TEST RUN BY ROAD USERS

Since the recessed pavement markings are expected to be installed at the road shoulder, the greatest concern is adverse effects on the handling stability of bicycles and motorbikes. Therefore, members of the public were recruited for driving tests. After running the test course, the test drivers were surveyed by questionnaire on how the marking affected the handling stability of the vehicle and on the effectiveness of each marking in preventing accidents.

The tests were performed for the seven days from November 26, 2005, by a panel of 104 subjects driving a sedan car (1500 cc), a large motorcycle (400 cc), a small motorcycle (< 50 cc), and a bicycle. The questionnaire survey was performed after each driver tested road sections installed with long-interval recessed pavement markings, short-interval recessed pavement markings and raised pavement markings (Figure 8).
The travels of the test drivers were video recorded. Handling instability was not observed. In

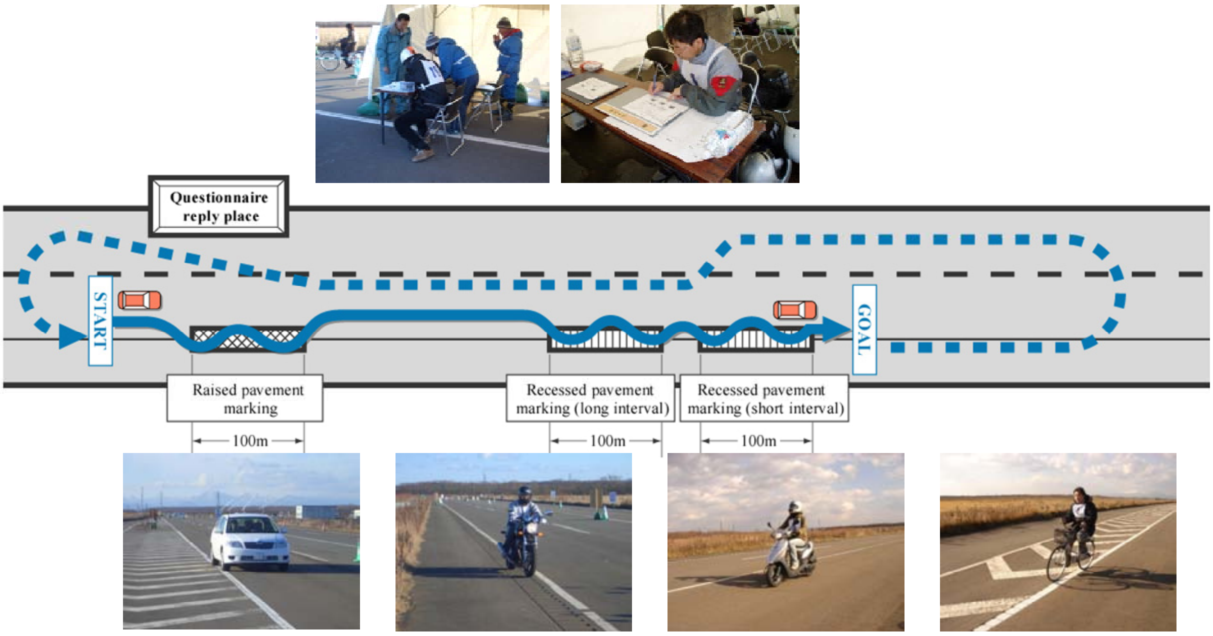


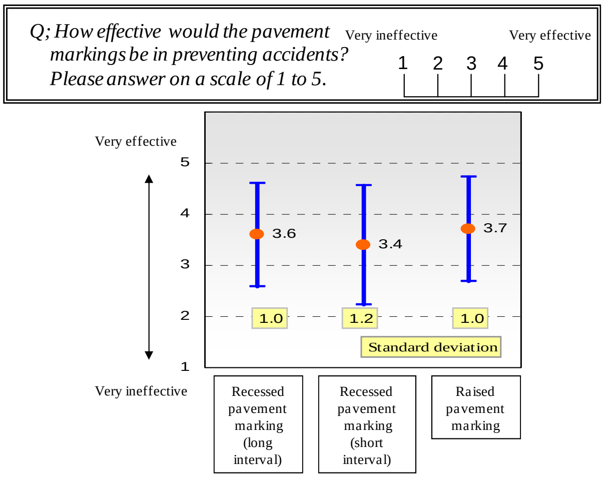
Figure 8 Running test

the questionnaire, the test drivers were asked to score the effectiveness of each marking in preventing accidents by generating noise and vibration to alert drivers' on a scale from 1 (Very ineffective) to 5 (Very effective). They were also asked to score how stably the large motorcycle, small motorcycle and bicycle handled on the markings, on a scale from 1 (Very unstably) to 5 (Very stably). Figure 9 shows average scores of respondents and standard deviation of each test run.

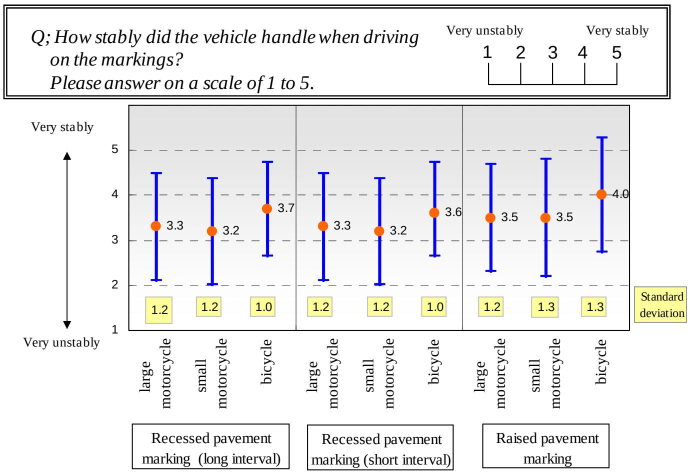
For effectiveness in preventing car accidents, the long-interval recessed pavement markings had a slightly higher average rating than the short-interval recessed pavement markings: The average score was 3.6 for the former (standard deviation of 1.0) and 3.4 for the latter (standard deviation of 1.2). These were similar to the average score for the raised pavement marking.

For handling stability reported by large and small motorcyclists, the long-interval recessed pavement markings had the same average score as the short-interval markings: The average handling stability score was 3.3 (standard deviation of 1.2) for both markings. For handling stability reported by cyclists, the long-interval recessed pavement markings had roughly the same average score as the short-interval markings: The average handling stability score was 3.7 for the long-interval recessed pavement markings (standard deviation: 1.0) and 3.6 for the short-interval recessed pavement markings (standard deviation: 1.0). The handling stability scores reported by cyclists for the long- and short-interval recessed pavement markings did not differ greatly from those reported by cyclists for the raised pavement marking.

At the end of the questionnaire, the test drivers were asked “Which is the better of the two recessed pavement markings?” (Figure 10). Thirty-eight percent answered “The short-interval one,” and 35% answered “The long-interval one.” Only 4.4% answered, “Neither is any good.” Road users indicated their support for installation of recessed pavement markings that incorporate rumble strips.



