Permeable Pavement Applied to Streets

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ABSTRACT: At present the pavement rate is over 99% in Nagoya with 54.6km^2 of pavement area which has been constructed mainly by asphalt mixture since 1970s. Pavement has contributed to amenity for users as well as improvement in the roadside environment by smooth vehicular traffic, no splash in the rain and no dust scatter in the dry weather meanwhile, it has been pointed out that the structure to intercept rainwater is likely to bring the depletion of groundwater, the bad influence on plant life and inundation of sewer or river. Then the regional heavy rain up to 600mm rainfall a day caused extensive damage to everywhere in Nagoya in September, 2000. Therefore, trial permeable pavement normally used for traffic roads has been constructed on streets since 2000 by the city of Nagoya. Heavy damage to road surface has not been observed and permeable function of the pavement has been maintained even during a years until now. And, some damage to road surfaces and some failure of permeable function have been observed. This is to report on the trial construction of permeable pavement, the follow-up, and the subject to be This is to report on the trial construction of permeable pavement, the follow-up, and the subject to be solved.

KEYWORDS: Permeable pavement, residential road, durability.

1 INTRODUCTION

1.1 Background

From September 11 through 12, 2000, Tokai heavy rains hit Nagoya and environs with a maximum daily rainfall of 97.0 mm per hour and total rainfall of 566.5 mm. Riverbanks in the city area burst in three places and river water overflowed the banks in 17 places, submerging nearly 37% of the urban area. The extent of flood damage was the second largest after that of the Ise Bay Typhoon in 1959. It is said that a regional heavy rain has been easy to occur due to warming in the city in recent years. The average temperature in Nagoya has risen by 1.8℃ in the last 60 years.（Japan Meteorological Agency HP,2010）

The average amount of the rainfall is 1,490mm/year, and the maximum amount of the rainfall is up for 8.5mm/h for past 60 years. Reduced green coverage ratio in the urban area may also have caused rainwater to concentrate immediately into drainage facilities and rivers and magnified the extent of the flood damage. Many overflows were observed at river confluences during this Tokai heavy rain, so that it was concluded that measures to reduce inflow of rain into the river as much as possible at the upper reaches of such confluences would be required. Therefore, Nagoya city decided to study the adoption of permeable pavements on residential areas.

1.2 Purpose of Test Pavement

To assure satisfactory testability, we selected a section of a residential road in a suburb of Nagoya as the test site and test-paved the section twice, once in 2001 and once in 2002. The test items included permeable pavement material quality, pavement structure, ease of paving work, change in water permeability and pavement bearing resistance caused by rainfall, tire/road noise and pavement temperature. In the first test in 2001, we paved the test section with different pavement structures and materials to continuously check their practicability. In 2002, we varied the thickness and other parameters of the 2001 pavement, so as to determine the practicability of permeable pavement and to measure the pavement temperature.
This paper reports the findings obtained mainly from the 2001 test paving.

