

STUDY ON DEVELOPMENT AND PRACTICAL USE OF RUMBLE STRIPS AS A NEW MEASURE FOR HIGHWAY SAFETY

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Abstract: We examined the use of rumble strips on a national highway as a measure against head-on collisions. The rumble strips were installed on a test track before installation on a road in service. Studies were conducted on the necessary construction machinery, the construction methods, and the effects of installation on a road in service. In addition, we examined the use of rumble strips as a measure against run-off-the-road accidents. The strips were found to be less costly, and easier to install and maintain than traditional measures against head-on collisions. They were found to be safer for motorcycles than are center poles and chatter bars, and effective in reducing head-on collisions.

Key Words: Rumble Strips, Traffic Accident Countermeasure, Run-off-the-Road, Head-on Collision

1. INTRODUCTION

Hokkaido has twice as many fatal head-on collisions as any other prefecture of Japan (Figure 1). Most such collisions occur on suburban two-lane roads. Traditional measures against head-on collisions on such roads are median barriers, center poles and road buttons. However, it is very expensive to build median barriers. Center poles and road buttons have not been widely installed as countermeasures because they hinder snow removal.

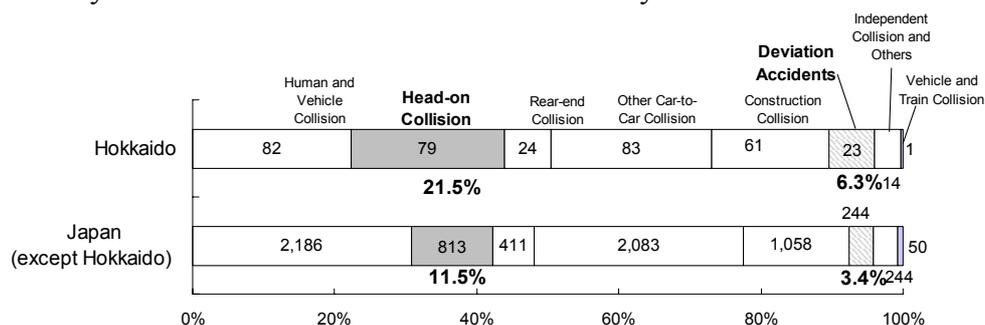


Figure 1. Types of Accidents in Hokkaido and Japan (2003)

This research aims to evaluate the effectiveness of rumble strips against head-on collisions. Rumble strips are rectangular grooves incised in the pavement (Figure 2). They warn drivers who deviate from their lane with rumbling sound and vibration of the steering wheel and chassis when the vehicle encounters the rumble strip. We propose installation methods and optimum standards for rumble strips and describe their effectiveness as a measure against head-on collision.



Figure 2. Rumble Strips Installed at the Centerline

2. HISTORY OF RUMBLE STRIPS IN THE UNITED STATES

Rumble strips were first used in 1955, in New Jersey. Called “singing shoulders,” these were wavy strips installed on concrete pavement.

Rumble strips are categorized into four types: milled, rolled, formed and raised (Table 1). Milled rumble strips were installed at the shoulder of the Pennsylvania Turnpike in 1987. Wood (1994) reported that run-off-the-road accidents decreased by 70% on the section of installation. Chen (1994) reported that milled strips generate 12.6 times the vibration and 3.4 times the noise of rolled strips. Many other states started to employ milled strips after the Virginia DOT introduced them. Perrillo (1998) reported that installation of 5,071 km of milled rumble strips at the shoulders of freeways in New York State from 1993 to 1998 reduced run-off-the-road accidents by 65% and that these facilities’ cost-effectiveness was 182. The high cost-effectiveness reported in some studies and the development of a milling method for installation on existing pavements promoted the spread of rumble strips in the early 1990s. The facility was quickly employed against run-off-the-road accidents on freeways.

Outcalt (2001) reported on milled rumble strips installed at the centerline of a 27-km two-lane section of State Highway 119 in Colorado. He found that the rumble strips reduced accidents per million vehicles by 34% for head-on collisions and 36% for sideswipe accidents.

Table 1. Types of Rumble Strip

	Milled	Rolled	Formed	Raised
Installation method	Pavement is ground using a grinding machine or customized machine.	Grooves are formed using a roller or a mold placed on the road surface.		A raised line or buttons are installed by heat adhesion.
Installed...	whenever necessary	at the time of road construction (asphalt pavement)	at the time of concrete casting (concrete pavement)	whenever necessary

3. DEVELOPMENT OF INSTALLATION METHODS IN JAPAN

In Japan, it has been necessary to develop a machine for installing such strips. Many methods for continuously installing milled grooves were examined, to clarify the installation effectiveness and economic efficiency. We modified an existing machine by equipping it with a guide wheel of non-circular profile that translates rotational movement into up-down movement as the vehicle moves ahead (Figures 3 and 4; Table 2). Bits on the milling drum are removable, which enables adjustment of the groove transverse width (length perpendicular to the roadway direction) at intervals of 6 mm in the range between 15 cm and 35 cm. The groove depth is also easily adjustable.

The milling rate of approximately 3 m per minute enables about 800 m of installation in a day. The low installation cost (about 1,500 yen/m) owes to 1) the low initial cost of machine development (simple modification of a commercially available machine) and 2) the low labor cost achieved by the high speed of installation. The installation cost is half that for center poles and one-third that for raised markers.

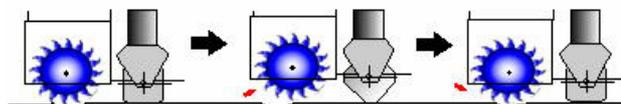


Figure 3. Milling by a Vehicle That Employs a Wheel of Non-Circular Profile



Figure 4. Installation Machine

Table 2. Specifications

Manufacturer	Wirtgen GmbH (Germany)
Model	W350
Driving method	3-wheel
Dimensions	L=2.79m, W=1.15m, H=1.87m
Weight	4.10t
Power	32kw
Milling drum dimensions	W=350mm, φ=460mm
Number of milling bits	118

4. MEASUREMENT OF SOUND AND VIBRATION ON THE TEST TRACK

The greater the groove dimensions, the greater the warning. The smaller the groove dimensions, the less the disruption in control for two-wheel vehicle riders. It was necessary to set optimum groove dimensions to satisfy these two contradictory conditions. The transverse width was set as 35 cm, to be smaller than the width of the yellow double centerline (50 cm). We installed three 100-m-long rumble strips of different dimensions and depths on sections of the Tomakomai Winter Test Track. The standard depths were set as 9 mm, 12 mm, and 15 mm. The longitudinal groove width (length in the direction parallel to the roadway) and the length of the flat intervals between grooves were determined according to the diameter of the milling drum, the non-circular profile of the guide wheel, and the groove depth (Table 3 and Figure 5). We measured sound and vibration for evaluation of three depths.