(a) Avg. responses of car drivers



(b) Avg. response for drivers of other vehicles

Figure 9 Accident prevention effectiveness and handling stability

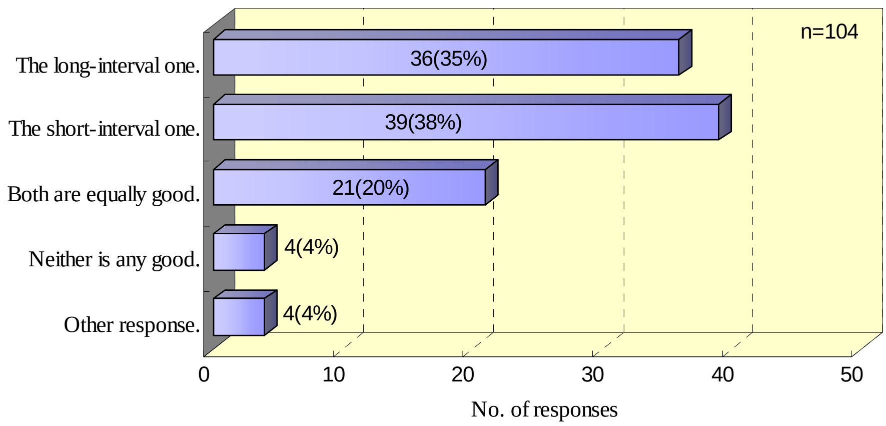


Figure 10 Which is the better of the two recessed pavement markings?

6. DURABILITY

To test the durability of the recessed pavement markings, test installations were performed in the Jozankei district of Minami Ward, Sapporo City, on National Highway 230 (Figure 11). The marking was installed at the shoulder on 10 m of straightaway and 10 m of curves. The recessed pavement markings for the test were the long-interval type. The test installation was performed late at night on November 24, 2005. Since the temperature dropped below 5ºC, a solvent-based marking paint was used, and it was heated for spraying.

Installation of recessed pavement markings

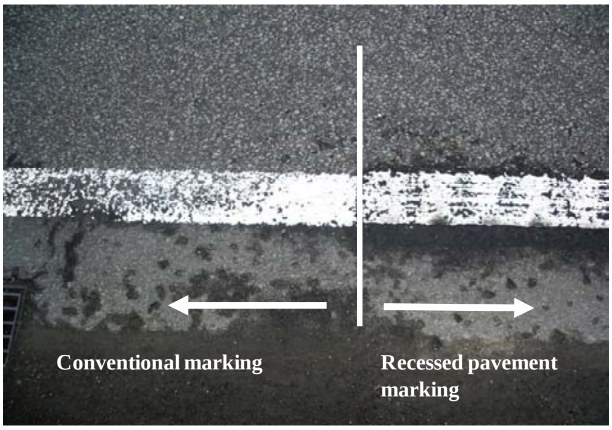
Immediately after milling

Pavement marking paint spraying

Immediately after marking paint spraying

Figure 11 Test installations at Sapporo City, on National Highway 230

Figure 12 shows a conventional pavement marking and a recessed pavement marking as of April 13, 2006 (i.e., after 19 weeks in service). The photo shows that the marking paint for the recessed pavement marking does not differ in durability from that for conventional pavement markings. The marking paint has spalled for both, although for the recessed marking the spalling is from small longitudinal grooves left by the milling machine. The paint at the spalled portions was brittle, and some portions could be removed by hand. Spalling of paint was also observed at the test installations on the Tomakomai Winter Test Track. The failure of the paint to adhere to the asphalt was attributed to inadequate flow into the small grooves. As a result, the pavement markings seem to have been partially damaged or spalled by wheel loadings. When the marking application method is spraying with waterborne or solvent-based paints, recessed pavement markings are not as durable as conventional surface markings (Figure 13).



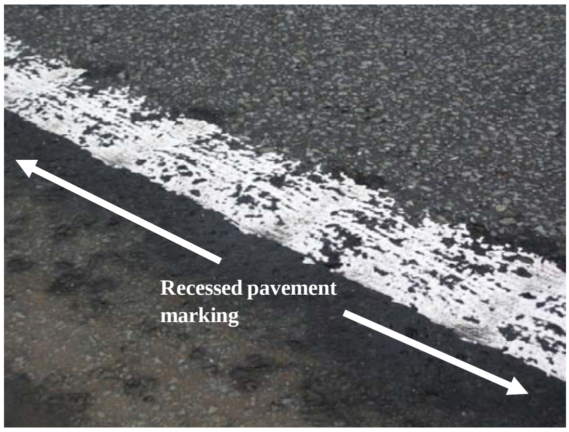


Figure 12 Conventional and recessed pavement markings (Rte. 230, 04/13/06)

