Development of the New Cleaning Vehicle for Porous Asphalt

T. Katu & S. Sasaki
NIPPO CORPORATION, Saitama-shi, Saitama, Japan

ABSTRACT: Porous asphalt has such functions as permeability and tire-noise reduction, therefore has rapidly spread due to contribution to safe driving and the improvement of environment around roads. Its annual achievement area in Japan is estimated at more than 30 million square meters.

But it is also known that these functions gradually deteriorate due to clogging with dirt and reduction in air voids by traffic loads. Some preventive measures to maintain the functions as long as possible are strongly demanded and partly put into practice. Among them is the use of a cleaning vehicle to remove dirt and sand from the air void by high-pressured water. But the cleaning operation has to be carried out at very low speed with conventional vehicles, which would disrupt road traffic and cause traffic jams. As a result, they have few chances to be applied.

We developed the new type of the cleaning vehicle characterized by a high-speed cleaning and a low cost. This vehicle has the new and unique system to clean at a high-speed. In the cleaning unit, jet nozzles spray high-pressured water, which is recovered through a spiral-like water course into a tank, only using kinetic energy of high-pressured water without a vacuum device after it dashes against the surface.

This paper describes performance of the new cleaning vehicle and its effect.

KEY WORDS: Porous, asphalt, cleaning, function, recovery.

1 INTRODUCTION

Porous asphalt has started in Japan since early 1990s and has become widespread initially to highways and national roads and even to roads on residential areas in recent years, because of the functions such as permeability and tire noise reduction that promote safe driving and improve environment along roads. At present, its annual achievement area is estimated at more than 30 million square meters and seems to still be increasing.

But it is well known that the functions of porous asphalt deteriorate over years due to clogging by dirt and sand and reduction in air void content by traffic loads. Preventive countermeasures against them have been strongly demanded. Among them are the use of high- viscosity modified binder, and a spray of resin onto the surface, and a filling of air voids on the surface by a permeable resin mortar. But these measures are too expensive to cover all the areas.

The cleaning vehicle using high-pressured water is considered economical relative to other methods to recover the functions. But the cleaning vehicles have not become widespread due to a slow cleaning speed and the low cost-effectiveness.

Considering these situations, we developed a new type of cleaning vehicle (hereinafter described as a high-speed cleaning vehicle), which can clean at higher speed and lower cost than conventional cleaning vehicles.

2 PROCESS OF DEVELOPMENT

Many measures have been tried for an effective cleaning of porous asphalt. Among technologies used so far are those with high-pressured water, high-pressured air, water-cavitation. It is believed that a cleaning with high-pressured water has high cost-effectiveness, therefore this method accounts for a large percentage in the past cleaning achievement. But a low speed and low productivity of conventional cleaning vehicles prevented the spread of application, because of leading to higher cost than expected. Moreover, in some cases where permeability badly deteriorated, enough recovery effect has not been successfully achieved with dirt or sand be clogging all the thickness of the layer.

Our initial goal was to clean dirt or sand out of the air void through all the thickness of porous asphalt, which is generally 4 or 5 cm in Japan, at a higher speed than conventional cleaning vehicles, even from a lower part of the layer to get enough recovery effect. For that purpose, we not only tried to improve conventional cleaning vehicles but also asked the Battelle Memorial Institute in the U.S. to analyze the present technologies and cooperate for new methods. But after all these efforts, we reached the conclusion in the end that it is very difficult to effectively clean the porous asphalt through all the thickness.

Instead, we focused on increasing in a cleaning speed and a cost reduction, aiming at removing dirt and sand up to 20mm deep under the surface. It was assumed that when cleaning is carried out regularly at short intervals from an early stage of the service life, a function should be kept in a good condition. A target of the speed was over 6 km per hour, at which a lane closure is said to be unnecessary in Japan, while that of conventional cleaning vehicles is 0.5 to 1.0 km per hour.