The sound and vibration generated by the rumble strips were measured using a noise meter (RION NL-22) and a vibration meter (RION VM-82) installed as in Figure 6. The test vehicle was driven on the rumble strips of three dimensions. The measurement vehicle was a 1,800-cc station wagon whose tire size is 185R14. The test vehicle drove at 40 km/h, 60 km/h, 80 km/h and 100 km/h three times for each speed on each test section. The sound and

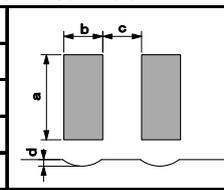
vibration values are the average of the three test runs (Figures 7 and 8).

The sound generated by rumble strips of all three depths was 15 dB greater than the sound on pavement without warning facilities. The deeper the groove, the louder the sound. Chen reported that warning drivers requires a sound increase of 4 dB. We can expect rumble strips of the three test depths to provide sufficient warning.

The vibration measured on the rumble strips of each depth exceeded that on smooth pavement by 7 dB. The smallest vibration was measured at the driving speed of 60 km/h, which we attribute to the vehicle characteristics, such as suspension performance. At each test speed other than 60 km/h, the measured vibration for each groove depth exceeded that generated on the smooth pavement by 10 dB.

Table 3. Dimensions of Rumble Strips Installed at the Test Track

	Pattern 1	Pattern 2	Pattern 3
Transverse width a	350	350	350
Lengthwise width b	127	147	163
Spacing c	175	155	139
Depth d	9	12	15



Unit: mm

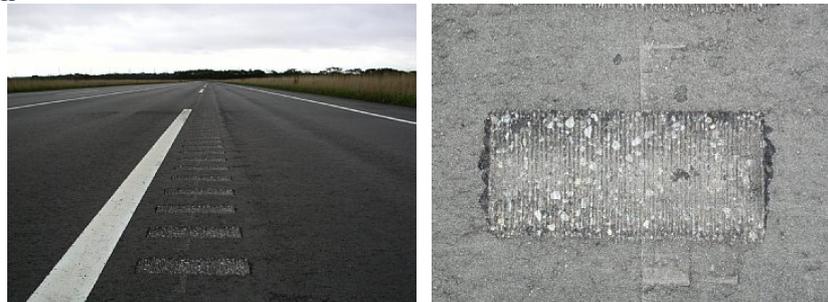


Figure 5. Rumble Strips (12 mm depth)



Figure 6. Setup for Measuring Sound (left) and Vibration (right)

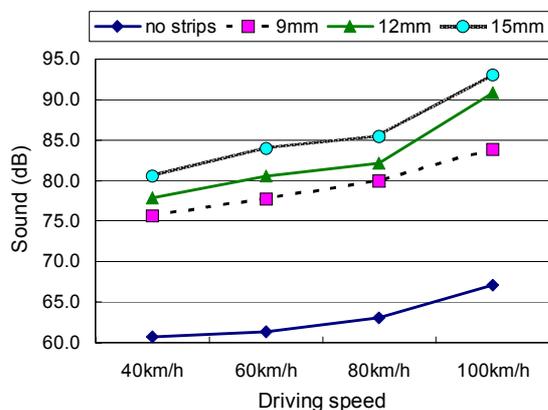


Figure 7. Sound vs. Speed

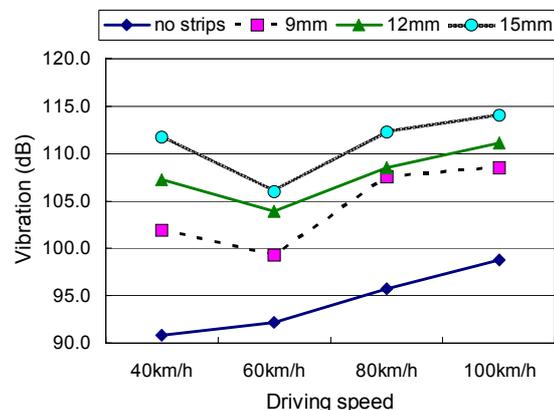


Figure 8. Vibration vs. Speed

5. EXPERIMENT ON THE TEST TRACK

Our experiments were conducted at Tomakomai Winter Test Track in November 2001 (Figure 9), with 62 road users participating. The vehicle driven by the participant was videotaped while traveling on road sections installed with rumble strips. The vehicles used were passenger cars, motorcycles, small (50 cc) motorcycles, and bicycles. Each participant traveled three times on each test section, each time in a different type of vehicle. After the driving/riding experiment, each participant filled out the questionnaire.

Some participants on their first run braked before reaching the section installed with rumble strips; however, no dangerous situations were observed. No participants braked on the second or third run. Some bicycle riders wobbled when riding on the grooves, but they did not brake suddenly, turn suddenly or fall on any of the three types of rumble strip. We concluded that safety can be secured on a road installed with rumble strips at the centerline.

Figure 10 shows the results of our post-test questionnaire on safety. The participants' negative evaluation of the rumble strips increases with the depth of the strips. More participants answered that they felt danger when riding on the deep grooves than on the shallow grooves.

Based on our measurements of sound and vibration, videotaped observations, and questionnaire survey, we concluded that grooves with a lateral width of 150 mm, transverse width of 350 mm, and depth of 12 mm are optimum (Figure 11).