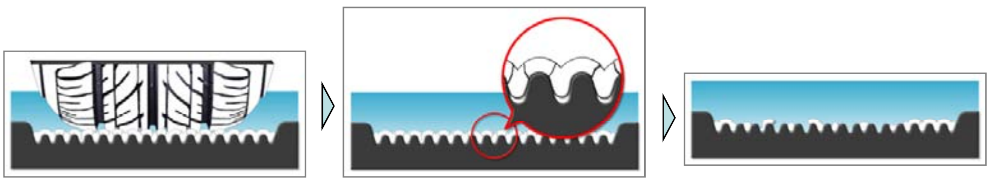


Figure 13 The paint fails to adhere to the asphalt

7. APPLICATION OF THERMOPLASTICS

The study found that waterborne or solvent-based paints are not durable when sprayed on recessed pavement markings. It was necessary to study an application method that could resist damage from passing vehicles. Thermoplastics are considered to be the most durable conventional paint. However, on surfaces with grooves, this paint has the disadvantage of flowing into and filling the grooves. One solution is to spray the paint. To study the durability of markings installed by this method, two test pieces were made to simulate the recessed marking: one sprayed with waterborne paint, and the other applied with thermoplastic paint. The test pieces were subjected to ravelling tests (Figure 14). The ravelling test was performed with a normal tire, and durability was evaluated according to spalling and reflectance measured by a luminance meter. The severity of spalling was measured by dividing the test piece into grids, visually counting the number of grids with spalling, and dividing that number by the total number of grids to achieve a spalling ratio (%). After 10,000 rotations, the waterborne paint showed a similar degree of spalling along the grooves to that observed on roads in service. Spalling was not observed on the test piece with the thermoplastic marking. The spalling ratio was 5% for the waterborne paint and 0% for the thermoplastic marking. The reflectance was the same for both types of paint (Figure 15).

Ravelling test

Luminance meter for pavement markings

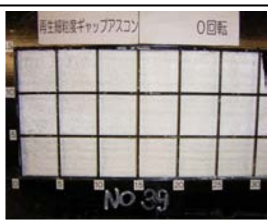
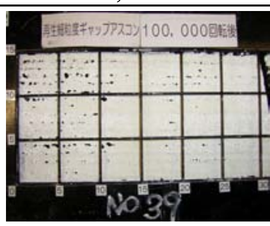
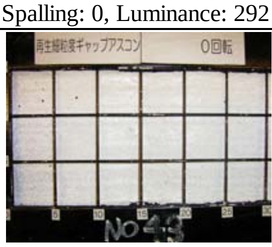
➢Specification of ravelling test machine

Diameter of the rotating table	200cm
Number of tires	2
Size of test piece	L1 * L2 * W * t = 28.7*41.0*35.0*5.0cm

➢Ravelling test conditions

Type of tire	Radial(6.15-13)
Tire pressure	1.7kgf/cm^2
Tire change	After every test
Rotating speed of the track table	40km/h
Wheel load	335 kgf/wheel (including weight of tire)
Test temp.	About 5ºC
Deviating width	±4.5cm
Water spraying	Sprayed at 2 locations at 10 l/min

Figure 14 Ravelling test

	Before test	After 100,000 rotations
Waterborne paint	 Spalling: 0, Luminance: 292	 Spalling: 5, Luminance: 320
Thermoplastic marking	 Spalling: 0, Luminance: 327	 Spalling: 0, Luminance: 303

Pavement: Recycled fine-graded gap asphalt mixture

Units: Spalling (%), Luminance (mcd/m^2•Lx)

