POROUS ELASTIC ROAD SURFACE AS AN ULTIMATE HIGHWAY NOISE MEASURE

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ABSTRACT

Highway traffic noise in urban areas of Japan is a serious problem, not only for residents along highways, but also for highway administrators. Only 13 percent of urban highways have met the environment standard for noise. Noise barriers cannot be used as a noise countermeasure on the majority of highways on which access is not controlled. Noise levels of areas along some urban highways exceed the standard by 15 dB(A) or more. This problem is impeding new highway construction in urban areas. Porous asphalt pavement has recently been introduced on urban highways in Japan. Its noise reduction effect of 3 dB(A) is insufficient, because it only improves the noise environment satisfaction rate by a few percent. Furthermore, the durability of its noise reduction effect usually seems to be only three years, which is shorter than its life-cycle as pavement.

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 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 standard if this noise reduction level were achieved. The PWRI has already solved several of the problems with PERS, for example, insufficient adhesion between the pavement and the base course, low skid resistance, and its poor fireproof performance. 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 recent research done to further improve the noise reduction levels of PERS and the first test construction using PERS in Japan. The final noise reduction target for any type of vehicle is between 15-20 dB(A). The author expects that PERS will reduce highway traffic noise problems in urban areas of Japan to a minor, negligible level in the near future.

KEYWORDS

pavement, noise reduction, highway traffic noise, skid resistance, durability, adhesion

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 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 standard if this noise reduction level were achieved. The PWRI has already solved several of the problems with PERS, for example, insufficient adhesion between the pavement and the base course, low skid resistance, and its poor fireproof performance. 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 improvement of noise reduction effect with changing its porosity and thickness, adhesion to the base course, durability, wear resistance, wet friction, and fire resistance, whereas the second part focuses on the laboratory performance testing in advance to identify a new construction method of PERS before trial construction on highways and the noise reduction effect observed at the construction site.

2. LATEST TECHNOLOGY

2.1 Noise reduction

Noise reduction is the most interesting aspect of PERS, and the author has examined this feature in each of the four specifications of PERS that have been released. In the first test construction, its porosity was 40% and its thickness was 5 cm. The author measured the power levels of vehicles by the controlled pass-by method based on ISO 326 and ISO 7188. The detailed methodology to calculate power levels was described by Meiarashi (1996). **Figure 1** illustrates that for all vehicles, PERS is superior to Drainage Asphalt Pavement (DAP). The superiority is expressed by differences of the total A-weighted sound power levels for constant speed. As compared to porous asphalt pavement (Dense Asphalt Pavement (DENAP)), the noise reduction attained with PERS is from 2 to 10 times greater than that attained with DAP. Note that the noise reduction for a car is 13 dB(A) at 60 km/h, and 6 dB(A) for light and heavy trucks. For cars, the coast-by noise is the dominant contribution to power-by noise, whereas for trucks it is the power-unit noise. Thus there is a clear difference in noise reduction between car and trucks owing to the relatively large power-unit noise of trucks.