Figure 9. Driving Test: Small (50 cc) Motorcycle (left) and Bicycle (right)

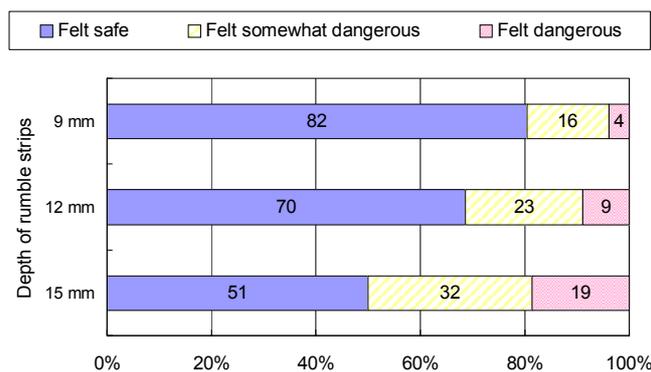


Figure 10. Subjective Ratings of Safety

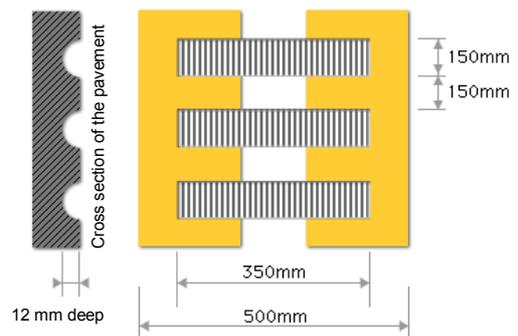


Figure 11. Dimensions of Rumble Strips Installed on Roads in Service

6. EFFECT OF RUMBLE STRIPS ON ROADS IN SERVICE

6.1 Installation and Effect of Rumble Strips on National Route 5

Japan's first milled rumble strips were installed as a countermeasure to head-on collisions on the Yakumo Town section of National Route 5 (Figure 12). The section is a straight two-lane road in the suburbs of the town. The road structure and environment were not

considered to be dangerous for driving, but there had been many head-on collisions. A median strip, center poles, and chatter bars were installed in one section for the test. We evaluated how rumble strips influenced driving behavior (driving speed, transverse location) relative to other facilities. Figure 13 shows the section and the installed facilities. Evaluation was conducted using video cameras that record the driving speed and the transverse location of passing vehicles.

Driving speed was calculated using the times recorded in the frames in which the vehicle was captured entering and exiting the measurement section. The differences in average driving speed of southbound vehicles measured in each section were within 2 km/h (Table 4). It is assumed that safety measures including rumble strips do not affect driving speed of the vehicles.



Figure 12. Installation (left) and the Milled Grooves of Rumble Strips (right) on the Yakumo Section of National Route 5

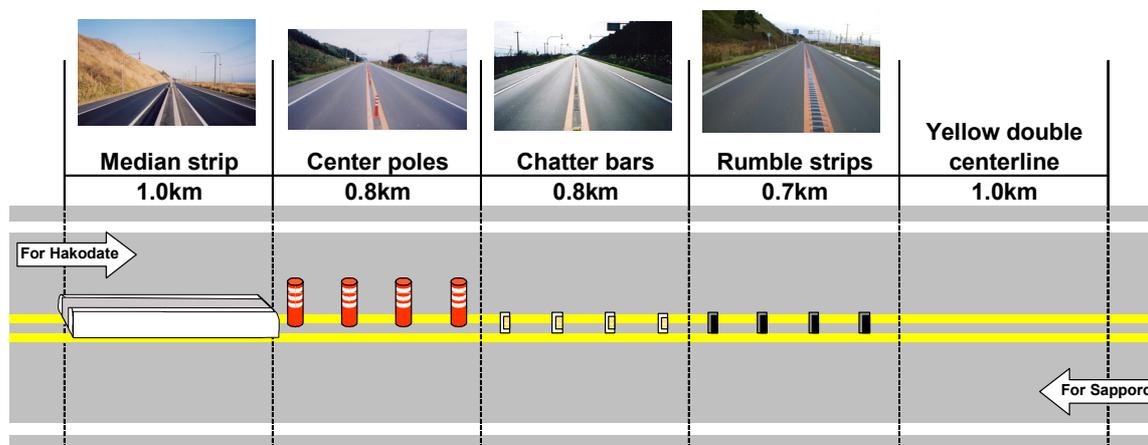


Figure 13. Installation of Measures against Head-on Collision on the Yakumo Section of National Route 5

Table 4. Average Driving Speed Observed for 2 h (Unit: km/h)

Hakodate-bound lane	Median strip section	Center pole section	Chatter bar section	Rumble strip section	Yellow double centerline section
Small cars	67.5 (589)	67.8 (587)	68.0 (593)	68.2 (592)	68.8 (570)
Large vehicles	66.0 (200)	67.3 (197)	67.1 (199)	67.0 (198)	67.4 (193)

Note: Numerals in parentheses are numbers of vehicles.

The transverse location in the lane (location of the left front wheel) was recorded by video camera. To clarify the transverse location of the passing vehicle, the pavement was marked in 20-cm increments in the transverse direction, with the numbers starting at the outer edge of the shoulder. The number of vehicles that passed each mark was added up. The cameras measured traffic in both directions for one hour. Figure 14 shows the number of large vehicles that passed each mark in the Hakodate-bound lane by the section with each countermeasure. The figures in boxes are the number of passing vehicles at each countermeasure section and the average of the distances from mark No. 4 (separating the shoulder and carriageway) to the vehicle passing locations.

In the section with a yellow double centerline, very few vehicles traveled on the shoulder. In the section where center poles separated the lanes, many vehicles distanced themselves from the center poles, and some even drove on the soft shoulder. In the chatter bar and rumble strip sections, the vehicles distanced themselves from these structures, but not as far as on the center pole section. Small vehicles showed the same behavior as large vehicles. The rumble strips were regarded as being effective in reducing head-on collisions because they kept vehicles at a proper distance from the centerline.