2. OUTLINE OF TEST PAVING

2.1 Cross Section of Test Pavement

In the 2001 test paving, the pavement section of the test road was divided into 4 zones as shown in Table 1. Each zone was 4 m wide (half of 8 m-wide road) and 30 m long. The test section had relatively heavy traffic of passenger cars and small trucks in the daytime. Assuming a pavement design traffic level of less than 100 vehicles/day one way and a subgrade design CBR of 4, we determined the target TA (required thickness of full-depth hot mix asphalt) to be 14.0 cm.
Modified Type-II polymer asphalt was used as the porous asphalt concrete (PAC(13)) for the surface course of zones 01-I through 01-III, whereas modified Type-H polymer asphalt was used for zone 01-IV. Porous asphalt stabilized material (PASM(20)), containing modified Type-II polymer asphalt, was used for the base course of zones 01-II through 01-IV.
An equal mixture of recycled base course material (KC40) and recycled cement-concrete aggregate (RA40-0) and recycled crusher-run cement-concrete (RC40) were used as the subbase course materials. The existing base course (Existing C30) was also tested without modification as a potential measure to save permeable paving work cost.
In zone 01-III, where Existing C30 was used, a perforated drainage pipe was buried to discharge rainwater that could not infiltrate into the shoulder. For the filter course, recycled aggregate was used after grading its grain size to 5 mm or less. Asphalt-stabilized layer thickness in zones 01-II to IV was set at 10 cm. The asphalt-stabilized layer thickness in zone 01-I was set at 5 cm to check its practicability for paving more lightly trafficked roads.
Regarding the general pavement to be used for comparison, the surface course was constructed of recycled dense-grained asphalt concrete (RDGAC(13)), whereas the base course was finished by laying recycled bituminous stabilized material (RBSM(20)) over the existing base course.
The water-storage capacities shown in Table 1 were determined by summing up the volumes of air voids capable of holding rainwater in each course and converting the total void volume into an equivalent rainfall depth2). As a result, the amount of water (converted into rainfall depth) held in permeable pavement was estimated to be about 20 to 35 mm, because the overall pavement was thin. (Goto,2003)

Table 1 Examination of permeable pavement（2001）

Type of pavement	01- I	01- Ⅱ	01-Ⅲ	01-Ⅳ	General pavement
Surface Course	PAC(13) (improved- Ⅱ As) t=5cm	PAC(13) (improved- Ⅱ As) t=5cm	PAC(13) (improved- Ⅱ As) t=5cm	PAC(13) (improved-H As) t=5cm	RDG AC(13) (stAs60/80) t=5cm
Base Course	—	PASM (20) (improved- Ⅱ As) t=5cm	PASM (20) (improved- Ⅱ As) t=5cm	PASM (20) (improved- Ⅱ As) t=5cm	RBSM(20) (stAs60/80) t=5cm
Subbase Course	KC40 + RA (40-0) t=20cm	KC40 + RA (40-0) t=15cm	Existing C30 t=20cm	RC40 t=15cm	Existing C30 t=20cm
Filter Course	Recycled aggregate (5-0) t=5cm	Recycled aggregate (5-0) t=5cm	None Draining foraminate tube	Recycled aggregate (5-0) t=5cm	—
Tentative T_A	12.0	14.3	14.0	12.8	14.0
Thickness of pavement (Filter Course is contained)	25cm（30cm）	25cm（30cm）	30cm	25cm（30cm）	30cm
Amount of water held (Rainfall conversion, mm)	21.2	28.8	21.8	34.8	—

2.2 Materials Used

1) Base Course Materials and Filter Material

The physical properties of the base course materials and filter materials used for the permeable pavement test are shown in Table 2. The recycled base course material (KC40) was made by adjusting the grain size of excavated base course material containing construction waste soil, and adding quicklime. KC40 is normally used as the base course material of Nagoya’s city roads, but is unsuitable as a base course material for permeable pavement because it consists of relatively small grains. To improve the permeability of this material, we mixed it with the same amount of recycled aggregate (grain size up to 40 mm). However, the coefficient of permeability of this material at maximum dry density was 4.83x10^{-4} cm/sec, slightly lower than that required for base course material of permeable pavement.

The recycled crusher run (RC40) was made by crushing only waste concrete blocks used for civil engineering structures. Its coefficient of permeability at maximum dry density was 6.70x10^{-3} cm/sec. The existing base course material (C30) had a grain size of PI = 3, slightly smaller than that required for the crusher run; the coefficient of permeability at maximum dry density was 1.45x10^{-4} cm/sec.