After a number of trials of various kinds of methods and technologies, we developed the new type of cleaning vehicle for porous asphalt, which characterizes a high cleaning speed of 6 to 10 km per hour and recovering water without a vacuum device.

3 SUMMARY OF THE HIGH-SPEED CLEANING VEHICLE

3.1 Appearance and Specification

A photo 1, 2 shows an overall view of the high-speed cleaning vehicle and a cleaning unit equipped behind it respectively. A table-1 shows the specification.

Photo1: The Cleaning Vehicle at Work

Photo2: The Cleaning Unit

Table1: Specification of the high-speed cleaning vehicle

Dimensions	Overall Length	11,900 mm
	Overall Width	2,490 mm
	Overall Height	3,620 mm
Weight	Deadweight	18,050 kg
	Total Weight	19,910 kg
Performance	Cleaning Width	20,000 mm
	Shift Width	Left:600mm, Right:700mm
	Cleaning Speed	6 ~ 10 km/h
	Max. Drive Speed	80 km/h
Cleaning	Number of Nozzles	40 (20 of each side)
Tank Volume	Clean Water Tank	1.75 m^3
	Muddy Water Tank	1.20 m^3
Pump	Discharge Volume	480 L/min
Engine	Output	235.4/2,000 kw/min^{-1}

3.2 Cleaning Method

The high-speed cleaning vehicle uses high-pressured water which is sprayed onto the surface from jet nozzles inside the cleaning unit. The figure 1, 2 shows the structure and the cross section of the cleaning unit respectively. Two rows of 20 jet nozzles each, which are placed to meet face to face, spray water toward both a travel direction and its opposite direction at an angle of some 45 degrees against the surface. Sprayed water is reflected on the surface and recovered with dirt and sand by the device called "Tornado Recovery System" by which water climbs up the spiral-like course into the recovery tank in the cleaning, using momentum of the sprayed water without a vacuum suction device. Then, the muddy water goes into the muddy water tank after passing the primary filters where large particles are removed. After fine particles are removed by the secondary filter, the water flows into the clear water tank to be reused for cleaning. Since recovery rate of water is about 50%, equivalent to amount of lost water is supplied anew during cleaning operation.

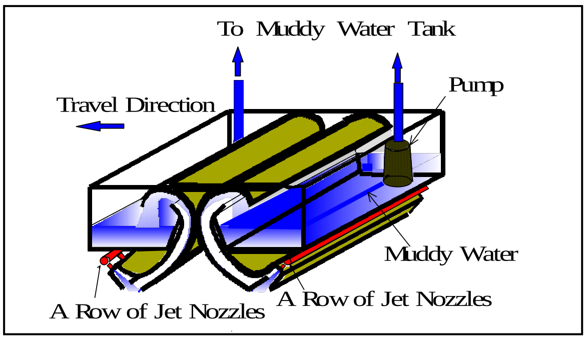

Figure1: Structure of Cleaning Unit

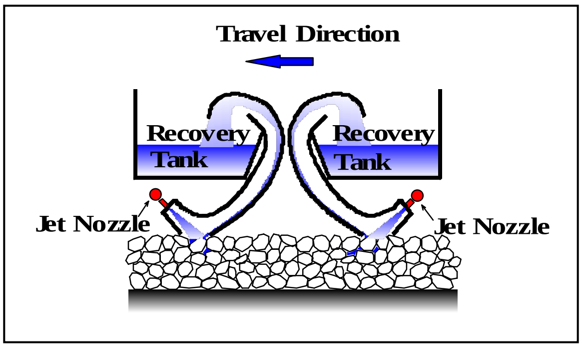

Figure2: Cross Section of Cleaning Unit

3.3 Advantage

The following are advantages of the high-speed cleaning vehicle.

