Applicability of Bright-colored Epoxy Asphalt Mixture for Repair of Concrete Pavements in Tunnels

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ABSTRUCT: In Japan, concrete pavements find wide application for use in tunnels for the purpose of ensuring higher durability, better visibility, etc. However, as tunnels become a bottleneck, it is requested to shorten the traffic regulation time during pavement repairs. In addition, because of yearly decreasing road budget, it is desired to lower costs. As a solution to these problems, we present a method of repairing concrete pavements in tunnels by using a bright-colored epoxy asphalt mixture in place of concrete. This bright-colored epoxy asphalt mixture is a solution to the problems with conventional epoxy asphalt mixtures such as [short handling time], [influence of air temperature and many other restrictions on construction] and [time taken for strength development]. Specifically, this mixture provides a handling time of about 3 hours and exhibits a slow hardening reaction in the high-temperature region (120-160℃) related to production and construction, so it can be applied in the same way as conventional asphalt mixtures. Moreover, even right after construction, this mixture maintains the same resistance to rutting and abrasion, keeps on hardening even at normal temperature and shows a performance equivalent to that of the SFRC. In the text, we report on the results of investigating the performance of this epoxy asphalt mixture, adding a lifecycle cost , based on the results of our 10-year follow-up survey at the places where the mixture was applied for repairs of concrete pavements in tunnels.

KEY WORDS: Concrete pavement, repair, epoxy asphalt mixture, long-life pavement

1 INTRODUCTION

In Japan, concrete pavements find wide application for use in tunnels for the purpose of ensuring higher durability, better visibility, etc. In the case of new construction, a sufficient time can be provided for execution of work, while in the pavement repair work in tunnels that form a bottleneck together with bridges it is requested to reduce the frequency of work still more and shorten the traffic regulation time during pavement repairs. In recent years, new construction of roads in the country has decreased. Today is called the “maintenance” age. The road budget has reduced year by year. Therefore, it is desired that the costs related to the paving work be cut down still more.

Considered as one of the effective solutions to these problems is the application of the so-called long-life pavement intended for reducing the lifecycle cost including the road users’ indirect costs, etc. by enhancing the pavement durability, decreasing the repair frequency and simplifying the repair work.

In the light of such a situation, we have considered paving with epoxy asphalt mixture for construction of a long-life pavement and have investigated the applicability of the mixture for repair of concrete pavements in tunnels.

The epoxy asphalt mixture investigated by us is a mixture in which an epoxy asphalt prepared by adding an epoxy resin consisting of base resin and hardener to asphalt is used as the binder. It provides a handling time of about 3 hours and exhibits a slow hardening reaction in the high-temperature region (120-160℃) related to manufacture and application. Therefore, it can be applied in the same way as conventional asphalt mixtures.

This paper presents an outline of the epoxy asphalt mixture, and results of investigating the validity of its application, adding a lifecycle cost "twist," on the basis of the results of the 10-year survey carried out after completion of work in an area repaired by applying the epoxy asphalt mixture as a repair method for concrete pavements in tunnels.

2 REPAIR MEHOD FOR CONCRETE PAVEMENTS IN TUNNELS

In the country, such methods as thin-layer concrete overlay, semi-flexible pavement and asphalt-based pavement, in addition to concrete slab replacement, are applied for repair of concrete pavements in tunnels. Though the application of thin-layer concrete overlay is effective in terms of durability, the application of asphalt-based pavement is the most advantageous in terms of the construction cost and time. Concrete-based materials are excellent in durability, but disadvantageous in that the traffic regulation time is long. Asphalt-based materials are inferior in durability though the working time involving traffic regulation is short. That is, these materials have each good and bad points.

In view of the foregoing, we have developed a mixture with epoxy asphalt which can be manufactured and applied as in the case of asphalt pavements and can be expected to be high in durability and have decided to put into application a repair method using the mixture.

3 EPOXY ASPHALT MIXTURE

3.1 Epoxy Resin

The epoxy resin used in the epoxy asphalt mixture consists of a base resin and a hardener. Different from conventional asphalt mixtures, the epoxy asphalt mixture develops strength due to the chemical reaction between base resin and hardens, so this hardening reaction is quicker, the higher the temperature is, as a rule.

