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Latest developments in Japan regarding improved porous elastic road surface

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ABSTRACT

The Public Works Research Institute (PWRI) has, since 1993, been developing a new low-noise pavement named "Porous Elastic Road Surface" (PERS). This new pavement has a porous structure composed of granulate rubber made from old used tires as its aggregate and urethane resin as its binder. The author estimates that the potential noise reduction levels in Leq exceed 10 dB(A). More than 90 percent of highways in urban areas would meet the standard if this noise reduction level were achieved. This paper summarizes the results of recent research done to further improve the noise reduction levels of PERS and the first test construction using PERS in Japan. It should be mentioned that the first construction has failed to be removed PERS 8 months after service starting, because of low wet skid resistance. It also mentioned on the improvement of PERS in wet skid resistance for the future test construction.

1 INTRODUCTION

The Public Works Research Institute (PWRI) has, since 1993, been developing a new low-noise pavement named "Porous Elastic Road Surface" (PERS). This new pavement has a porous structure composed of granulate rubber made from old used tires as its aggregate and urethane resin as its binder. Its porosity is approximately 40 percent. The pavement was first proposed in Sweden in the 1970s, however, Swedish researchers have failed to improve it as a practical pavement. Noise reduction levels[1] are 15 dB(A) for cars and 8 dB(A) for trucks. The author estimates that the potential noise reduction levels in Leq exceed 10 dB(A). More than 90 percent of highways in urban areas would meet the environment standard for noise, if this noise reduction level were achieved. The PWRI has already solved several of the problems with PERS[1], for example, insufficient adhesion between the pavement and the base course, low skid resistance, and its poor fireproof performance[2]. Its technical level has already reached the stage of test construction on urban highways.

This paper examines the general performance of PERS obtained through past development at the PWRI. It also summarizes the results of noise reduction levels of PERS at the first test construction site in Japan. The first part deals mainly with noise reduction effect of PERS on the test construction site. The second part gives the information on the problem experienced at the site and recovery trial to improve the problem.

2 FIELD MEASUREMENT AND DATA ANALYSIS

In September 2003, the test construction was completed on the national highway route 23 in Tsu, Mie prefecture. This was the first test construction on a highway in Japan. Table 1 shows the detail specification of pavements laid on the site.

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Table 1 Pavement Specification

Pavement	Surface				Note
	Thickness (cm)	Aggregate (mm)	Porosity (%)	MPD(mm)	
DENAP	5	20-0	-	0.20	
SDAP	5	13-5	20	0.35	
DDAP	2(upper) + 3(lower)	5-3(upper) + 13-5 (lower)	25(upper) + 20(lower)	0.70	
PERS #1	3	3-1	40	0.44	On-site construction
PERS #2	3	3-1	40	0.35	Prefabrication type
PERS #3	3	3-1	30	0.32	Prefabrication type

Note) DENAP: dense asphalt pavement, SDAP: single-layer drainage asphalt pavement, DDAP: double-layer drainage asphalt pavement

Figure 1 shows the allocation of the pavements constructed at the second test site. We set a sound level meter (SLM) as a microphone at the shoulders of the each differently paved section as illustrated in Figure 2 to avoid the influence of the safety fence on noise measurement.

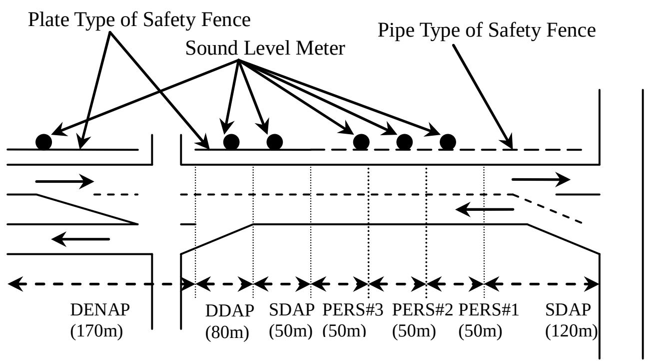


Figure 1: Pavement allocations.