1) No need of a vacuum suction device to recover water, allowing high-speed cleaning at 6 to 10 km/hour by introducing the new method called “Tornado Recovery System”.
2) No need of a lane closure due to the high speed cleaning (subject to approval of a road administrator), easing traffic congestion during operation.
3) Sharp cutback in a cleaning cost by high productivity (70% cut at maximum), therefore it allows a frequent cleaning at short intervals, maintaining the function in a good condition for a long time.
4) Depth up to some 20 mm under the surface to be cleaned, which is almost equivalent to the performance of conventional cleaning vehicles.
5) Shift of the cleaning unit to both sides to help clean an overall width of a road.

4 PERFORMANCE

4.1 Data Collection

Cumulative achieved area by the high-speed cleaning vehicle has reached about 300,000 m^2 (as of the end of March 2009). We gathered the performance data on-site to see if the high-speed cleaning vehicle compares with conventional cleaning vehicles .The following is performance confirmed so far.

4.2 Permeability

Permeability is determined on-site by measuring a run-out time of water of 400 ml that fills a hollow cylinder with a diameter of 5 cm. The permeability is quantified as the amount of water which permeates on the surface area of 5cm in diameter in 15 seconds by converting the run-out time of 400 mL (hereinafter described as on-site permeability). Porous asphalt is considered to keep a good condition if this figure is 1,000 mL or more.

In typical cases where on-site permeability of porous asphalt (with 13 mm maximum aggregate size) was reduced to the range between 400 and 900 mL due to clogging, it was observed that the figure was improved by 20 to 200 mL each time of cleaning using the high-speed cleaning vehicle. But in the case where the main cause of deterioration seemed to be reduction in air void by traffic loads, recovery effect of permeability was hardly confirmed.

4.3 Tire/Pavement Noise

The tire/pavement noise is measured with a vehicle called a “Road Acoustic Checker Vehicle” (RAC Vehicle), which is equipped with a special tire mounted behind the rear axle, and a microphone near the side of the tire (CPX measurement type). Measured with this vehicle, dense-graded asphalt (with 13 mm maximum aggregate size) has a noise level of around 100 dB, and porous asphalt (with 13 mm maximum aggregate size and 20% air void) has 87 to 89 dB immediately after paving. In typical cases, maximum reduction of around 0.5 dB was confirmed after each time of cleaning.

4.4 Productivity

As an example of the application, the cleaning of some 10,000m^2 of porous asphalt was achieved in the nighttime between 22:00 and 6:00 without closing lanes on the national roads in an urban area with two lanes in each direction, which has heavy traffic even during midnight. The cleaning was performed at a speed of about 10 km per hour, but it never caused any traffic disruption on both of a driving lane and a passing lane. The productivity is about 1,800 m^2 per hour including the time of supplying water and out-of-operation. If the same area had been cleaned by a conventional vehicle, it would have taken at least fivefold more time, forced to close a lane and prolong the period over one night.

5 SIMULATION OF RECOVERY EFFECT

5.1 Purpose

It has been acknowledged that if cleaning of porous asphalt is regularly conducted at short intervals, the function can be kept in a good condition for a long time. But in practice, it was not economical to repeat the cleaning in view of a life-cycle cost due to a high cost of conventional cleaning vehicles. Therefore it was unusual to clean porous asphalt regularly at the same section. But the high-speed cleaning vehicle allows the cleaning to be repeated at short intervals, offering far lower cost.

We needed evidence to convince road authorities to apply the high-speed cleaning. But we had only data in a few years after an introduction of cleaning and there was few past data that indicates a change of permeability by repeated cleanings over a long period. A simulation of repeated cleaning by the high-speed cleaning vehicle was tried to demonstrate its effectiveness and justify repeated cleaning based on on-site permeability data before and after cleaning of porous asphalt that has various levels of permeability. A similar simulation with conventional cleaning vehicles was also attempted for comparison.

5.2 Deterioration of Permeability

Figure 3 shows the relationship between the on-site permeability of porous asphalt with no experience of cleaning, and the service period since it opened to traffic. This figure indicates that the on-site permeability tends to decrease as the time goes by. Equation (1) indicates the approximation of the relationship in Figure 3.