Therefore, for the epoxy resin used in the present case, we have designed its structure, etc, with consideration to workability so that in the high-temperature region in which to manufacture and apply asphalt mixtures the reaction progresses slowly, making it possible to ensure a proper working time and attain the specified strength promptly after application. The characteristics of the epoxy resin are as follows:

- As the reaction speed in the high temperature region of 100℃ or more is made slow, the low molecular weight and low viscosity can be maintained at the time of manufacturing and placing the mixture.
- As the reaction speed in the normal temperature region is made quick, the reaction occurs after mixture placing so that the epoxy resin becomes low molecular weight and high in viscosity.
- Excellent in compatibility with asphalt and bright-colored binder.
- The molecular structure after hardening is a linear (straight-chain) type (rigidity and stress relaxation are promising as compared with such a resin that presents a three-dimensional structure).

3.2 Addition Amount of Epoxy Resin

The addition amount of the epoxy resin was investigated by determining the relation between addition amount and flexural strain on 10 types of straight asphalts 60-80 of different manufacturers or refineries. Based on the results shown in Figure 1, the minimum addition amount with which the flexural strain becomes almost constant irrespective of the type of asphalt used was standardized at “straight asphalt 60-80 : resin = 65 : 35”.

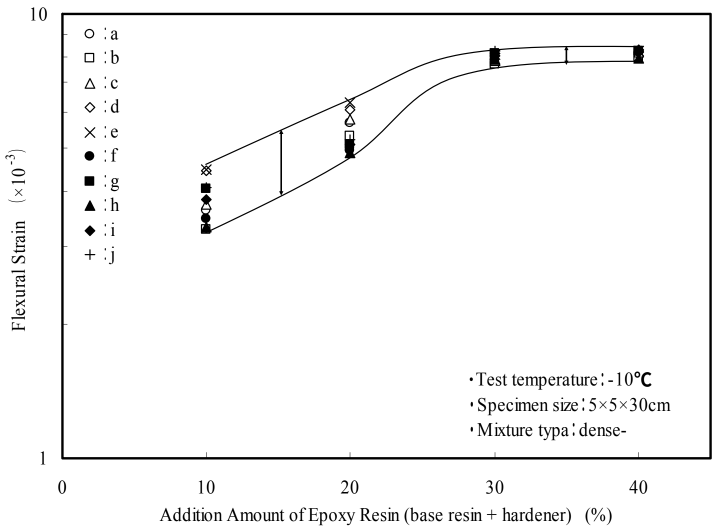

Fig 1: Addition Amount of Epoxy Resin Vs. Flexural Strain

3.3 Mixing Temperature and Handling Time

In order to confirm the mixing temperature and handling time of the mixture with the epoxy resin, the mixture was mixed and kept hot under the conditions shown in Table 1 and marshall test specimens were fabricated and measured for density and marshal stability. The fabricated specimens were all tested after 10-day curing at 60 ℃. Figure 2 shows the “relation between heat-retaining time and degree of compaction” and “relation between heat-retaining time and marshall stability” at the density of 100% with the heat-retaining (mixing) temperature of 180 ℃ and heat-retaining time of 0 hours.

From the test results, the following could be confirmed:

- The degree of compaction and marshall stability are greater in the order of 180 160℃ >140℃ > 120℃.
- The degree of compaction decreases about 1% in one hour after mixture manufacture at every mixing (heat-retaining) temperature, after which the degree of decrease becomes gentle.
- The marshall stability decreases gently till 3 hours after the start of heat retaining at the mixing (heat-retaining) temperatures of 180℃ and 160℃, after which the degree of decrease becomes greater.

From these results, we judged it appropriate that the mixing temperature of the mixture with the epoxy resin be about 160℃ and that the handling time be around 3 hours.