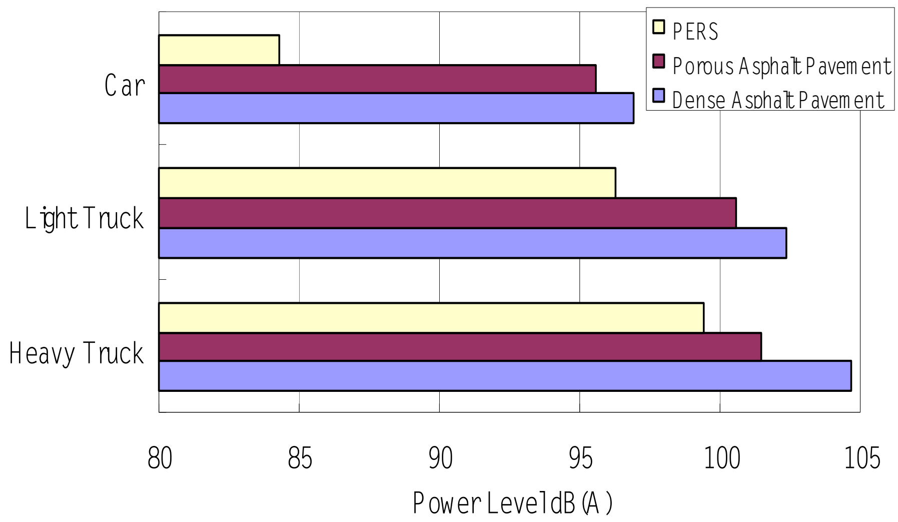
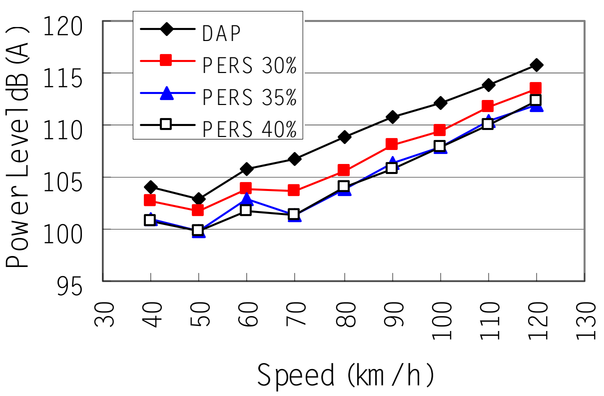
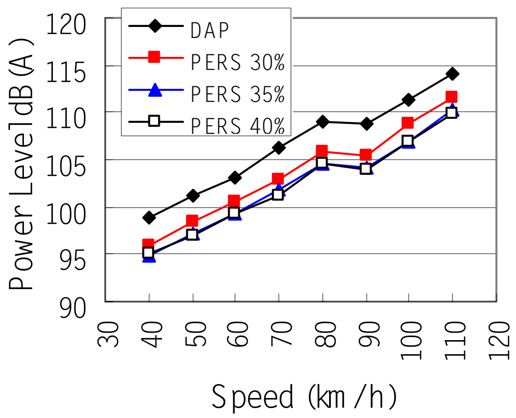


Figure 1 - Power levels measured at PWRI test course in 1994
: 5 cm thick, 35% of porosity, L=25m, W=5m

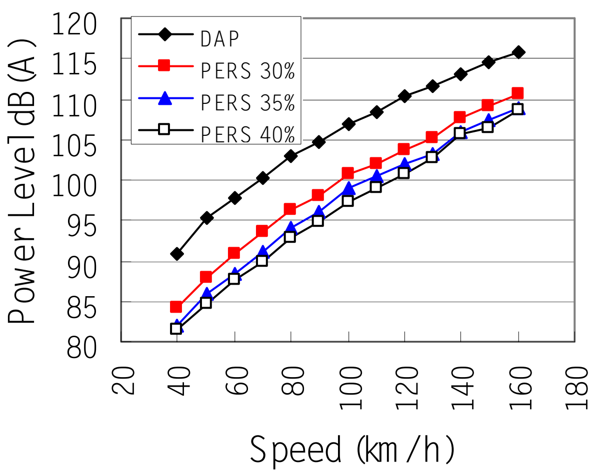
The author has conducted four noise measurements in total at the PWRI testing course to improve the noise reduction effect of PERS, including the first one described above. The second noise measurement in 1995 was focused on the influence of porosity on noise reduction. **Figure 2** shows that noise reduction of PERS is almost saturated at the porosity of 35% and over. In the third noise measurement of 1996, a major issue was the effect of PERS thickness on noise reduction. The optimal PERS noise reduction levels for passenger cars, light trucks, and heavy trucks are 14-16 dB(A), 4-5 dB(A), and 3-5 dB(A), respectively. **Figure 3** reveals that the noise reduction of PERS becomes a maximum at the thickness of 3 cm. Considering the relatively small difference of noise reduction between 3 cm thickness of PERS and 2 cm thickness of PERS, and material cost reduction, the optimal thickness of PERS seems to exist between 2 cm and 3 cm. The optimal PERS noise reduction levels for passenger cars, light trucks, and heavy trucks are 13-19 dB(A), 8-9 dB(A), and 6-10 dB(A), respectively.