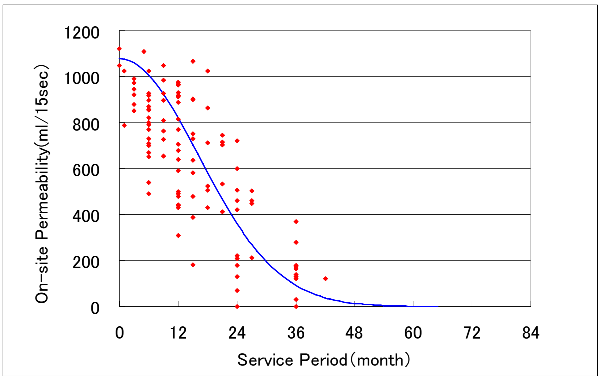

Figure 3: Relationship between on-site permeability and service period

$$f_1(m) = \frac{1}{0.0037\sqrt{2\pi}} \exp(-0.0019 m^2) \tag{1}$$

In which

$f_1(m)$: Approximation of the on-site permeability after “m” months of the service period

m : Service Period (month)

5.3 Recovery Effect

Figure 4 shows the relationship between the on-site permeability before and after the cleaning by the high-speed and the conventional cleaning vehicle. The difference in the recovery effect, which seems to depend on how deep sand or dirt penetrates, was observed among points of measurement for both cleaning vehicles.

Overall, in the stage where clogging progressed badly, conventional cleaning vehicles have superiority in performance. But when clogging is mild or slight, there is no big difference between two types of the cleaning vehicles. This means that if the cleaning starts in early stage of clogging and is repeated properly, the high-speed cleaning vehicle will keep porous asphalt in a good condition.

Equation (2) indicates the approximation in Figure-4 for the high-speed cleaning vehicle, Equation (3) for the conventional cleaning vehicle respectively.

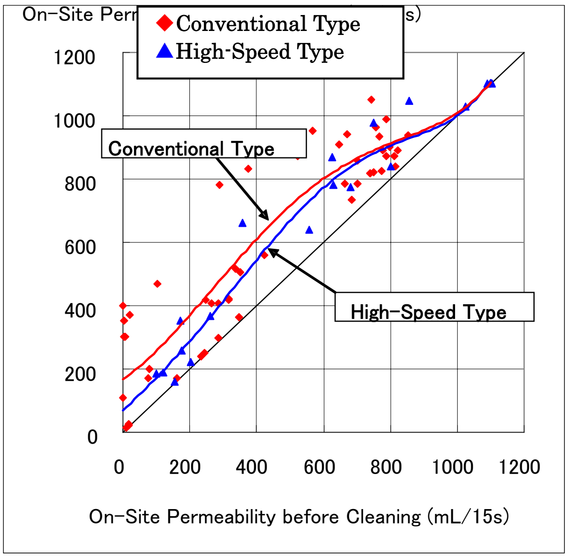

Figure 4: Relationship between on-site permeability and service period

[High-Speed Cleaning Vehicle]

$$f_2(v_b) = 3\times10^{-12} v_b^{\ 5} - 6\times10^{-9} v_b^{\ 4} - 3\times10^{-6} v_b^{\ 3} + 0.0002 v_b^{\ 2} + 0.9891 v_b + 69.852 \qquad (2)$$

[Conventional Cleaning Vehicle]

$$f_2(v_b) = 1\times10^{-12} v_b^{\ 5} - 5\times10^{-10} v_b^{\ 4} - 2\times10^{-6} v_b^{\ 3} + 0.0018 v_b^{\ 2} + 0.7516 v_b + 166.86 \qquad (3)$$

in which

$f_2(v_b)$: Approximation of on-site permeability after the cleaning (mL/15seconds)

v_b : On-site Permeability before the cleaning (mL/15seconds)