We measured and analyzed the sound levels and calculated the vehicle power level (L_w). We used the finite-length square-integrating method[3,4] to work out L_w. We categorized each L_w according to the vehicle type, i.e. to small vehicles and large vehicles as Table 1 shows. The regression analysis finally determined L_w classified by the vehicle type.

2.1 Car-running Condition

For the traffic measurements, we put a video camera at the SDAP section and had continuous shots of the running vehicles at this section, assuming that it represented the traffic condition at all sections. We analyzed the video and computed traffic volume and speed every 10 minutes. As described in Figure 3, we put a photo-detector, which was composed of a light-source and a detector, 10m behind and ahead of the noise measurement point to measure the location and running speed of the test vehicles.

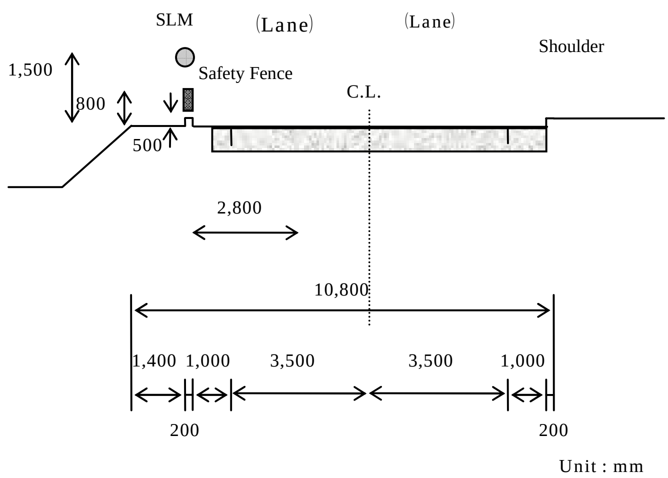


Figure 2: Cross-section of noise measurement point.

By using the signal of the photo-detectors and equations (1)-(4), we calculated the average running speed $\bar{v}$, acceleration α, length of the vehicles l, and the time when the center of the vehicle pass the microphone t_c.

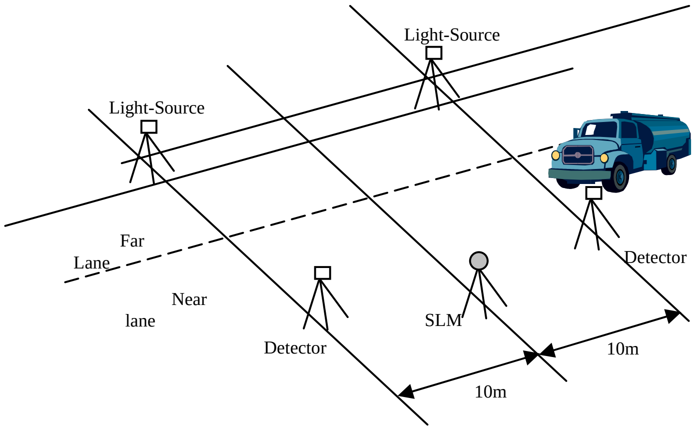


Figure 3: Photo detector allocations.

$$\bar{v} = v_0 + \alpha t_c \qquad (1)$$

$$\alpha = \frac{2}{t_2} \frac{t_1 + t_2 - t_3}{(t_1 - t_3)(t_2 - t_1 - t_3)} L \qquad (2)$$

$$l = \frac{t_1}{t_2} \frac{(t_3 - t_2)(t_2 + t_3 - t_1)}{(t_3 - t_1)(t_3 + t_1 - t_2)} L \qquad (3)$$

$$t_c = \frac{\sqrt{v_o^2 + \alpha(L + l)} - v_0}{\alpha} \qquad (4)$$

t_1: ending time of shielding the forward photo detector

t_2: starting time of shielding the backward photo detector

t_3: ending time of shielding the backward photo detector

L: distance between the forward and backward photo detector (=20m)

The starting time of shielding the forward photo detector is t=0.