a) Heavy truck



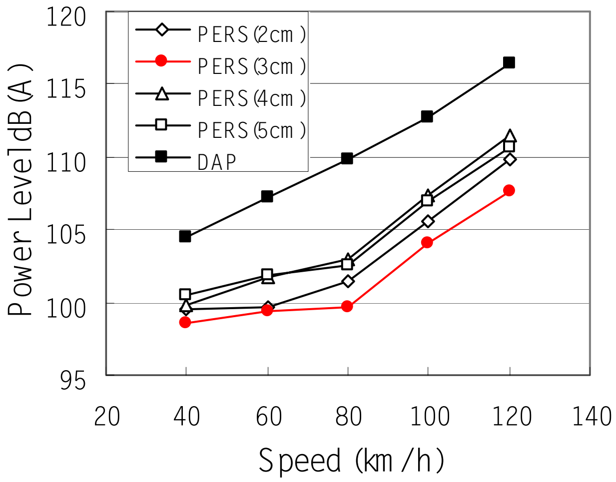
b) Light truck



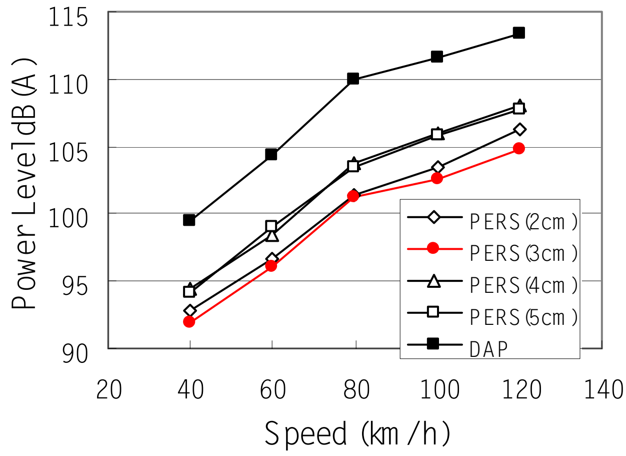
c) Passenger car

Figure 2 - Power levels vs. PERS porosity

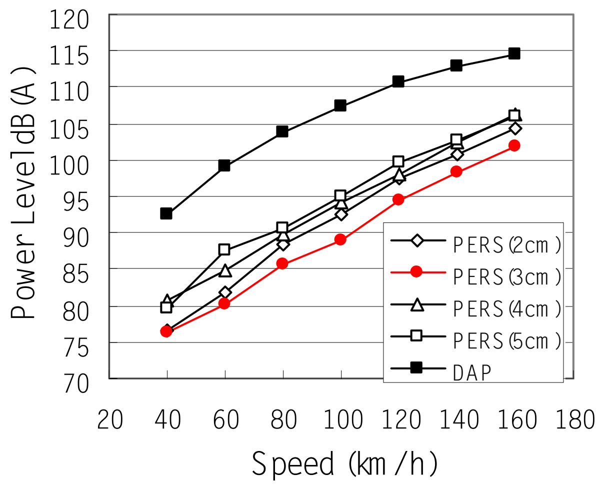
The fourth noise measurement was conducted to confirm the noise reduction effect of PERS, which met the final criteria for PERS, obtained in the cooperative research of PWRI and private rubber product companies. One of the serious issues to solve in this research was to improve the low wet friction of PERS. Almost all the companies had changed the component of PERS. The noise reduction levels of PERS on the passenger car are 12-15 dB (A) excluding only one product whose reduction level is 8-9 dB (A). Those of PERS on trucks are 8-10 dB (A). As a result, the author had to improve wet friction while sacrificing noise reduction for passenger cars.



a) Heavy truck



b) Light truck



c) Passenger car

Figure 3 - Power levels vs. PERS thickness

2.2 Adhesion to base course

Poly-urethane adhesive between PERS and semi-flexible pavement as base course showed insufficient performance. In 1994, passage by a heavy truck caused PERS to peel off from the base course. In 1997, the author identified the adhesion performance criterion as 0.8 MPa for PERS after moisture and heat accelerated deterioration tests through both analytical and numerical calculations, and found that epoxy resin adhesive, which showed much stronger adhesion than polyurethane resin in the two-face shear test, satisfied this criterion.