5.4 Corrective Coefficient for Aging

Recovery effect by the cleaning vehicles tends to decrease as a service time passes because of reduction in air void content by traffic loads, and dusts sticking to asphalt film around aggregate, which could coarsen the film and hinder a smooth discharge of sand and dirt. Consequently, while larger on-site permeability than Equation (2) and (3) can be expected in an early stage of a service period after the cleaning, smaller one is likely after some or long service period. This tendency is expressed by a corrective coefficient for aging, using Equation (4).

$$a_m = \frac{v_a - v_b}{f_2(v_b) - v_b} \tag{4}$$

in which

a_m: Corrective Coefficient for Aging at a service time of "m" month after paving

v_a : On-site Permeability after cleaning at a service time of “m” month (mL/15seconds)

v_b : On-site Permeability before cleaning at a service time of “m” month (mL/15seconds)

m : Service Period (month)

Figure 5 shows the relationship between a corrective coefficient for aging and the on-site permeability after cleaning, which comes from data on Figure 4. Equation (5) and (6) indicates the approximation in Figure 5 for a high-speed cleaning and for conventional cleaning vehicles respectively.

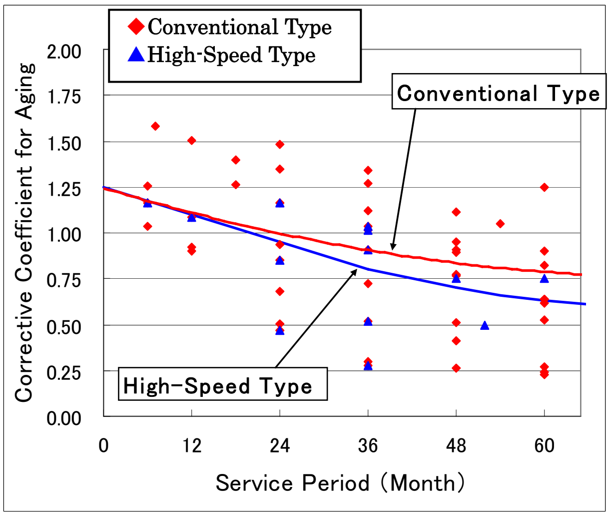

Figure 5: Relationship between a corrective coefficient for aging and the service period

[High-Speed Cleaning Vehicle]

$$a_m = 9 \times 10^{-5} m^2 + 0.0165m + 1.271 \tag{5}$$

[Conventional Cleaning Vehicle]

$$a_m = 1 \times 10^{-4} m^2 + 0.0113m + 1.238 \tag{6}$$

5.5 Procedure of Simulation

Using the result mentioned above, simulation curve of on-site permeability of porous asphalt cleaned regularly can be drawn according to the following process.

1) The blue line in Figure 6, which comes from Equation (1), indicates the relationship between the on-site permeability of porous asphalt with no experience of cleaning, and a

service period. Assuming that cleaning is repeated at the interval of "n" (month) after paving, the first cleaning starts at the point that the on-site permeability is v_{b1}. The expected on-site permeability after the first cleaning is given as v_{a1} from Equation (7) with the recovery effect of a_n ($f_2(v_{b1})$ - v_{b1}) expected from Equation (2) or (3).

2) To simulate the deterioration of the on-site permeability after the cleaning, the part of the blue line, which begins from the point of v_{a1} in y-coordinate with a curve-length of "n" (month) in x-coordinate, is copied and pasted with the starting point of (n, v_{a1}) on the red line of a simulation curve as seen in Figure 6.

3) This procedure can be repeated as the cleaning is carried out over again.