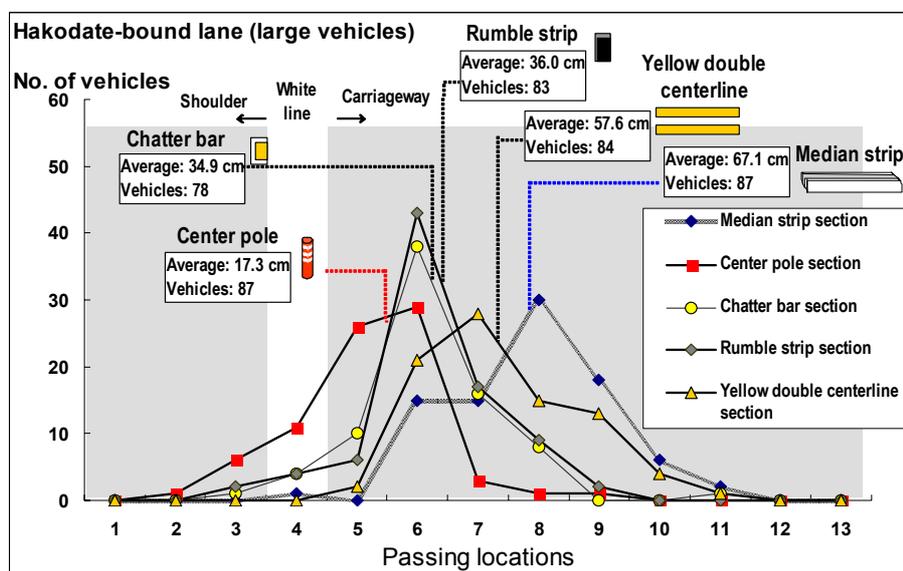


Figure 14. Number of Vehicles at Each Transverse Point (Hakodate-bound Lane, Large Vehicles)

6.2 Road User Questionnaire Survey

A questionnaire survey was conducted to assess the road users' evaluation of the four types of head-on collision countermeasure installed on the experiment section of National Route 5 in Yakumo Town. Hokkaido Prefectural Police Headquarters assisted the survey by stopping all the vehicles that passed the experiment section. The police guided the drivers into roadside parking areas and handed them our questionnaire (Figure 15). We explained the aim of the questionnaire to each driver and asked each to cooperate in filling it out and returning it later by post. The survey was conducted on November 8, 2002, and 601 questionnaire forms were distributed and 229 were collected later.

Respondents were asked, "What was it like to drive on the section with the median strip?" More respondents answered favorably for this facility ("I felt comfortable driving there" or "I felt safe driving there") than for any other facility (Figure 16). To the question about the center poles, many respondents answered that they felt uncomfortable there, which explained

why the vehicle passing location was farther from the centerline for that facility than for any other. Nearly half of the respondents, however, answered that center poles may be good at preventing head-on collisions. This suggests that road users see center poles as a measure against head-on collisions. The largest number of respondents chose median strips as the best measure against head-on collisions. The second largest number chose rumble strips.

We attached a reference on construction and maintenance costs and the warning (sound and vibration) of each measure, and asked, “Do you think this measure should be employed?” More respondents answered that rumble strips should be employed than any other facility (Figure 17).

Although the construction cost for the median strip is much higher than for other head-on collision mitigation measures, for sections where head-on collisions frequently occur median strips were the most popular facility. We found that large numbers of road users wished for median strips to be installed at dangerous road sections. This may be attributable to the reference data we provided, which showed that median strips afford nearly 100% mitigation of head-on collisions. As Figure 16 shows, the respondents gave median strip test sections favorable evaluations for ease of driving and safety.



Figure 15. Roadside Questionnaire

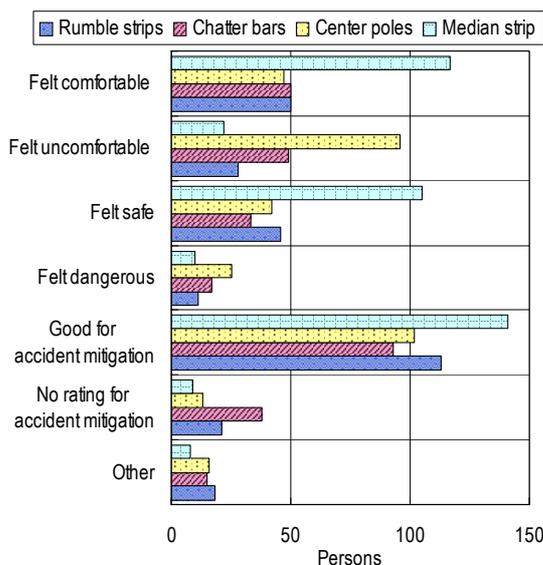


Figure 16. Drivers' Subjective Ratings of Comfort, Safety and Accident Mitigation

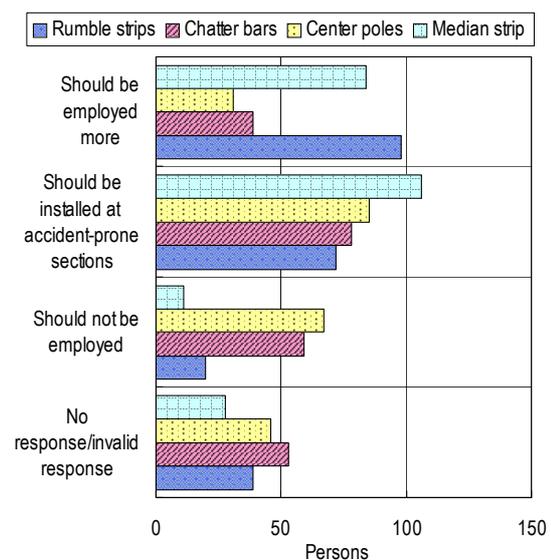


Figure 17. Drivers' Opinions of the Countermeasures

Many respondents expressed a wish that road managers not install center poles or chatter bars, but they did call for those facilities to be employed at road sections prone to head-on collision. The respondents had negative opinions regarding the two facilities, but they understood that the two facilities were effective against head-on collisions. The many negative answers regarding the two facilities may be attributable to discomfort felt by drivers passing those facilities (Figure 16).

6.3 Sound and Vibration on Winter Roads

The noise and vibration in a vehicle running on rumble strips were empirically confirmed on snow-covered roads. We measured the sound and vibration on winter roads using a noise meter (RION NL-22) and a multipurpose vibration meter (RION VM-82) mounted in a test vehicle. The measurement method is the same as in Section 4.

Figure 18 shows the road surface condition of National Route 274 at the time of measurement and the sound and vibration measured inside the test vehicle. The road surface was slushy, and the centerline was not visible. Without rumble strips, the sound was 60 to 65 dB; with rumble strips it was 75 to 80 dB. Vibration was 90 to 95 dB when not running on rumble strips, versus 95 to 105 dB when running on the strips. It was confirmed that the strips gave sufficient warning (sound and vibration) of lane deviation on slushy winter roads, even when the centerline was invisible. Sound and vibration on winter roads were measured for 10 days. Warning on compacted-snow road surface and slushy road surface was sufficient. The warning given by rumble strips on national highways with the present snow removal and maintenance level is sufficiently reliable in winter.