Table 1: Mixing/Heat-retaining Temperature Vs. Heat-retaining Time

Mixing/heat-retaining temperature	120℃, 140℃, 160℃, 180℃
Heat-retaining time	0h, 1h, 2h, 3h, 4h, 5h, 6h

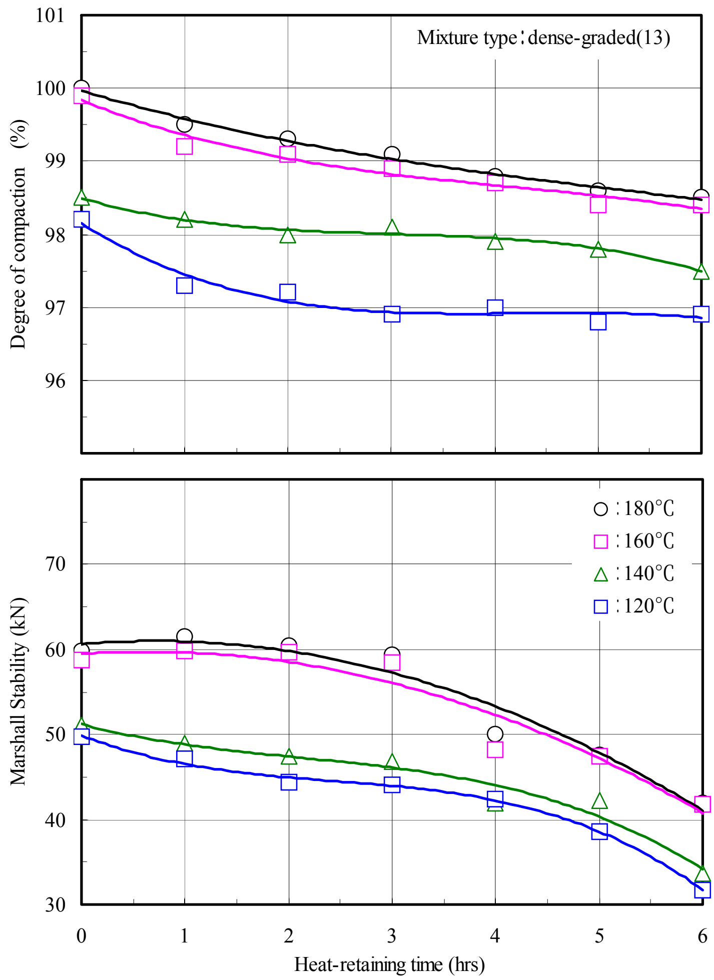

Fig 2: Heat-retaining Time Vs. Degree of Compaction and Marshall Stability

3.4 Strength Development After Opening to Traffic

In order to check for strength development in the mixture with the epoxy resin after opening to traffic, the marshall stability test was performed with the specimen curing temperature and period made to vary under the conditions of Table 2. The results are given in Figure 3.

According to the test results, the final strength (stability: about 70 kN) is virtually attained in 1 week at 50 ℃ and 60 ℃, 2 weeks at 40 ℃ and 4 weeks at 30 ℃. Even at 20 ℃, the stability equivalent to about 70% of the final strength is obtained in 4 weeks, so the final strength is presumably attained in about 6 weeks.

When the epoxy asphalt mixture is applied for repair of concrete pavements in tunnels, it will presumably take a longer time to attain the final strength because the rise in pavement temperature is smaller than that on ordinary roads. However, possible effect on rutting resistance is considered smaller owing to the limited rise in pavement temperature.

Table 2: Curing Temperature and Curing Time

Curing temperature	20℃, 30℃, 40℃, 50℃, 60℃
Curing Period	1week, 2weeks, 3weeks, 4weeks