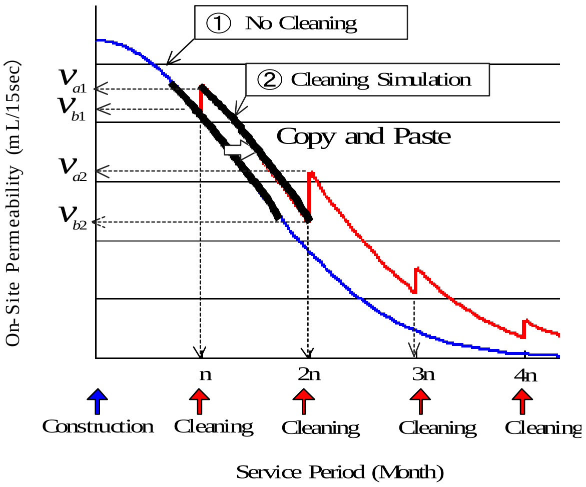

Figure 6: Relationship between a corrective coefficient for aging and the service period

$$\begin{aligned} v_{a1} &= v_{b1} + a_n\left(f_2(v_{b1}) - v_{b1}\right) \\ v_{a2} &= v_{b2} + a_{2n}\left(f_2(v_{b2}) - v_{b2}\right) \\ &\;\;\vdots \\ v_{an} &= v_{bn} + a_{tn}\left(f_2(v_{bn}) - v_{bn}\right) \end{aligned} \tag{7}$$

in which

v_{at}: On-site Permeability after "t" th times cleaning (mL/15seconds)
v_{bt}: On-site Permeability before "t" th times cleaning (mL/15seconds)
a_{tn}: Corrective coefficient for aging, "tn" month after paving
t : Cumulative cleaning times
n : Interval of month for cleaning (month)

With the procedure mentioned above, the simulation curves of the on-site permeability were drawn in Figure 7 for the high-speed cleaning vehicle, and in Figure 8 for the conventional cleaning vehicle, assuming that the interval of the cleaning is every twelve months or every six months or every four months.

From these simulation curves, the following are highly probable.

1) Permeability of porous asphalt can be maintained for a long time when cleaning is carried out at the relatively short interval as a preventive maintenance.
2) The high-speed cleaning vehicle shows almost the same effect of function recovery as conventional cleaning vehicles by shortening the interval of cleaning.

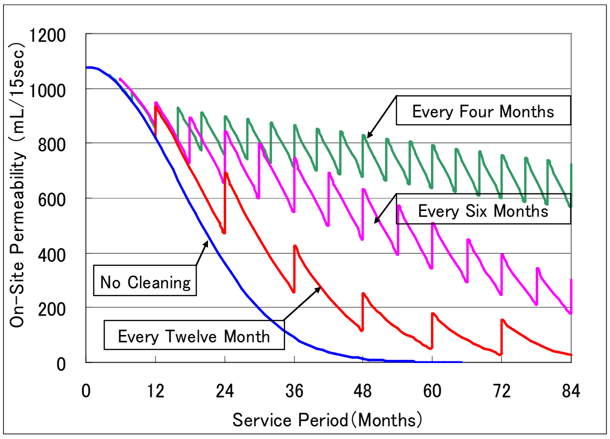

Figure 7: The simulation curve for the high-speed cleaning vehicle

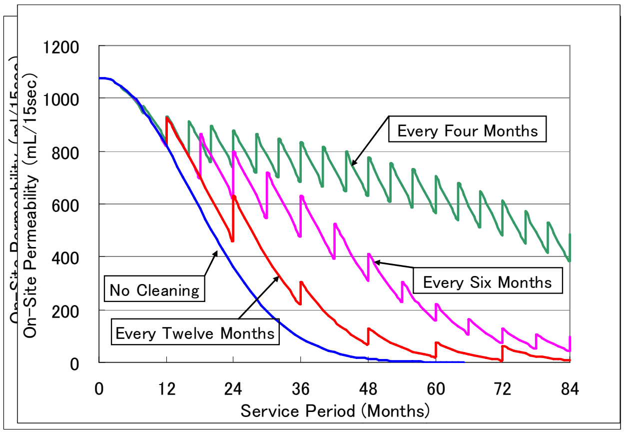

Figure 8: The simulation curve for conventional cleaning vehicles

6 ECONOMICAL EFFICIENCY

To prove that the cleaning by the high-speed cleaning vehicle is economical, we tried calculations of a life cycle cost of porous asphalt using Figure 7 and 8. Although a life cycle cost is divided into some elements, we focused on only a maintenance and repair cost.