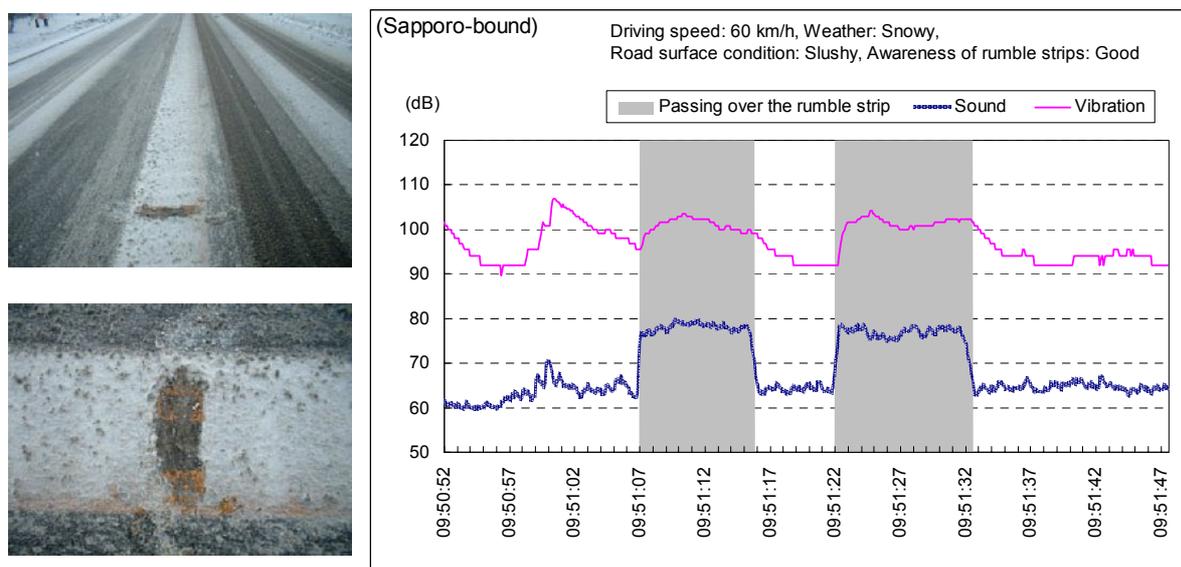


Figure 18. Sound and Vibration Measured on a Winter Road (R274, Jan. 20, 2004)
(Left: Road Surface Conditions, Right: Sound and Vibration Measurements)

7. DEVELOPMENT OF A STANDARD FOR RUMBLE STRIPS AT A YELLOW SINGLE CENTERLINE AND AT THE SHOULDER

The length of rumble strips installed against head-on collisions on national highways in Hokkaido increased from zero in July 2002 to 89.5 km in September 2004. The Hokkaido Regional Development Bureau has a policy of installing rumble strips on road sections with

yellow double centerlines that indicate no passing (see Figure 2). To promote their further use, we conducted examinations to determine standards for 150-mm-wide rumble strips (hereinafter, slim rumble strips), the width of a yellow single centerline. We installed grooves of three different depths (9 mm, 12 mm, and 15 mm) at Tomakomai Winter Test Track for a driving test.

We also examined standardizing shoulder rumble strips as a measure against run-off-the-road accidents. Their installation on national highways would require that they not disrupt control of light two-wheel vehicles such as small (50 cc) motorcycles and bicycles. The examined shoulder strips are narrower in lateral width and shallower than the standard existing rumble strips used between yellow double centerlines (see Figure 11). Based on our examination, we set the lateral width, transverse width, and depth as 80 mm, 350 mm, and 9 mm. We chose 115 mm (short-interval strips) and 150 mm (long-interval strips) for the flat interval between the two grooves. We conducted driving experiments to compare the two types of shoulder strip at Tomakomai Winter Test Track.

For comparison, our driving experiment on rumble strips of the new standard included yellow double centerlines with 12-mm-deep grooves (center rumble strips), high-visibility carriageway markings, and chatter bars (Figure 19). We developed a machine for milling shoulder strips, because the lateral width for such strips is 80 mm and a milling drum with a small outer diameter of 180 mm is required (Figure 20).

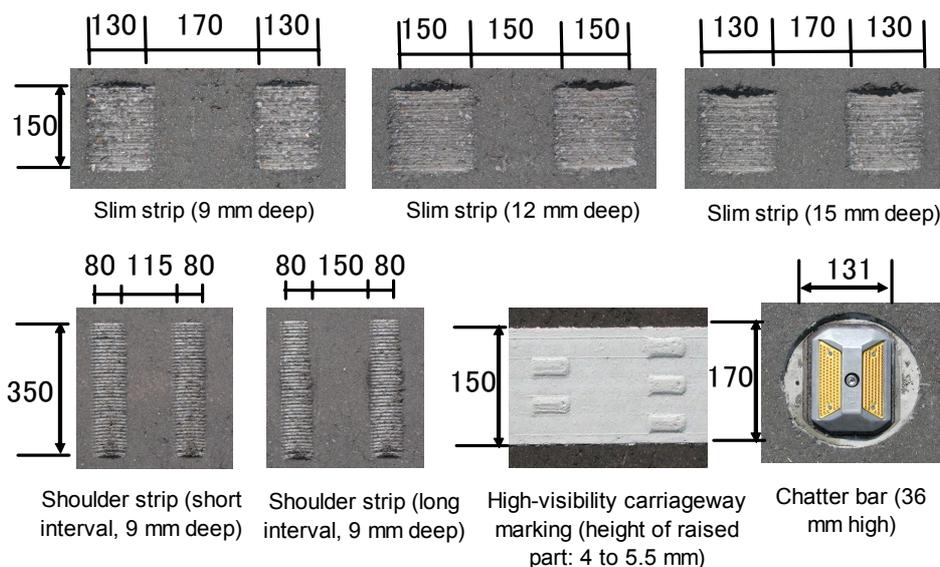


Figure 19. Dimensions of Slim and Shoulder Rumble Strips (mm)



Figure 20. Installation Machine for Shoulder Rumble Strips (Left: Machine, Right: Milling Drum)

7.1 Driving Experiment at the Test Track

We conducted driving experiments on rumble strips of the new standard in October and November 2003. We measured sound and vibration inside the test vehicle, and did a road user questionnaire survey. Figures 21 and 22 show the results of sound and vibration measured inside the test vehicle driving the sections with the facilities. The measurement method was the same as in Section 4. The sound generated by each type exceeded that generated on the smooth pavement by 15 dB. The deeper the groove, the greater the noise inside the test vehicle. The slim rumble strips (15 mm) generated much more sound than did the center rumble strips. The long-interval and short-interval strips did not differ greatly in warning. Vibration measurement showed about the same results as sound measurement, and showed greater values than for high-visibility carriage markings.