Figure15 Ravelling test results

8. DURABILITY VERIFICATION OF MARKINGS ON ROADS IN SERVICE

To verify the durability of recessed pavement markings consisting of thermoplastic paint, markings already created in a 2005 experiment in the Jozankei district of Sapporo City's Minami Ward along National Highway 230 were reapplied by spraying over sections of 10 m each. The test applications were conducted during the night on March 19, 2007 (Figure 16). Figure 17 shows the pavement markings after winter on May 16, 2008. Compared with standard pavement markings that use waterborne paint, the sections of recessed pavement marking remained more clearly visible and were without damage. Accordingly, the application of thermoplastic paint is expected to further improve durability.

Figure 16 Application of thermoplastic paint to National Highway 230 (March 19, 2007)

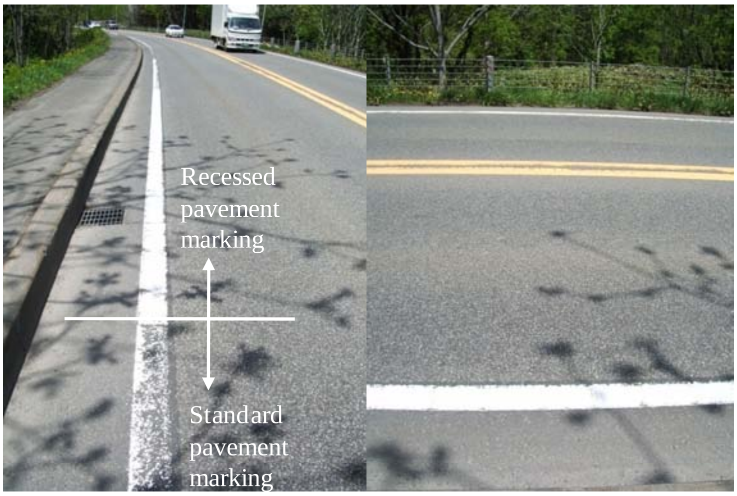
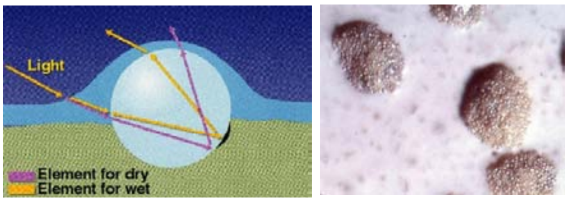


Figure 17 Recessed pavement marking observed on May 16, 2008

9. DISCUSSION OF VISIBILITY IMPROVEMENT FOR RAINY NIGHTTIME CONDITIONS

One potential disadvantage of recessed pavement markings (i.e., those located lower than the pavement surface) is decreased visibility when roads are wet in rainy nighttime conditions. Since the visibility of standard pavement markings also deteriorates in such conditions, there is concern that recessed pavement markings might show an even larger decrease in visibility. For this reason, high-refractive-index glass beads that improve visibility in rainy nighttime conditions were tested to ascertain their effects. High-refractive-index glass beads are a pavement marking material that provides improved reflective performance in wet conditions (Figure 18). They are produced by coating the surface of sand granules larger than standard-size glass beads with fine glass beads to achieve their characteristic high refractive index (Figure 19).

Thermoplastic paint containing standard glass beads and the same paint containing high-refractive-index glass beads were each applied to a recessed pavement marking over sections of 100 m on the Tomakomai Winter Test Track. When wet road surface conditions were created by spraying water on each section at night, visibility was clearly better for the section with high-refractive-index glass beads than for that with standard glass beads (Figure 20).