As the filter material, recycled aggregate was used after grading its grain size to 5 mm or less. This material had a grain size larger than that of pit sand (washed sand) and screenings, and was excellent in coefficient of permeability. (Goto,2003)

Table 2 Properties of subbase course material used for permeable pavement(2001)

Properties item \ Material name		Recycled B-C (KC40) + RA(40-0)	Recycled crusher-run (RC40)	Existing crusher-run (C30)	Recycled aggregate (5-0)
Weight percentage of fraction passing sieve (%)	53.0mm	100	100	100	
	37.5	98.6	97.1	100	
	31.5	90.0	88.8	96.0	
	26.5	81.2	79.3	88.9	
	19.0	67.5	65.4	77.9	
	13.2	55.1	52.2	67.7	100.0
	4.75	34.8	27.5	37.9	83.9
	2.36	23.9	16.7	25.2	51.1
	1.18	16.9	12.3	17.1	32.7
	0.425	9.1	7.5	11.4	13.8
	0.075	5.7	2.4	7.5	3.6
PI		NP	NP	3.0	N.P
Maximum dry density (g/cm^3)		2.185	1.922	2.236	2.815
Optimum moisture content (%)		7.1	10.2	5.5	15.2
Coefficient of permeability (cm/sec)	maximum dry density	4.83×10^{-4}	6.70×10^{-3}	1.45×10^{-4}	(1.36×10^{-3})※
	Field-sampled specimen	1.15×10^{-3}	8.17×10^{-3}	1.61×10^{-4}	–
modified CBR (%)		221	89.9	76.0	(18.7)※

※: The figure in parentheses represents the coefficient of water-bound specimen.

2) Asphalt Mixture

The physical properties of the open-graded asphalt mixture used for permeable pavement are shown in Table 3. This mixture consisted mainly of modified Type-II open-graded asphalt concrete added with 0.2% vegetable fiber so as to increase asphalt layer thickness. For purposes of comparison, modified Type-H asphalt mixture was also used. This mixture is usually used for drainage pavement. The wheel tracking test showed that the dynamic stability was 2,555 passes/mm. This stability was rated sufficient for the flow resistance of residential roads. The coefficient of permeability of both mixtures was 3x10-1 cm/sec, which was enough as water permeability. In contrast, the Cantabro scattering loss of the mixture consisting of modified Type-II asphalt was two times or more that of the mixture containing high-viscosity asphalt. (Goto,2003)

Table 3 Properties of asphalt mixture used for permeable pavement (2001)

Properties item \ Name of asphalt mixture	Surface course		Base Course
	PAC(13)	PAC(13)	PASM (20)
Kind etc. Of binder	Improved Type- Ⅱ asphalt (Vegetable fiber 0.2%)	Improved Type-H asphalt	Improved Type- Ⅱ asphalt (Vegetable fiber 0.2%)
Kind and top size of coarse aggregate (mm)	Hard Sandstone 13mm	Hard Sandstone 13mm	Hard Sandstone 20mm
Bitumen content (%)	5.0	5.0	4.9
Percentage of air voids （%）	20.8	20.5	20.2
Coefficient of permeability （cm／sec）	3.0×10^{-1}	$4.3\text{x}10^{-1}$	3.2×10^{-1}
Wheel Tracking Test Dynamic stability (pass/mm)	2,560	5,280	3,440
Cantabro Scattering Loss (%)	16.2	7.0	–

3 FOLLOW-UP STUDY RESULTS

3.1 Rainwater Permeation Change with Time (Measurement of Amount of Drainage from Perforated Drainage Pipe)

In zone 01-III, where the existing base course was used without modification, a water-collecting tank was installed at the exit of the perforated drainage pipe to measure the amount of water that could not spread down below the base course. The measurement result is shown in Figure 1. There was no rain for four consecutive days before the measurement date, when there was a total of 9 mm rainfall between 7:00 to 11:00 in the morning. We measured during the rain that followed the above rain, on the same day. The coefficient of permeability of the base course in zone 01-III was as low as 1.6x10-4 cm/sec. The ratio of rainwater discharged from the perforated drainage pipe to the amount of rainwater corresponding to the rainfall depth of nearly 8 mm was 0.005%. However, this ratio was inaccurate because rainwater flowed into the test zone from outside areas.