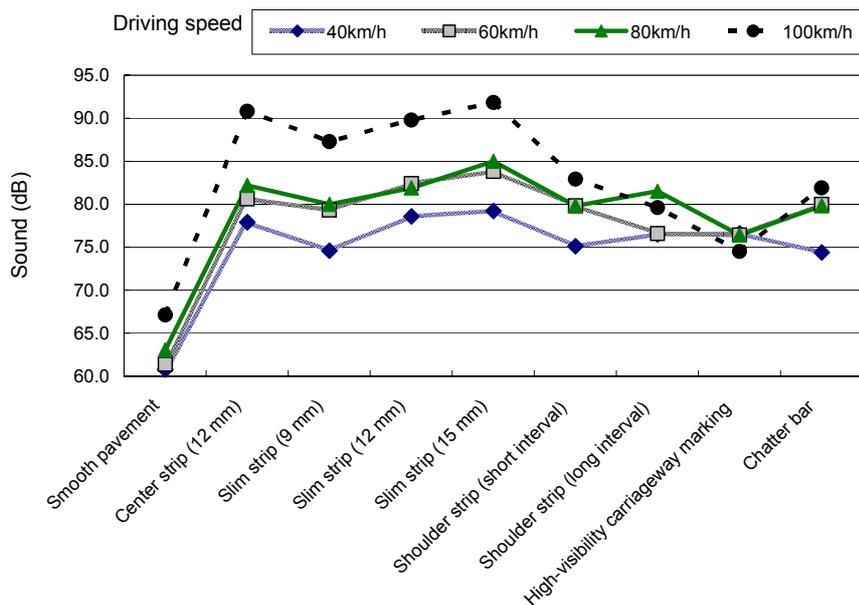


Figure 21. Sound Measured Inside the Vehicle

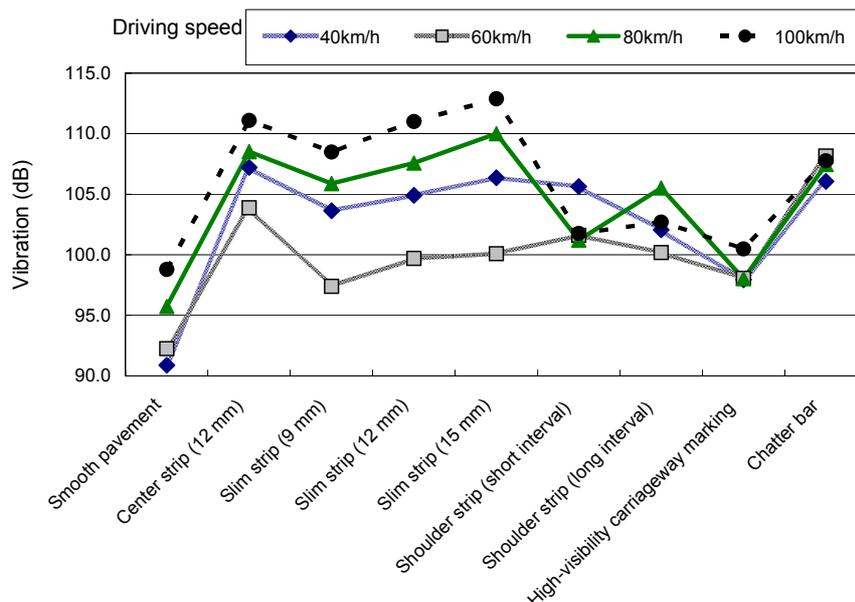


Figure 22. Vibration Measured Inside the Vehicle

Table 5 shows the test vehicles used and the number of participants for each vehicle. A total of 106 road users participated. A passenger car, a motorcycle (400 cc), a small (50 cc) motorcycle, and a bicycle were used. The participants answered a questionnaire after the test track experiment. The participants indicated a subjective evaluation of the effectiveness of rumble strips against head-on collision, and a subjective evaluation of the safety of driving (for motorcycle and bicycle) for each test vehicle. Evaluations were given according to a 5-point scale (Figure 23). We totaled the evaluation scores for each vehicle and divided the sum by the number of participants who used the vehicle. The results are shown in Figure 24.

Table 5. Driving Test Participants and Vehicles Used

Vehicle	Number of participants
Passenger car	105
Motorcycle	69
Small (50 cc) motorcycle	101
Bicycle	105

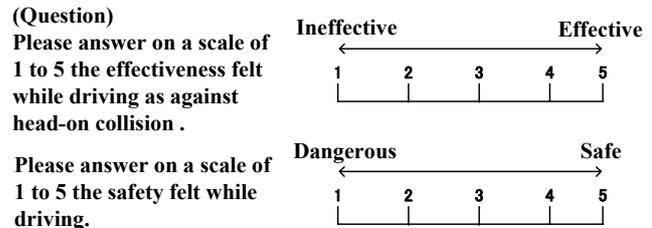


Figure 23. Questionnaire Answer Form (excerpt)