2.2 Power Level Calculation[6]

There are two common ways to calculate L_w from the sound pressure levels, the peak level method (PLM) and the more accurate square integrating technique (SIT). We have introduced a new method based on the SIT and called it the "finite square integrating method" (FISIM). We measured the vehicle power level for the test vehicles at three speeds: 40km/h, 50km/h and 60km/h.

Disregarding the acceleration of the normal vehicles, we used all the data of the normal vehicles to do regression analysis of L_w. We documented that both the test vehicles and the normal vehicles were under the condition of single vehicle pass by, when we only detected the target vehicle signals by all the twelve photo-detectors set in the zone of test construction. If we detected a signal of other vehicles, we discarded all the data of the target vehicle.

2.3 Equivalent Continuous A-weighted Sound Pressure Level[6]

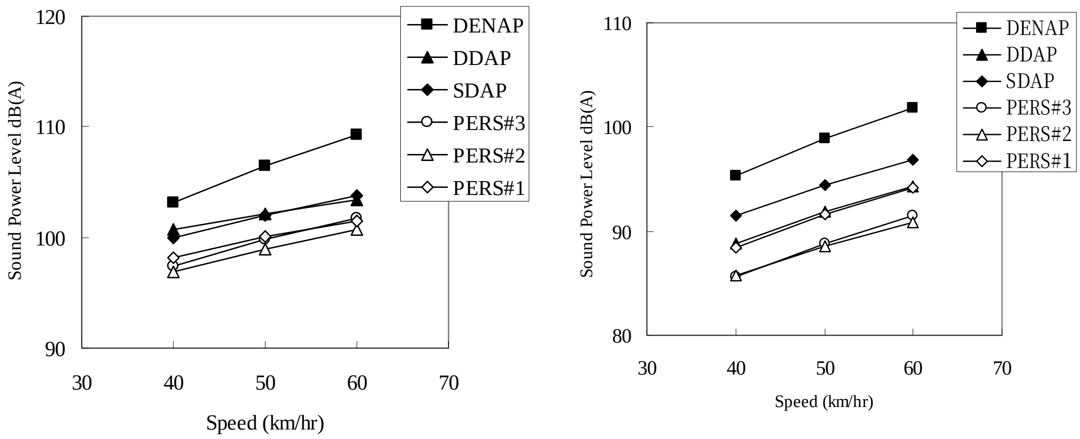
We used this L_w, traffic volume and vehicle running speed as inputs to the highway traffic noise model[7] named "ASJ Model 1998".

It enabled the calculation of L_{eq}. We set the different unit pattern for each pavement section with considering the difference in the sound power levels observed in each pavement section. We verified the validity of the measured L_w by comparing this calculated L_w with the actually measured L_w.

At last we again calculated equivalent continuous A-weighted sound pressure level, L_{eq} assuming the section length of the test construction is infinitely long, by using the verified L_w and a highway traffic noise model. From the difference in calculated L_{eq}, we could achieve noise reduction effect of PERS.

3 NOISE MEASUREMENT RESULT

We categorized the L_w, as Figure 4 shows, of the two kinds of the general motor vehicles from the analysis result. We also worked out the continuous 24 hours data from the 10 minutes data. We measured the traffic and running speed of each lane at the same time. The total daily traffic volume was 21,229 units. The average vehicle speed was 51.0 km/h., and the commercial vehicle ratio was 10.8%. Figure 5 shows the daily average of L_{eq}. The apparent difference in L_{eq} is about 5-6dB measured in PERS and DENAP, and about 4-5dB measured in DAP and DENAP. It also means that the discrepancy in the noise reduction effect between PERS and DAP is only 1-2dB.



(a) Large Vehicle (b) Small Vehicle

Figure 4: Sound power level.