The time difference between maximum rain intensity and maximum drainage after rainfall was about 30 minutes. This time difference is thought to increase as the number of days between rains increases, since the rainwater storage capacity of the base course will increase accordingly. Since a perforated drainage pipe will begin discharging rainwater before the water infiltrates fully into the base course, installation of the pipe in the lowest possible position, installation of a penetration trench, or other measure will also be effective. (Goto,2003)

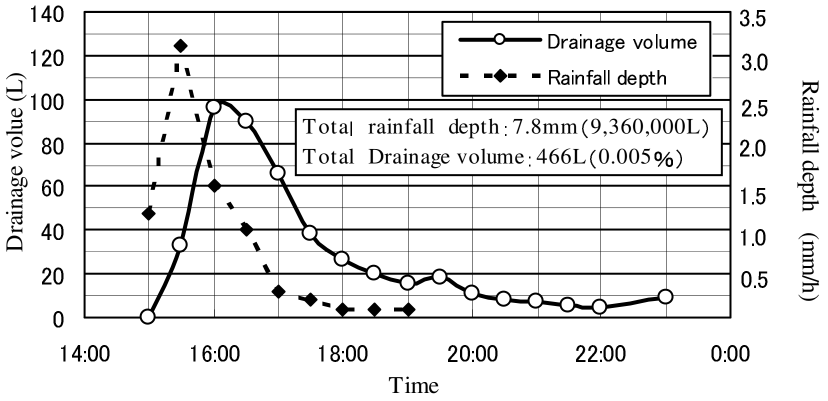

Figure 1 Relation between rainfall depth and amount of drainage from perforated drainage pipe

3.2 Pavement Surface Characteristics Survey Results

The pavement surface characteristics survey results are shown in Figures 2 through 5. Flatness and rut depth remained almost unchanged independently of time, confirming that permeable pavement road surface profile changes are equivalent to those of general pavement. The skid resistance was converging to around 65, though it increased for two years after paving.

The in-site water permeability dropped to about 25% of the value measured immediately after paving. In particular, the permeability dropped conspicuously in the areas adjoining the dense-graded asphalt concrete and in lower base course areas. Figure 6 shows the pavement surface condition (6 years after paving) during a rainfall of 3.5 mm/h. Though the volume of air voids in some parts of the surface course decreased, rainwater permeated the pavement surface as expected in areas whose in-site water permeability was 400 mL/15 sec or more. All surfaces paved in 2002 demonstrated excellent water infiltration performance, as shown in Figure 6.

On the basis of the above survey results, we concluded that infiltration performance deterioration was not attributable to air void fracture by vehicular traffic, but to clogging of the voids by soil, sand, and other matter brought into the test zone together with the fallen leaves of roadside trees or rainwater from outside areas.

Pavement infiltration performance deterioration depends largely on the lineation and location of the road, and its surrounding environment. Although permeable pavement infiltration performance deteriorates gradually with time, increasing permeable pavement area contributes considerably to preservation of the aqueous environment and the control of floods in urban areas.

It is practicable to pave residential roads with a porous asphalt mixture consisting mainly of modified Type-II asphalt, because this material has high resistance to air void fracture and pavement surface deformation. (Umeda,2007)