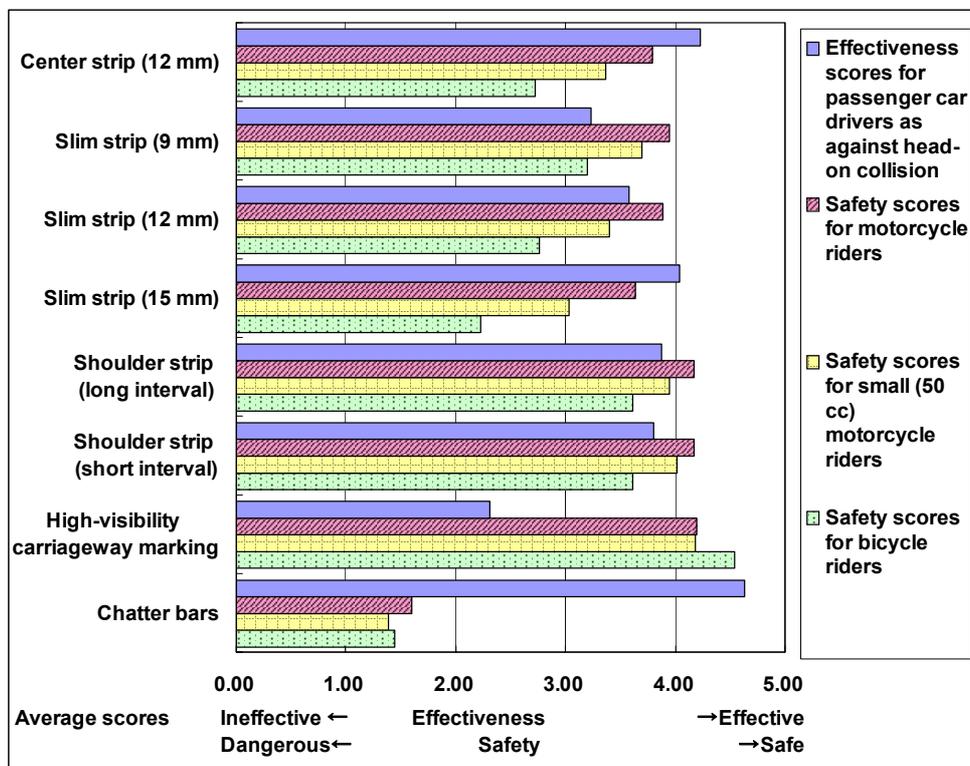


Figure 24. Results of Questionnaire

Of all the rumble strips tested, the center strips were rated the highest as a countermeasure to head-on collision, followed by the slim strips (15 mm deep). The long-interval shoulder strips rated slightly higher than the short-interval strips, receiving scores about 70% of those given for center rumble strips. Two-wheel vehicle riders gave high scores for safety to the slim rumble strips, but bicycle riders gave low scores for safety to the slim strips with 15-mm-deep grooves. The shoulder rumble strips were given high scores for safety by the bicycle riders. The safety evaluation for high-visibility carriageway marking was high among riders of large and small motorcycles and bicycles, but was low among passenger car drivers. The results for chatter bars were the opposite.

Fig. 25 shows the results of the questionnaire survey regarding the optimum dimensions of new rumble strip types. For the rumble strips being installed on the yellow single centerline, the slim strips with the depth of 15 mm were received most favorably. Evaluation for the long-interval and the short-interval shoulder rumble strips did not show any difference between the two.

Q: Which rumble strip do you think is the best in preventing lane-deviation accidents?

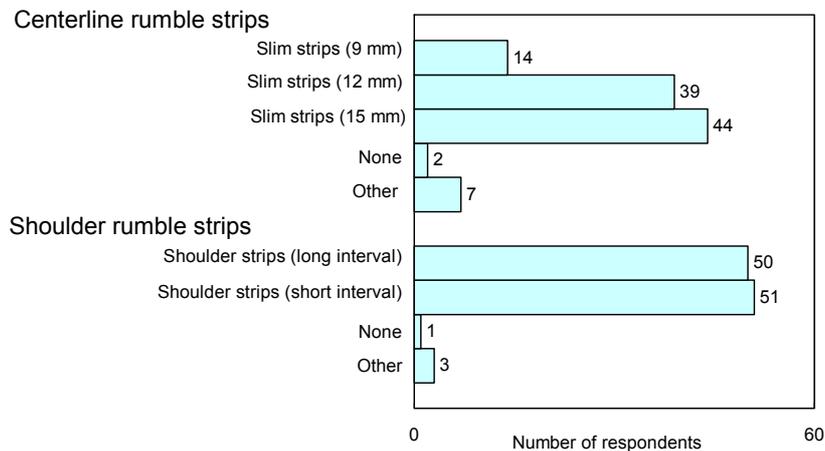


Figure 25. Responses regarding Optimum Standards

7.2 Standards for Slim and Shoulder Rumble Strips

We concluded by recommending the 15-mm-deep, slim rumble strips as the standard for installation on the yellow single centerline. The slim strip generated sufficient sound inside the vehicle, and earned the second highest evaluation for its warning by the passenger car drivers. The scores drivers gave to the slim rumble strips were about 90% of those given to the center rumble strips (12 mm deep).

As a standard of shoulder rumble strips, we decided to recommend the long-interval strips, although we found no difference between the short-interval and long-interval strips regarding the sound and vibration inside the vehicle, the warning score given by passenger car drivers, or safety ratings by riders of large and small motorcycles and bicyclists. The long-interval strips are cost-effective because they require less milling per installation length than the short-interval strips.

8. USE OF RUMBLE STRIPS ON ROADS IN SERVICE

8.1 Installation of Rumble Strips

Rumble strips have been installed since 2002 in the priority of location determined by the Traffic Accident Analysis System. The effectiveness and low cost of rumble strips began to be recognized in 2003. The Hokkaido Regional Development Bureau has promoted rumble strips as a measure against head-on collisions, and in the two years and eight months since the first installation on July 22, 2002, on the Yakumo section of National Route 5, center rumble strips have been installed at 61 locations (111.9 km as of Mar. 31, 2005) (Figure 26).

Figure 27, 28, and 29 show center strips, slim strips, and shoulder strips in use on national highways.

The Bureau experimentally installed five sections with slim strips (7.7 km) and six sections with shoulder strips (21.3 km) in FY 2004. The Bureau will finish evaluating these facilities at the end of FY 2004, and start practical installation on national highways in Hokkaido in FY 2005.