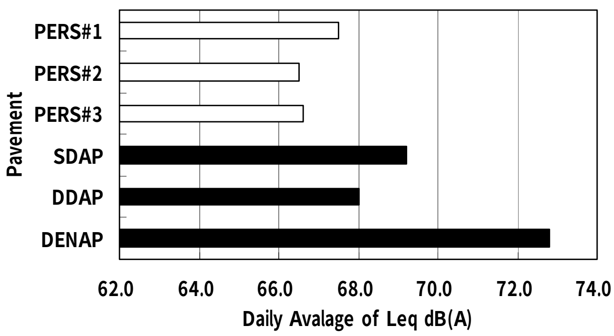


Figure 5: Daily average equivalent continuous A-weighted sound pressure level.

Strictly, however, it is incorrect to regard the noise reduction effect of DAP and PERS as the difference in measured L_{eq}. The measured L_{eq} is influenced by the noise from the neighboring paved sections. When the pavement with higher noise is next to the pavement with lower noise, L_{eq} measured in the pavement with higher noise shows lower L_{eq}, and in the pavement with lower noise, L_{eq} becomes higher. As a result, the difference in L_{eq} of these two pavements is estimated as a smaller figure than the true one because of this interference. Moreover the vehicle's running movement is different in the six paved sections. For example, in the PERS#1 next to T junction, the noise level is low because the vehicle running on the neighboring highway is mostly slowing down. And as Figure 1 shows, the right turn lanes of DENAP and DDAP exist between the close lane from the SLM and the far lane from it, so the distances between a SLM and a far lane in these two sections are longer than those of other sections. This results in lower L_{eq}.

Figure 6 shows the argument supporting this hypothesis. This is what we got when we measured the large-sized vehicle's L_w to confirm the influence of the safety fence. The SLM placed at the DDAP section (80m long) between the DENAP section and the SDAP section, detected this sound pressure level. The vehicle's speed is 61.6km/h (17.1m/s). The horizontal axis indicates the central point of the vehicle. The origin is the location of the SLM. The data between the two vertical lines (±21.8m) is the data for working out L_w by the finite length square-integrating technique (3-5). The data before −30m represented by the thick line is the one measured when the vehicle ran on the DENAP. The data represented by the thin line is the one measured when the vehicle ran on the section of the DDAP. A very interesting fact appears from the change of the noise level under such a postulate. The peak of sound pressure level increases when the vehicle is closer to the SLM. The sound pressure level is smaller when the vehicle runs behind and ahead of the SLM. The resulting graph appears like ridgelines running from a mountain peak. But the data for the vehicle in the DENAP section shows a non-uniform ridgeline. That is to say, the sound pressure level in the section of the DDAP contains the influence of the higher noise occurring in the neighboring section of the DENAP.

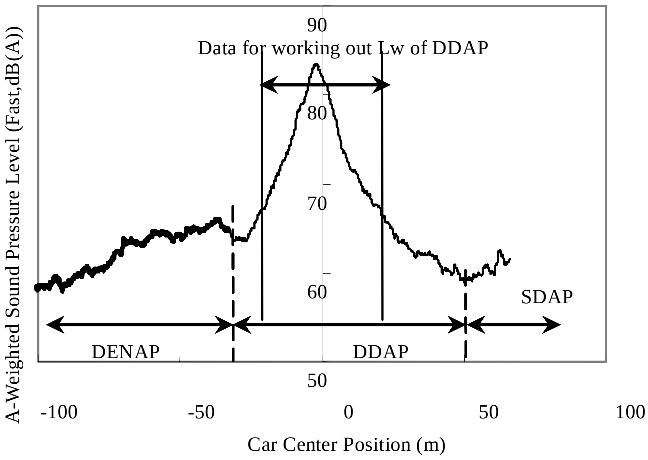


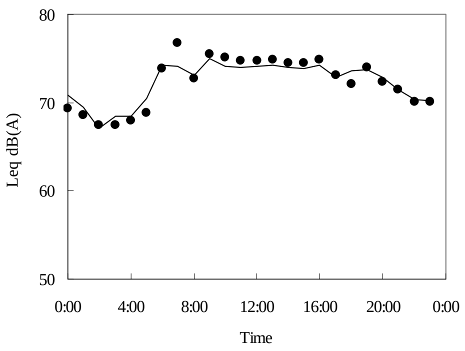
Figure 6: Influence of neighboring section on noise measurement.