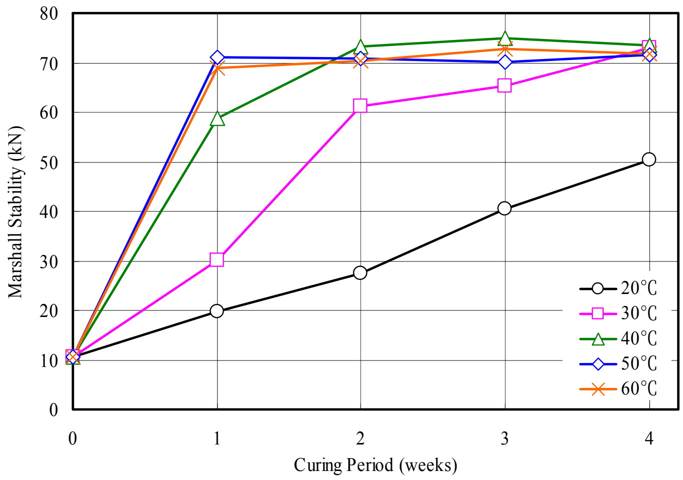

Fig 3: Results of Marshall Stability Test

3.5 Examples of Mixture Properties

Examples of the properties of the mixture with the epoxy resin are given in Table 3. The epoxy asphalt mixture exhibits dynamic stability (standard DS in the table) 10 times or more as great as, and marshall stability 3 times or more as great as, the polymer-modified asphalt type II mixture.

According to the test results on the initial resistance to rutting and wear just after opening to traffic (corresponding to the initial DS and initial wear by raveling test in the table), the epoxy asphalt mixture is equivalent to or greater than the polymer-modified asphalt type II mixture in dynamic stability and wear by raveling test. In addition, the area of wear by rotating raveling test is 4.7 cm^2 as compared with 6.7 cm^2 for steel fiber-reinforced concrete (hereinafter referred to as the SFRC), so it has a high resistance to wear by tire chains.

Table3: Examples of Mixture Properties

Item		Epoxy asphalt mixture	Polymer-Modified asphalt type II	Standard Value*5
Mixture type		Dense-graded(13)		—
Asphalt content	(%)	6.3	5.7	—
Density	(g/cm^3)	2.367	2.397	—
Void ratio	(%)	4.1	3.9	3〜6
Marshall Stability*1	(kN)	47.4	15.6	≧ 7.35
Standard DS*1	passes/mm)	63,000	4,200	≧ 3,000
Initial DS*2	passes/mm)	4,850	—	—
Standard wear by ravering test*1	(cm^2)	0.83	1.14	—
Initial wear by ravering test*3	(cm^2)	0.95	—	—
Wear by rotating ravering test*1,	(cm^2)	4.9	—	Ref.:SFRC 6.7

*1 Test value after 1-week curing at 60℃

*2 Test was done after 1-hour curing in thermostat 60℃ when specimen surface reached 50℃

*3 Specimen was removed from mold form when specimen surface reached room temperature and test was done after

*4 30,000 passes/mm at test temperature of 5℃

*5 Refer to the Guidelines for Pavement Design and Construction (Japan Road Association)

4 EVALUATION OF LONG-TERM SERVICEABILITY

The long-term serviceability of pavements with a bright-colored epoxy asphalt mixture was evaluated on the basis of the results of the 10-year survey carried out after completion of work in an area repaired by applying the epoxy asphalt mixture as a repair method for concrete pavements in tunnels in snowy and cold districts.

4.1 Description

Subjected to the survey was the tunnel about 600 m in length located on the top of a mountainous district in the central part of the country. Repair was made using the epoxy asphalt mixture in 1997, and 10 years have passed since then. In this area, the ratio of chains installed in winter is about 16% and the design traffic volume is from 1,000 to less than 3,000 (units/day/way).

4.1.1 Outline of the work

- Repair time: November 1995
- Repair area: Upbound and downbound lanes 3,900 m^2 each
- Repair method: Mill and overlay (thickness: 5 cm)
- Repair section: See Figure 4.