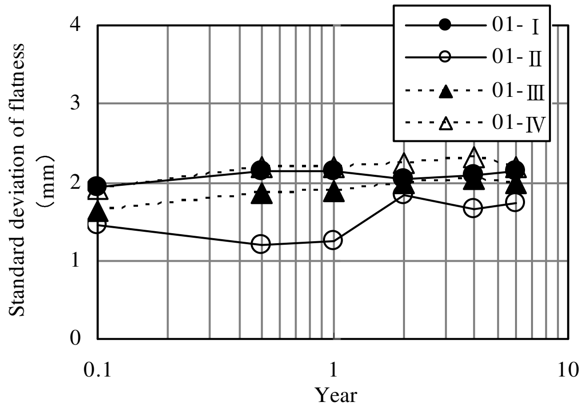

Figure 2 Flatness change with time

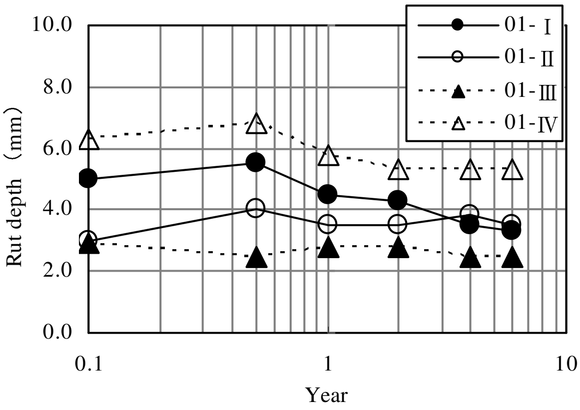

Figure 3 Rut depth change with time

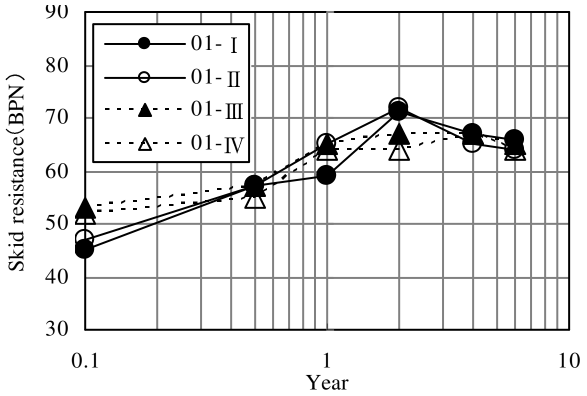

Figure 4 Skid resistance change with time

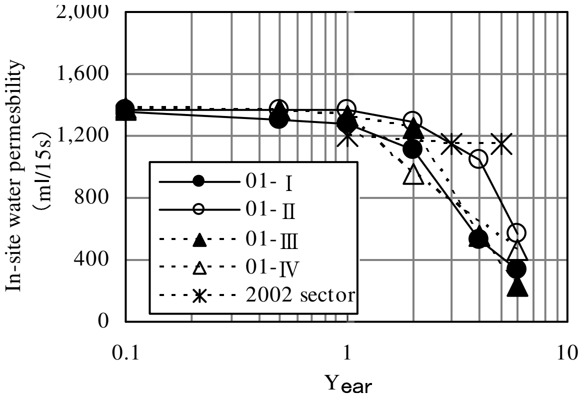

Figure 5 In-site water permeability rate change with time

Figure 6 Road surface in 3.5 mm/h rain six years after pavement in 2001

Figure 7 Road surface in 3.5 mm/h rain five years after pavement in 2002

3.3 Noise Measurement Results

We measured tire/road noise level on the test-paved zones and a nearby dense-grade asphalt-paved road by driving a simplified noise-measuring vehicle at 50 km/h. The measurement results are shown in Figure 8. The tire/road noise levels on the test zones was 2.5 to 3.9 dB and 1.0 to 2.6 dB lower than that on the general (densely graded, asphalt-paved) road at two years and six years after paving, respectively. At five years after pavement, the noise level on the 2002 test-paved road was 3.9 dB lower than that of the general road, demonstrating that the pavement surface characteristics had been maintained in good condition.

Considering that general drainage pavement (13 mm thick) generates tire/road noises of around 88 dB, permeable pavement is very effective for noise reduction, owing to its large volume of air voids.

The measurement data were analyzed to demonstrate the dependence of tire/road noise reduction effect on in-site water permeability in Figure 9. It was confirmed that the test permeable pavement zones reduced the noise level by about 3 dB at an in-site water permeability rate of 1,000 mL/15 sec and about 2 dB at an in-site water permeability rate of 500 mL/15 sec, as shown in the figure. This result verified that paving residential roads with permeable materials is effective in reducing traffic noise caused by small-capacity trucks and other vehicles. (Umeda,2007)