Thus it is necessary to consider on these factors to determine the improvement of the noise reduction effect by PERS. To remove these influence, we calculated L_{eq} by the highway traffic noise model[9] under the same condition, i.e. infinitely long paved section of only two lanes, the same traffic volume and vehicle running speed. We applied the measured L_w of the general motor vehicles in this report instead of the L_w described in the model.

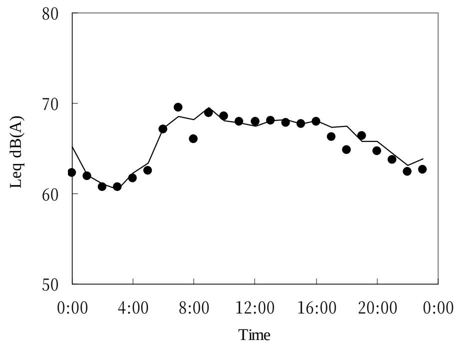
Figure 7 illustrates the calculated L_{eq} and the measured apparent L_{eq}. The difference between the calculated one and the measured one in all the paved sections is within ±1dB. The average error over all the pavements is -0.1dB. Given that this influence is ±1dB we can verify the validity of the measured L_w.

Moreover we again calculated L_{eq}, changing the calculation condition. Each paved section is considered to be infinitely long. For the DENAP and the DDAP, we calculated L_{eq}, assuming that these sections had no right turn lane as is the case with the other paved sections. The comparison in the calculated L_{eq} enables us to estimate properly the noise reduction effect of the two types of DAP and three kinds of PERS.

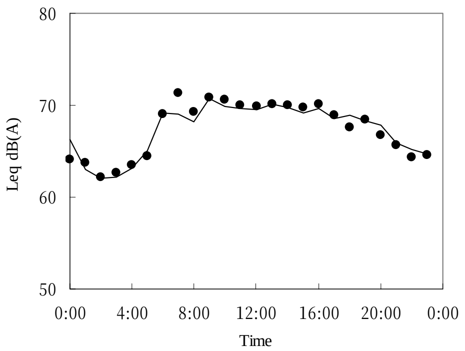
We show the daily average of the calculated L_{eq}, and the measured L_{eq} in Figure 8. The calculated one is larger than the measured one in the DENAP section, and the calculated one in the two kinds of the DAP section are about the same as the measured ones. On the other hand, the calculated L_{eq} for the three kinds of PERS are lower than the measured ones.



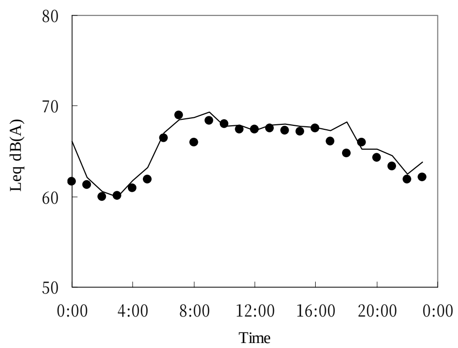
(a)DENAP



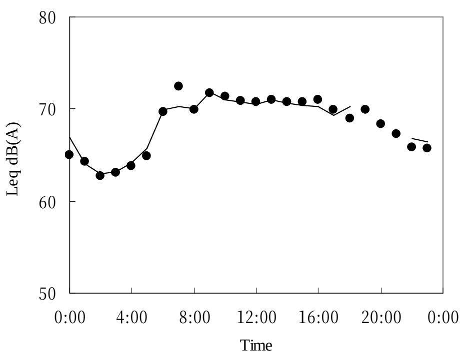
(d) PERS#3



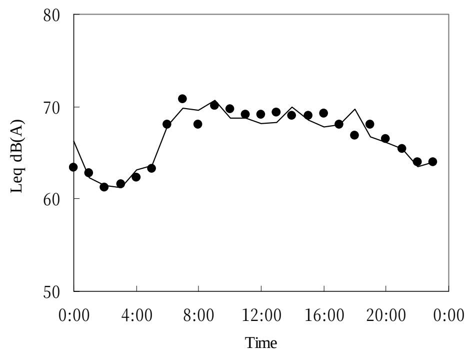
(b) DDAP



(e) PERS#2



(c) SDAP



(f) PERS#3

Figure 7: Comparison between measured and calculated equivalent continuous A-Weighted sound pressure level.
”Solid line” means the measured L_{eq} and “black dot mark” shows the calculated $L_{eq.}$