Reflection mechanism Reflecting elements

Figure 18 Improvement of nighttime visibility under rainy conditions by highly reflective beads

Figure 19 Standard glass beads (left) and high-refractive-index glass beads (right)

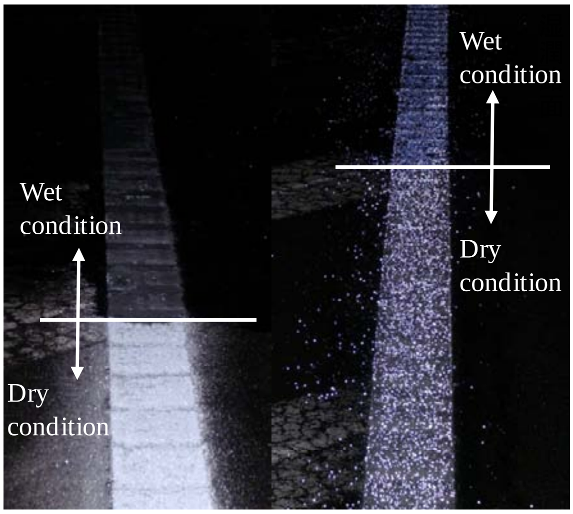


Figure 20 Standard thermoplastic paint (left) and thermoplastic paint with high-refractive-index glass beads (right)

To enable the quantitative evaluation of visibility in rainy nighttime conditions, a driving test was conducted on November 26, 2007 at the Tomakomai Winter Test Track with research participants consisting of 52 general road users chosen from among members of the public. In terms of testing conditions, the experiment was carried out on a cloudy night, and water was regularly sprayed using a road sprinkler to produce a wet road surface. The test vehicle was a passenger car, and research participants drove at a speed of approximately 20 km/h along the test course, which had no lighting, with the headlights set to low beam. At the point where the start of the recessed pavement markings came into sight, research participants gave a signal to a member of the testing staff who was also on board, who then identified the location from traffic cones placed at intervals of 5 m along the roadside and regarded the resulting value as the visible range. The visible range indicates how far into the distance a pavement marking can be seen. In this test, a black board was placed in front of each pavement marking, and the distance from which research participants could see them was measured. The location at which the pavement markings came into sight was used to judge the extent of the pavement markings that research participants could see. For comparison, a non-recessed pavement marking consisting of regular thermoplastic paint was also tested to evaluate its visibility (Figure 21).

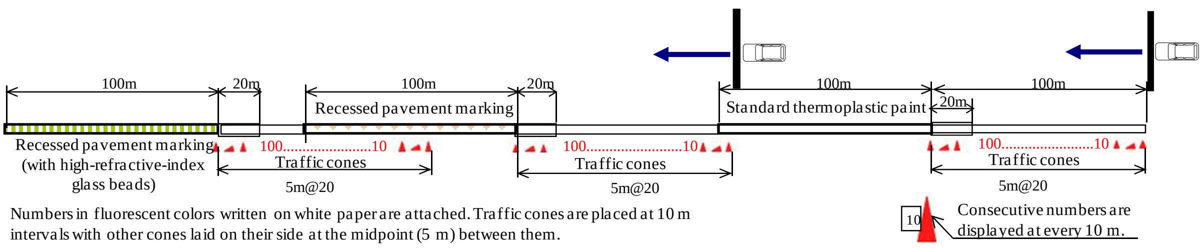


Figure 21 Outline of visibility evaluation testing involving general road users

According to the results of the visibility evaluation test, the average visibility range for the standard pavement marking was 29.1 m and that for the recessed pavement markings was 32.4 m. There was only a slight discrepancy between the two, and no statistically significant difference was found. The average range for the recessed pavement marking with high-refractive-index glass beads was 55.0 m – a significant difference of just 1% from the other two types (Table 1). The difference in the average visibility range between the recessed pavement markings with and without high-refractive-index glass beads was 22.6 m, indicating an improvement effect on visibility in nighttime wet road surface conditions.

In terms of the cumulative frequency distribution of the visibility range, 85% of research participants were able to visually confirm the standard pavement marking 15 m ahead, the recessed pavement marking 20 m ahead and the recessed pavement marking with high-refractive-index glass beads 40 m ahead (Figure 22).