2.3 Durability and wear resistance

Accelerated pavement tests, as illustrated in **Figure 4,** were conducted from 1994 to 1997. The total cumulative traffic volume of test cars finally reached 180,000, corresponding to a 1.2-month exposure to ordinary highway whose heavy traffic volume is 3,000 per day per lane. **Figure 5** shows the result of maximum rutting depth. PERS shows better performance than DAP, with far better deformation performance than conventional pavement such as DENAP.

Figure 4 - Accelerated pavement test

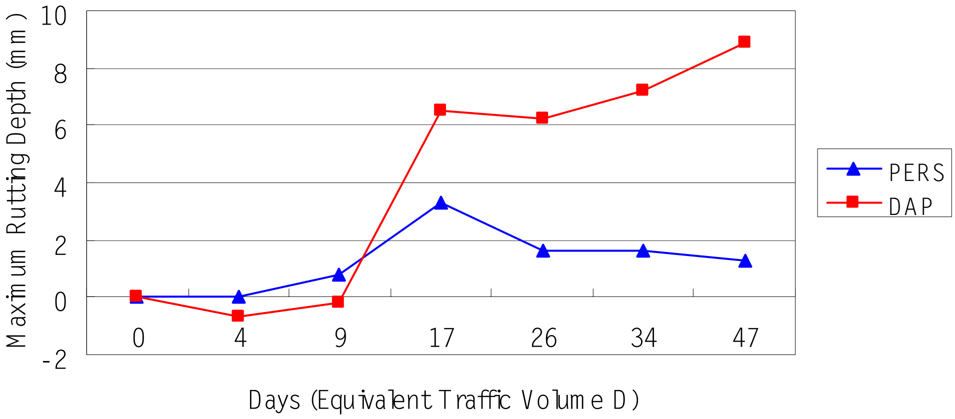


Figure 5 - Rutting depth after accelerated pavement test

2.4 Wet friction

Low wet friction had been a serious issue of PERS from the initial development stage. The component of PERS was changed through cooperative research between PWRI and rubber product companies to solve this problem, as mentioned in the previous section. **Figure 6** shows the results of the wet friction measurement test described in **Figure 7**. The black dotted line, R.S.O., means the minimum criterion of wet friction regulated in the technical guideline for highway design in Japan.

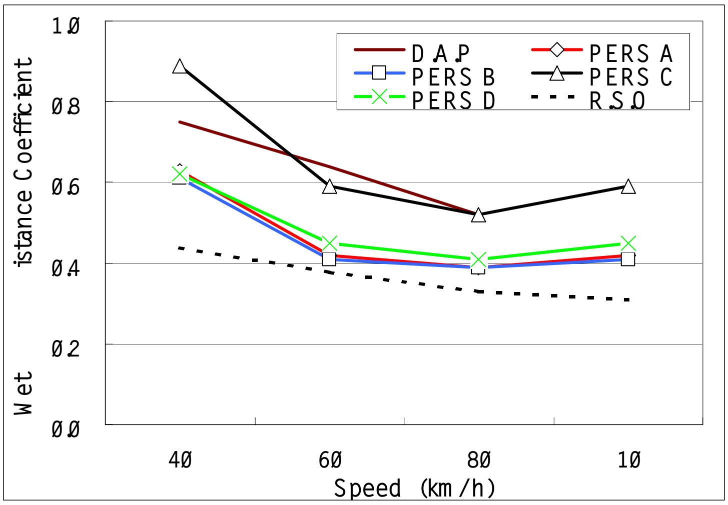


Figure 6 - Wet skid resistance

Figure 7 - Apparatus for wet skid resistance

2.5 Fire resistance

Fire resistance was thought to be a potential problem, since rubber may burn fiercely. The fire hazard problem has been studied by PWRI. Squares of PERS 5×5 m were placed outside a laboratory, 36 liters of diesel oil or gasoline were sprinkled on the surface as well as on an adjacent (conventional) asphalt pavement. The fluid was then ignited with a torch, and factors such as pavement materials, height of flames and generation of smoke were observed and the tests were also filmed.

In the experiments, three surfaces were compared: dense asphalt concrete, porous asphalt concrete and the 5×5 m panels of PERS. The results, as given in **Table 1**, show that regarding spreading speed and flame height, the PERS was safer than the dense asphalt concrete. **Figure 8** illustrates these tests.