It corresponds with the hypothesis mentioned at the beginning of this part. The DENAP is next to the DAP with lower noise, so the noise measured in the section of the DENAP is apparently low. In the section of the two types of the DAP, an offset occurs between the DENAP with higher noise and the PERS with lower noise. It coincidentally brings the correspondence of the measured one and the calculated one. The sections of the three kinds of PERS are next to the section of DAP with higher noise, so the noise levels measured in the sections of the PERS are apparently high.

Figure 9 describes the difference in L_{eq} with the calculated daily average base on the DENAP. It is this difference that achieves true noise reduction effect. We finally found out the noise reduction effect of the DAP is 5-6dB, and that of PERS is 7-9dB. As the result, it becomes clear that the discrepancy in the noise reduction effect between PERS and DAP is 3-4dB.

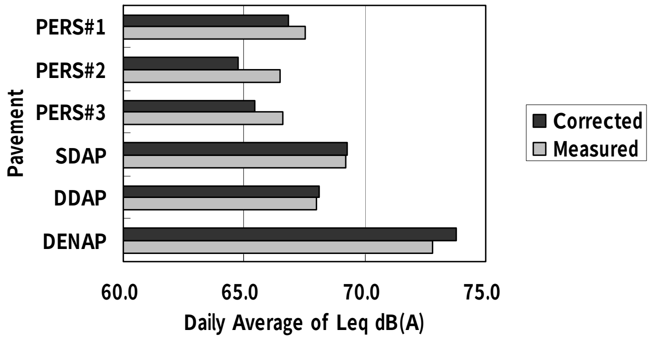


Figure 8: Corrected equivalent continuous A-weighted sound pressure level.

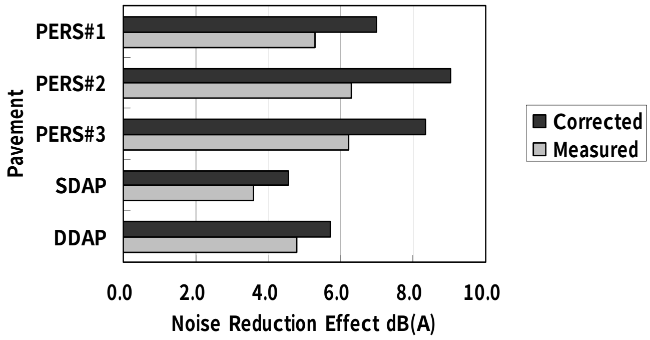


Figure 9: Noise reduction effect of PERS & DAP in equivalent continuous A-weighted sound pressure level.

4 IMPROVEMENT IN WET SKID RESISTANCE AND CONSTRUCTION METHOD

4.1 Wet Skid Resistance

All the PERS constructed in the second test construction site was removed 7 months after service, because of lower wet skid resistance than the standard value of 0.33 at 60km/h. In order to simulate the damage, we developed the testing method shown in Figure 10. This testing method is modified from the JIS S 1038-75. PERS is set on a turning table. A chair caster is put on PERS and a yellow counter weight is fixed on the top of chair axial. The rotation speed is 65 rpm. The contact pressure is 0.85MPa. Wet skid resistance of PERS is measured by Dynamic Friction Tester described in ASTM E-1911_75. Figure 11 illustrates the result of two PERS constructed at the site. The both of these two are pre-fabricate type of PERS. The wet skid resistances become lower than 0.3 observed at the site when the total rotation number becomes 50-100 thousands. It could be decided that the damage of 7 months,

Figure 10: Rotation test for chair-caster.

caused by the traffic volume at the site, is regarded as the rotation number of 80 thousand in the laboratory test.