Table 1 Visibility range (N=52)

Pavement marking	Average (m)	Standard deviation
Standard thermoplastic paint	29.1	16.0
Recessed pavement marking	32.4	16.0
Recessed pavement marking (with high-refractive-index glass beads)	55.0	18.3

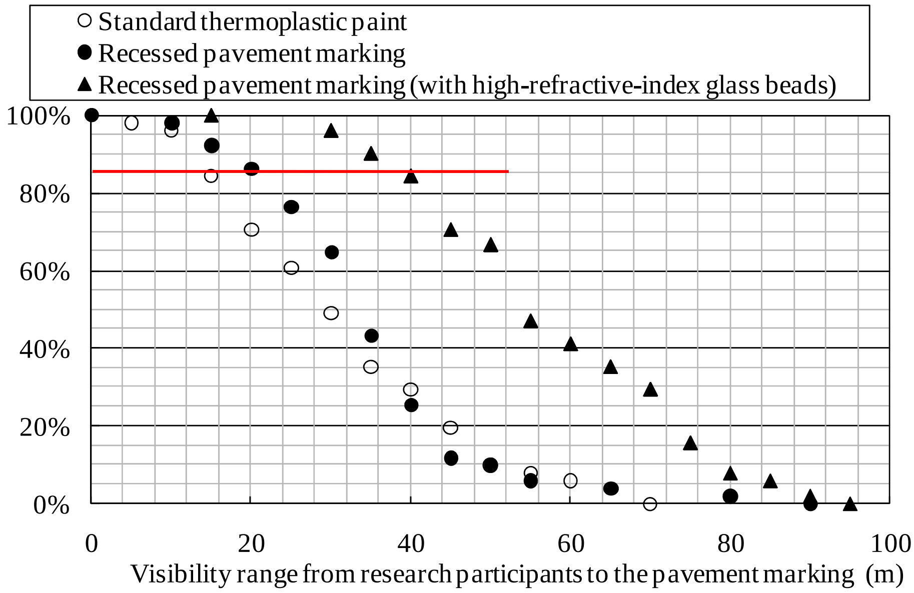
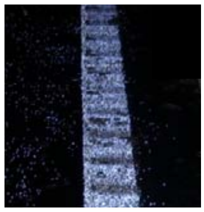


Figure 22 Cumulative frequency distribution of visible range

10. DISCUSSION ON THE ACCEPTABILITY OF RECESSED PAVEMENT MARKINGS

To verify the acceptability of recessed pavement markings by general road users, a questionnaire survey was conducted among research participants after the visibility evaluation test. On the questionnaire, the characteristics of each pavement marking type, including estimated application costs and service life, were listed as shown in Table 2. In response to a question about application to roads in service, most subjects selected recessed pavement markings with high-refractive-index glass beads – despite their high application costs – as the preferred pavement marking type (Figure 23). In response to a question about the application of recessed pavement markings and recessed pavement markings with high-refractive-index glass beads, 43 subjects (83%) and 50 subjects (96%), respectively, selected either "Should be actively applied" or "Should be applied in accident-prone areas," showing that the majority of subjects had a positive opinion on the application of these two types (Figure 24).

Table 2 Characteristics of each type of pavement marking presented to research participants

	Standard thermoplastic paint	Recessed pavement marking	Recessed pavement marking (with high-refractive-index glass beads)
			
Costs incurred in the application of 1 m of pavement	¥250	¥850	¥1,300
Service life	One year	Three years	Three years
Traffic accident reduction effectiveness	None	Vibration and noise generated by bumps alert drivers when they stray from the lane.	Vibration and noise generated by bumps alert drivers when they stray from the lane.
Visibility in rainy nighttime conditions	Average	Bad	Good