Table 1 - Fire resistance test condition

Surface type	Burning of fuel and pavement materials	Flame height	Smoke generation
DENAP	Fuel oil spreading over the pavement surface strongly burned with reddish flames but the pavement did not burn.	2.5-3.0 m	Fuel oil burned incompletely, producing a column of black smoke.
DAP	Fuel oil evaporating through the voids of the pavement ignited, causing blue flames. However, pavement materials did not burn.	Approximately 0.3 m	Only a little smoke was observed.
PERS	Fuel oil evaporating through pavement voids ignited; rubber panels burned up, causing reddish flames. Fire spread over the pavement very slowly.	1.0-1.5 m	A column of black smoke was observed from the burning rubber panels.

a) Dense Asphalt Pavement b) PERS

Figure 8 - Fire resistance

3. FIRST TEST CONSTRUCTION

PERS construction in highways requires the structure to be developed as a total pavement system and a construction method that is very different from the previous ones in PWRI test courses. There are two reasons for improving the structure and construction method.

The first one is a time constraint. One potential application of PERS is for heavy-traffic arterial highways in urban areas, where the working time is limited to 10 hours at night (such as from 8 PM to 6 AM) to avoid causing traffic congestion. The standard area of pavement resurfacing of an urban highway is 2,000-3,000 square meters per day. The construction work involves removing the existing wearing course & base course, constructing new semi-flexible pavement as the base course, putting adhesive on the base course, and paving PERS as shown in **Figure 9(a)**. Considering the working time before paving PERS, it is impossible to complete all the works within the limit.

The second reason is for quality control of adhesive performance. In the early stage of development of PERS, there were various troubles concerning the adhesive as mentioned in the previous section. The polymer type of adhesive is very sensitive to the ambient conditions of curing such as temperature and humidity. It seems very difficult to maintain stable performance of the adhesive during outdoor work.

In response to these problems, pre-fabricated types of PERS would appear to be the only solution. The main pre-fabricated types of pavement products are Inter-Locking Block (ILB), Pre-stressed Concrete Panel (PCP), and Reinforced Concrete Panel (RCP). The ILB has been widely used for pedestrian ways especially in prestige areas and shopping malls, where architects and planners are interested in the visual impact of paving. Some ILBs are also to be found in industrial areas, such as storage yards and dock-side paving, where the main concerns are structural performance, cost and maintenance. The PCP is pre-tensioned in the transverse direction during fabrication, and post-tensioned together in the longitudinal direction after placement. The PCP and RCP are mainly used for sections where extremely high durability is required, such as the pavement in tunnels.

In view of the time constraints, it is impossible to use PCP and RCP as the base course of PERS because of the slow speed of construction of less than 100 square meters per ten hours. The present mechanical method of laying ILB improves the construction efficiency and overcomes the constraint. With this background, the author has proposed using ILB for the first test construction of PERS. However, ILB has been used in very few cases for highways and its durability for the surface course is unknown. The author has clarified the initial durability of the ILB-PERS composite surface by accelerated pavement tests in the laboratory shown in **Figure 9(b)**. No fatal damage to the surface

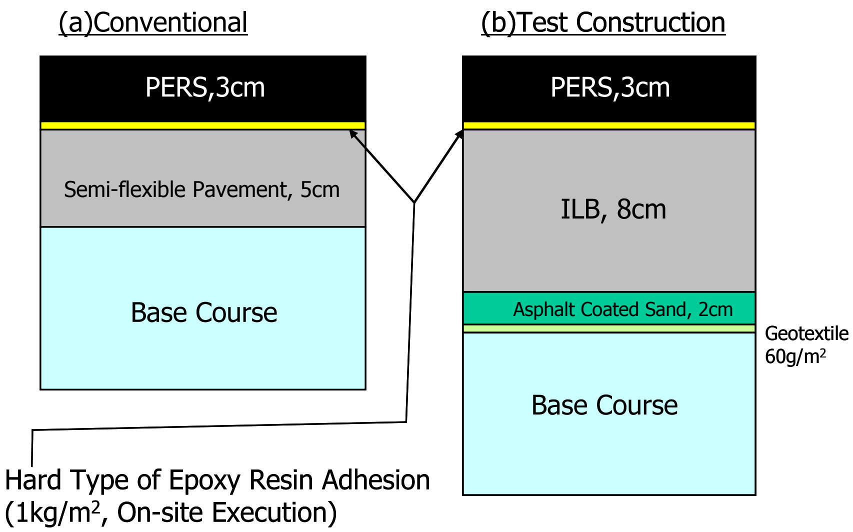


Figure 9 Pavement Structure

was found after 12,000 passes of the test truck.