Moreover, to simplify the calculations, it was assumed that a maintenance and repair expense only consists of the cost of a cleaning and a mill and overlay.

The following is the specific conditions of the calculations.

1) The starting point of the calculations is a mill and overlay of porous asphalt.
2) Cleaning is carried out by the high-speed cleaning vehicle every twelve months or every six months or every four months.
3) When the on-site permeability deteriorates to 200 mL /15 seconds, the porous asphalt is regarded as losing permeability and repaired with a mill and overlay.
4) The cleaning cost by the high-speed cleaning vehicle is assumed to be 130 yen per square meters, a mill and overlay is 5,000 yen per square meters.

Figure 9 indicates the result of the calculations of the maintenance and repair cost. In cases where the service period is over 60 months, the cleaning of every 4 months shows the lowest cost. From these calculations, it is expected that if cleaning started from the early stage of the service period and continued at short intervals, the cost can be reduced significantly.

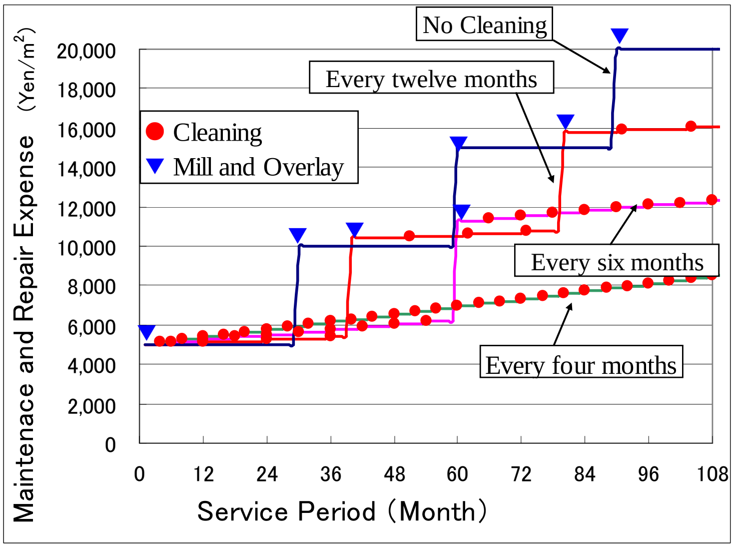

Figure 9: The calculation of the maintenance and repair cost over the service period

7 CONCLUSION

Most cases of the cleaning of porous asphalt have been performed after a terrible reduction in the on-site permeability arose. This is mainly because of inefficiency and a high cost of conventional cleaning vehicles and therefore a lack of thought of a repeated regular cleaning. In fact, in cases where sand and dirt penetrated deep into the layer, the cleaning didn't take effect. As a result, cleaning porous asphalt was considered efforts in vain.

From the above result, we came to a conclusion that if cleaning is repeated regularly at short intervals by the high-speed cleaning vehicle which is equipped with "Tornado Recovery System", the function of porous asphalt would be maintained in a good condition for a long time. The high-speed cleaning vehicle also can increase productivity up to four times what conventional vehicles achieves, cutting a cost down to one fourth that of conventional vehicle due to a high-speed cleaning. The cost calculations also showed that repeated cleaning by the high- speed cleaning vehicle reduces a maintenance and repair cost.

We are continuing to collect more data of on-site permeability from porous asphalt during a service period. It will help us demonstrate consistency between the simulation and actual data. We hope that cleaning of porous asphalt will spread and take root as a preventive maintenance.

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