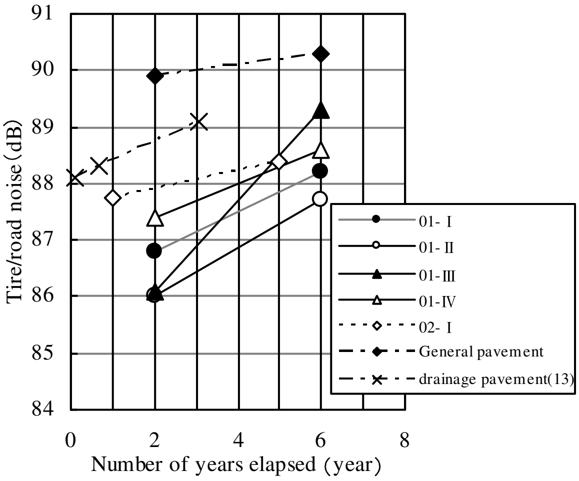

Figure 8 Tire/road noise change with time

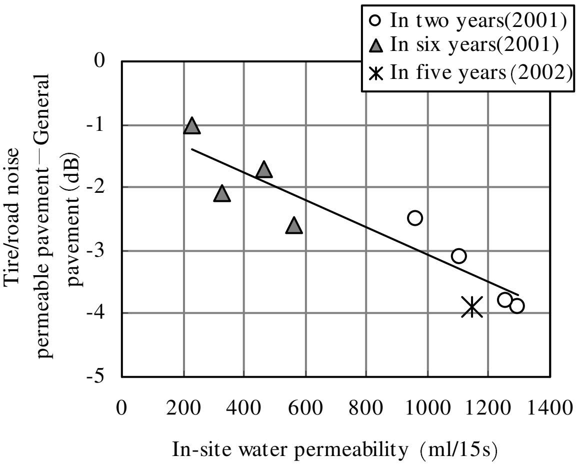

Figure 9 Noise reduction effect versus in-site water permeability

3.4 Results of Deflection Measurement by Falling Weight Deflectometer (FWD)

Figure 10 shows the change in estimated elastic modulus of each layer with time. The load-bearing capacity of the asphalt concrete layer showed a tendency to increase gradually. The base courses of zones 01-I and 01-II, constructed by mixing recycled base course material (KC40) and recycled cement-concrete aggregate (RA40-0) , also maintained a satisfactory load-bearing capacity. The load-bearing capacity of the subgrade also remained unchanged. On the basis of the above results, we confirmed that permeable pavement would retain its initial load-bearing capacity continuously. Regarding the base course of zone 01-IV, constructed of recycled crusher run (RC40), the estimated elastic modulus increased with time, probably because of the hydraulic setting of the recycled concrete aggregate.

The elastic modulus of the zone 01-III subbase course tended to decrease to below that of general pavement using the same subbase course. The estimated elastic modulus of subgrade beneath the base course did not decrease.

It was found that test base courses containing relatively fine grains diminish in strength when they absorb rainwater. This suggests that the use of smaller PI materials is preferable for base courses.

In conclusion, it is essential to investigate the material properties of existing base courses when reusing them without modification for permeable pavement. (Umeda,2007)