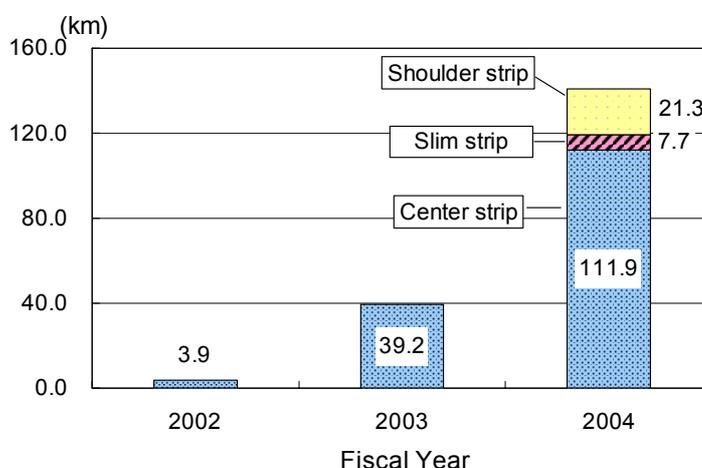


Figure 26. Length of Rumble Strips Installed on National Highways

Table 6. Number of Accidents Before and After Installation

Route	Length installed (m)	Date of construction	Number of head-on collisions			
			Before installation (2 years)	From installation to Dec. 1, 2004	Extrapolated after installation (2 years)	
1	5	727	2002/7/22	1		0.0
2	274	2,708	2002/11/6	3	3	3.0
3	5	457	2002/12/10	1		0.0
4	37	6,197	2003/5/13	1	1	1.2
5	5	1,500	2003/5/26	3		0.0
6	40	1,178	2003/6/2	2		0.0
7	274	2,860	2003/6/9	3		0.0
8	274	5,050	2003/6/16	7	6	7.8
9	274	3,815	2003/6/23	3	3	3.9
10	5	1,507	2003/7/1	3	1	1.3
11	275	730	2003/7/8	1		0.0
12	39	1,100	2003/7/22	1		0.0
13	44	400	2003/7/25	0		0.0
14	230	2,943	2003/7/30	1		0.0
15	5	300	2003/8/5	1		0.0
16	230	1,057	2003/8/26	2		0.0
17	5	522	2003/9/22	1	1	1.6
18	276	3,448	2003/9/4	2		0.0
19	5	600	2003/9/3	1		0.0
20	393	440	2003/9/16	0		0.0
21	5	442	2003/10/2	0		0.0
22	40	382	2003/10/22	1		0.0
23	236	200	2003/10/27	1		0.0
24	38	721	2003/11/1	3		0.0
Total	39,284			42	15	18.8

Reduction rate for head-on collisions: $(42-18.8)/42 \times 100 = 55.2\%$



Figure 27. Center Strips (R230)



Figure 28. Slim Strips (R5)



Figure 29. Shoulder strips (R238)

8.2 Head-on Collision Reduction Rate

Table 6 shows the numbers of head-on collisions in 2002 and 2003, before and after installation of center rumble strips at 24 locations. The number of accidents for “before” is that for the two years before installation. The number of accidents for “after” is that from the day of installation to December 31, 2004.

Head-on collisions before installation numbered 42 at 24 locations, and after installation numbered 15. To compare the accident rate of before and after, the figure for after needed to be extrapolated, which yielded a figure of 18.8 collisions. The accident reduction rate was calculated to be 55.2%.

8.3 Effectiveness of the Rumble Strips

The advantages of the rumble strips are these:

- A high degree of warning is given to drivers who deviate to the edge of the road.
- Two-wheel vehicles can travel more safely on sections with rumble strips than on those with center poles or chatter bars.
- Rumble strips do not hinder snow removal.
- The costs are low (half of that for center poles, and one-third of that for chatter bars).
- Because the rumble strips are not installed where the wheels of vehicles pass, they cause very little tire abrasion and they do not affect the traveling speed.
- The warning given by sound and vibration was confirmed on road surfaces whose carriageway markings were covered by compacted snow.
- The snow accumulated in the groove was removed by using anti-freezing agent. No disadvantages in winter road maintenance are expected.
- Currently, center rumble strips reduce head-on collisions by 55%. The installation cost is moderate, and high cost-effectiveness can be achieved.

High effectiveness can be expected in using center rumble strips against head-on collisions. Unlike median strips, center poles, and chatter bars, rumble strips do not hinder snow removal. They can be highly effective against head-on collisions in cold, snowy regions like Hokkaido.

Currently, the Hokkaido Regional Development Bureau is concerned that rumble strips might be a factor in accidents caused by loss of control of two-wheel vehicles. The Bureau has limited them to no-passing zones. On road sections where head-on collision mitigation requires physical structures, median strips have been constructed. On such sections, it is ideal to take measures that satisfy the requirements of effectiveness within the constraints of the road environment.

The standards presently employed for shoulder strips have improved safety for small motorcycles and bicycles but reduced the warning given to passenger cars. Shoulder strips can be effectively employed on the road sections that have had many run-off-the-road accidents and on approaches to narrow bridges and tunnels that are prone to serious accidents such vehicle-structure crashes.

8.4 Promotion of the Facility

To promote wider use of rumble strips, it is important to closely cooperate with police departments and to provide technical information to construction and maintenance divisions of the road management authority.

We have opportunities to exchange opinions with the traffic control authority at the Hokkaido Traffic Accident Examination Council. We are providing them with information on rumble strips, including experiment results and recommended standards.

For facilitate the provision of information to road maintenance site managers, the Civil Engineering Research Institute of Hokkaido has held technical training sessions, launched a Web site (<http://www2.cer.go.jp/rumble/>), produced and distributed video materials on related

technologies and skills, and registered with the New Technology Information System (NETIS) of the Ministry of Land, Infrastructure and Transport. At our Web site, we outline rumble strips and their installation methods and effects. We established the site for use by both road managers and general road users.

9. CONCLUSION

Rumble strips are an inexpensive way of mitigating head-on collisions, and they cost nothing to maintain. There are fewer constraints on their installation than for conventional measures. They are much safer for motorcyclists than are center poles and chatter bars. The facility can be installed continuously on a long section, which can provide greater accident reduction.

In the past, even after a head-on collision or run-off-the-road accident on a certain section of a two-lane road, it was often difficult to take decisive countermeasures using conventional methods because of the constraints of cost and/or roadside environment. Rumble strips are a possible solution for such sections.

Local road administrators have given the facility a favorable evaluation. We were concerned about unnecessary noise and vibration, but have not received any complaints regarding such matters. The Hokkaido Regional Development Bureau emphasizes rumble strips as a major measure against head-on collisions and is planning to install about 500 km of rumble strips in the five years from 2004.

For future study, we will assess and verify the effectiveness of rumble strips installed in no-passing zones with yellow single centerlines and at the shoulder. We will promote widespread use of rumble strips to further reduce head-on collisions. We plan to launch a Web site in English (<http://www2.ceri.go.jp/rumble/eng/>) in 2005. Through this site we will work to raise awareness of rumble strips and to disseminate knowledge in developing countries where traffic accident mitigation is urgently required.

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