Figure 12 shows the resistance of improves PERS. All the PERS can satisfy the standard of 0.33 after the rotation number of 600 thousand. It means that improved PERS can satisfy the resistance more than about 5 years after service.

4.2 Construction Method

The construction method of the site is not practical for heavy traffic volume of urban highway because of excessive construction time. It takes about one day each for base course cause, semi-flexible pavement and adhesive work of PERS attached on the base course shown in Figure 13(a). The latest research work identified a new construction method shown in Figure 13(b), which total work time for 500 m^2, a standard area of urban re-pavement work in Japan, is estimated less than 8 hours. The author verified the initial adhesive strength by a deceleration test of a heavy truck. The weight and maximum load is 100kN and 94kN, respectively. The average magnitude of deceleration was 10 m/s^2. He could not find any displacement in the position between the initial condition and the final condition after 20 times of deceleration trials.

5 CONCLUSIONS

The author can obtained the noise reduction levels of 10dB in equivalent continuous A-weighted sound pressure level in the construction site. Reflecting the result of wet skid resistance and construction work time,

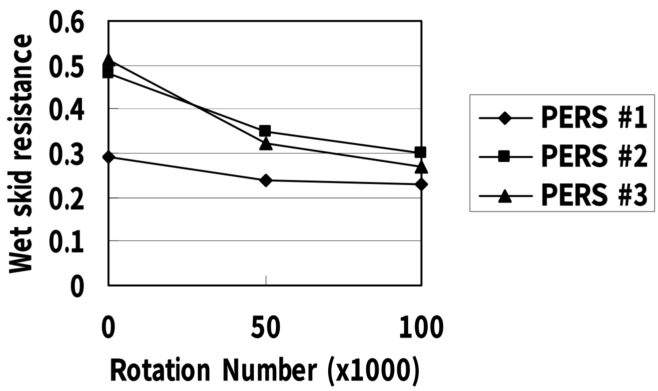


Figure 11: Wet skid resistance of PERS constructed on the site.

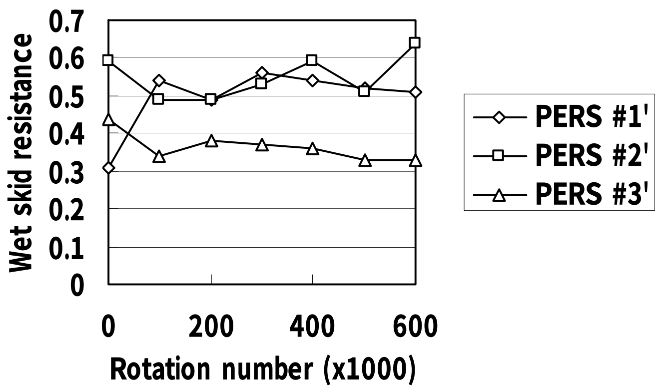
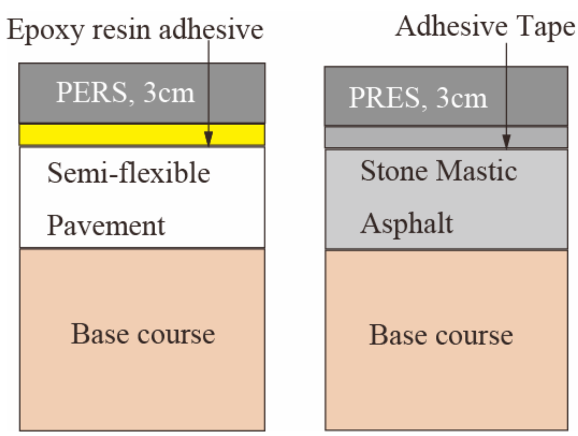


Figure 12: Wet skid resistance of improved PERS.



(a) Old (b) New

Figure 13: Pavement structure.

the author improved more durable PERS and proved its performance by a new testing method, and a new construction method.

6 ACKNOWLEDGEMENTS

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