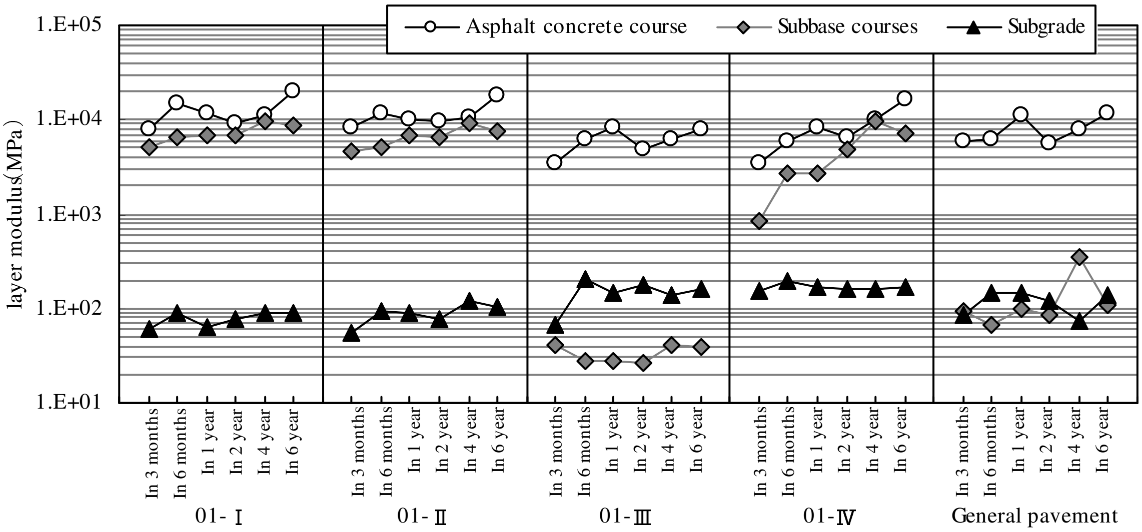

Figure 10 Estimated elastic modulus of each pavement layer

4 CURRENT STATUS OF PERMEABLE PAVEMENT AND PROBLEMS TO BE SOLVED

4.1 Permeable Pavement of Roads in Nagoya

Since 2000, the Nagoya city government has paved with water-permeable materials 24 road courses comprising a total area of about 10,000 m2. These are residential roads of approximate width 4 to 8 m and one-way large-vehicle traffic of less than 20 vehicles per hour. These pavements have remained free of conspicuous damage and infiltrate rainwater as expected. However, partial scattering of broken aggregate was observed near the gates of some privately owned garages alongside the roads. (Umeda,2007)

4.2 Problems associated with permeable pavement and solution

1) Scattering of Broken Aggregate by Parking

Partial scattering of broken aggregate near a privately owned garage was likely caused by a vehicle being steered at rest for orientation before leaving or entering the garage. Though the intensity of the aggregate scattering depends on garage construction and driver skill, the intensity of aggregate scattering increased as the road width decreased.

One possible preventive measure is to pave road shoulders with concrete over a width of about 1 m. This measure will be time consuming and costly. Another effective measure is to reinforce broken pavement sections with permeable resin mortar or other suitable material. (Umeda,2007

2) Pavement Cross-Section and Pavement Cost

The thickness of pavement for residential roads is smaller than that for general roads. In cross-section, permeable pavement for residential roads is designed to have a TA value 1.4 times that of general roads, so as to ensure adequate water infiltration performance and water storage capacity, as well as to compensate for strength deterioration due to water infiltration. Modified Type-II asphalt is used as the asphalt mixture. These measures elevate pavement cost to twice that of general pavement.

Pavement cost-cutting is desired, so as to popularize permeable pavement. Long-range, continuous investigation and study of permeable pavement construction is essential to achieving this purpose.

5. CONCLUSIONS

1) The test pavements maintained the same surface profile as general pavement, even after 6 years had passed.
2) Modified Type-II asphalt did not demonstrate air void fracture or road surface profile change.
3) Immediate deterioration of pavement strength due to water infiltration was not observed, which verified the practicability of permeable pavement for residential roads.
4) Permeable pavement had higher tire/road noise reduction performance than drainage pavement.
5) Course configuration and the surrounding environment affected the water-infiltration performance of permeable pavement so considerably as to cause a 25 to 80% drop from the initial value.
6) When an existing base course with low water-infiltration performance was used, the base course bearing capacity decreased due to infiltration of rainwater, even if a perforated drainage pipe was installed. However, the subgrade bearing capacity did not decrease.
7) Since a perforated drainage pipe increases the amount of drainage, it is desirable to locate the pipe in the lowest possible place, or combine it with a penetration trench.

AFTERWORD

Research on the application of carriageway permeable pavement to residential roads has confirmed that permeable pavement is effective for minimizing rainwater outflow from the roads, and reducing tire/road noise.

Our future tasks are to continue this research in parallel with permeable pavement of residential roads in hilly areas in the city, as environmentally friendly pavement that can preserve the aqueous environment and help control urban flooding.

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