PERS was first constructed at Tazawa of National Highway Route 46 on 18 October, 2002. The total number of lanes is two and the width of each is 3.75 meters. The total length is 20 meters. The traffic volume, heavy traffic ratio, and speed limit are 10,120 vehicles per day, 20%, and 60km/h, respectively. **Figure 10** shows the general view of the section and the initial condition of the PERS surface. The author measured the noise of individual vehicles by using a special method proposed by Meiarashi (1996). The vehicles were limited to smaller ones such as passenger cars and light trucks, because of the short section length. **Figure 11** illustrates the arrangement of equipment, including a sound level meter as a microphone and two sets of photo-detectors as a speed meter. **Figure 12** shows the A-weighted peak levels of vehicles measured at PERS and DENAP. When noise reduction levels are defined as the difference in levels between PERS and DENAP, they are approximately given by the formula:

$$\Delta PWL = 0.1V$$

ΔPWL: Noise reduction level dB (A)
V: Vehicle speed   km/h

These noise reduction levels seem to be smaller than those measured at the PWRI test course. This discrepancy may be caused by the difference in geometric relationship between vehicles as noise sources and the microphone. The distance between vehicle running position and a microphone in the highway area was shorter than that of noise measurement in the PWRI test course, which means that additional attenuation loss could not be expected in the field measurement. A lower reflecting angle of the site than that of the PWRI test course might be another factor for the lower noise reduction of PERS. In general, lower sound reflecting angles provide smaller sound absorption coefficients.

Figure 10 - First test construction site

Figure 11 - Equipment for noise measurement

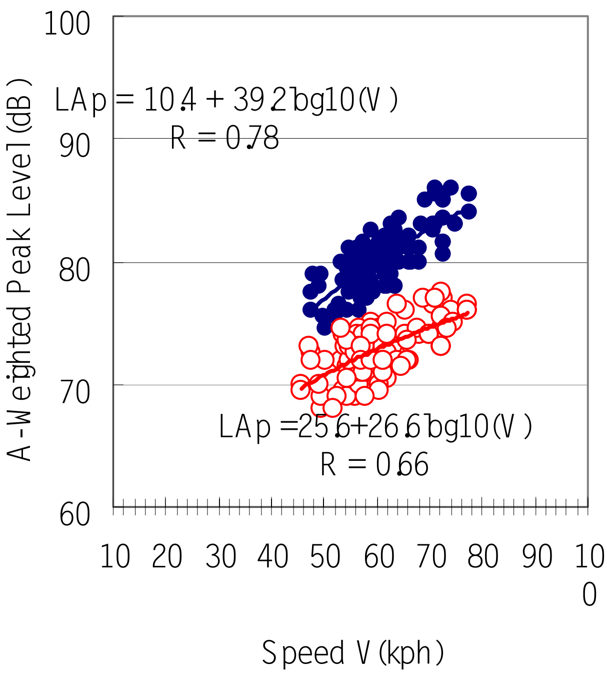


Figure 12 - Power levels measured at first test construction site

4. CONCLUSIONS

The Public Works Research Institute (PWRI) has, since 1993, been developing a new low-noise pavement named “Porous Elastic Road Surface” (PERS). The author estimates that the potential noise reduction levels in Leq exceed 10 dB(A). The PWRI has already solved several of the problems with PERS such as insufficient adhesion between the pavement and the base course, low skid resistance, and poor fireproof performance.

Based on the above research results, PERS was first constructed at the National Highway Route 46. Noise reduction levels measured in the field were less than expected, because the size of the construction area was very small.

The author will continue these investigations in the field and will attempt another test construction using a more efficient construction method than ILB.

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