11. CONCLUSION

The development of recessed pavement markings was started with the goals of improving durability and reducing the costs incurred in annual repainting. No improvement in durability was achieved with the waterborne paints usually applied to national highways in Hokkaido, but an improvement was found with thermoplastic paints, although these involve higher costs. The effect of high-refractive-index glass beads on the improvement of visibility in rainy nighttime conditions was also confirmed. Since both thermoplastic paints and high-refractive-index glass beads have a certain thickness, they are prone to scraping during snow removal operations in Hokkaido, and can therefore be said to have low durability. However, the use of recessed pavement markings produced by milling the road surface improved durability in these two types, which were also supported by many of the general road users participating in the driving test.

Taking into consideration the costs of road surface milling, thermoplastic paints and high-refractive-index glass beads, it is believed that recessed pavement markings are very expensive despite their advantage of eliminating the costs associated with waterborne paints. However, as their use is expected to reduce the number of road-departure accidents as a result of noise and vibration generated in vehicles that veer onto them and improve visibility in

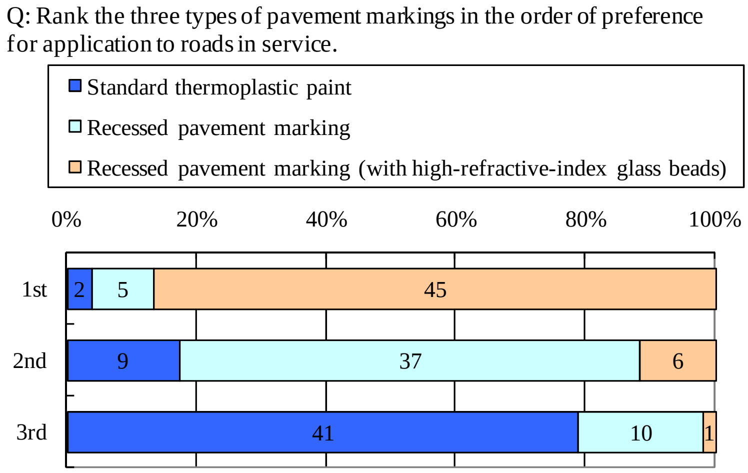


Figure 23 Preferred pavement marking type for application to roads in service

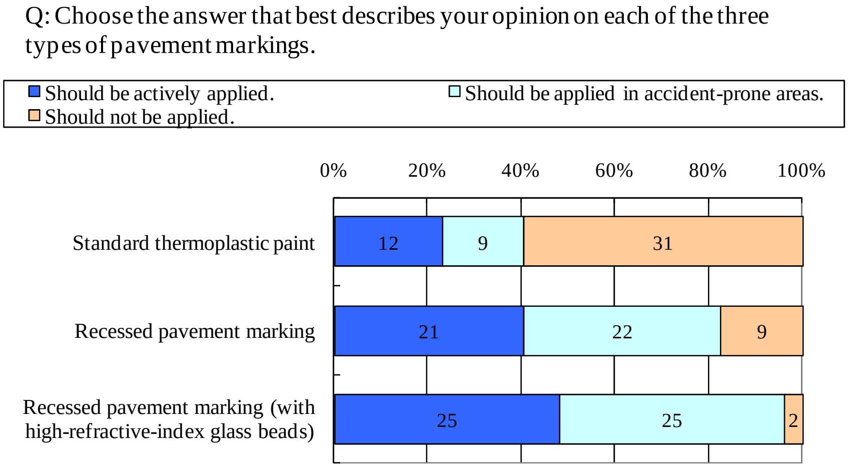


Figure 24 Acceptability of each pavement marking type

rainy nighttime conditions, the technique may be useful in terms of overall cost reduction and road safety.

In November 2008, a test application was performed along a 566-m section of National Highway 333 in Kitami City. Further studies are planned to enable examination of the results of test applications on roads in service and their traffic accident reduction effect to consider their applicability to national highways in Hokkaido.

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