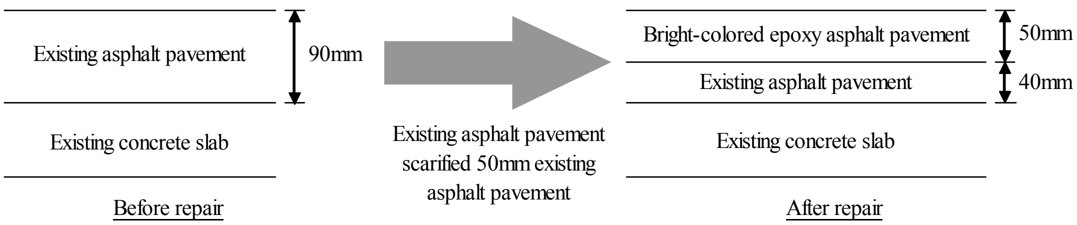

Fig 4: Repair Section

4.1.2 Mixture properties

In this area, a bright-colored epoxy asphalt mixture added with titanium oxide in a mass ratio of 0.5% to the aggregate was used to enhance brightness. The mixture properties are shown in Table 4.

Table 4: Mixture Properties

Item		Bright-colored epoxy asphalt mixture	Standard value
Mixture type		SMA (13)	－
Asphalt content	(%)	5.8	－
Density	(g/cm^3)	2.393	－
Void ratio	(%)	3.2	3～6
Marshall Stability*1	(kN)	41.7	≧7.35
Standard DS*1	passes/mm)	43,000	≧3,000
Initial DS*2	passes/mm)	4,200	－
Standard wear by ravering test*	(cm^2)	0.46	－
Initial wear by ravering test*3	(cm^2)	0.50	－

*1 Test value after 1-week curing at 60℃

*2 Test was done after 1-hour curing in thermostat 60℃ when specimen surface reached

*3 Specimen was removed from mold form when specimen surface reached room temperature

4.2 Follow-up Survey

The follow-up survey was carried out immediately after completion of work, 1 year after, and 10 years (10 years and 10 months) after. The items of survey were as follows:

- Wear: by cross section profilometer.
- Surface roughness: by 3 m profilometer.
- Skid resistance: by portable skid resistance tester.
- Cracking ratio: visually.
- Density: marshall stability: by cut-out core
- Brightness: Measured by illuminance meter just after repair and after lapse of1 year and evaluated through conversion by use of colorimeter after lapse of 10 years.

4.3 Survey Results

The survey results are given in Table 5.According to the data after 10 years of service, the depth of wear is about 10 mm (1 mm/year) and the surface roughness is about 0.4 mm (0.04 mm/year). Cracks that are concerned about because of the use of the epoxy resin are not observed at all. Moreover, there is no change in the density and marshall stability of the cut-out core.

Table 5: Survey results

Item			Just after repair	1 year after	10 years after
Wear		(mm)	–	2.0	9.9
Surface roughness		(mm)	1.46	1.56	1.86
Skid resistance		(BPN)	64	71	64
Percent cracking		(%)	–	0	0
Density		(g/cm^3)	2.384	2.386	2.386
Marshall stability*1		(kN)	8.3	37.7	39.0
Illuminance*2 (lx)	Vicinity of entrance to tunnel		26.0	38.3	–
	Vicinity of middle of tunnel		3.3	5.5	–
Brightness*3	Vicinity of entrance to tunnel		–	–	35
	Vicinity of middle of tunnel		–	–	35

*1 Tested on 100 mmφ core and converted to value at 63.5 mm thickness
*2 Measured from height of 1 m with illuminance meter directed toward surface at angle of 45°
*3 Measured by colorimeter (Concrete structure in tunnel: 50, asphalt pavement in vicinity of entrance to tunnel: 23)

Based on these survey results, the time to repair was estimated with reference to the target value of repair (for ordinary well-traveled roads) for judging the need for maintenance and repair, specified in the Manual of Road Maintenance and Repair (Japan Road Association, 1978). The results are given in Figure 5. Hence, the road under investigation is assumed to have to be repaired 30 years after repair as shown in Figure 5.

4.4 Tentative Calculation of Lifecycle Cost

Based on the survey results, the time to repair is estimated with reference to the target value of road administration (for ordinary well-traveled roads) for judging the need for maintenance and repair, specified in the Manual of Road Maintenance and Repair. In this case, possible wear in the pavement repaired by the present repair method will reach the permissible limit in 30 years after repair, so the pavement will have to be repaired again. The lifecycle cost tentatively calculated based on this prediction is shown below in comparison with that for

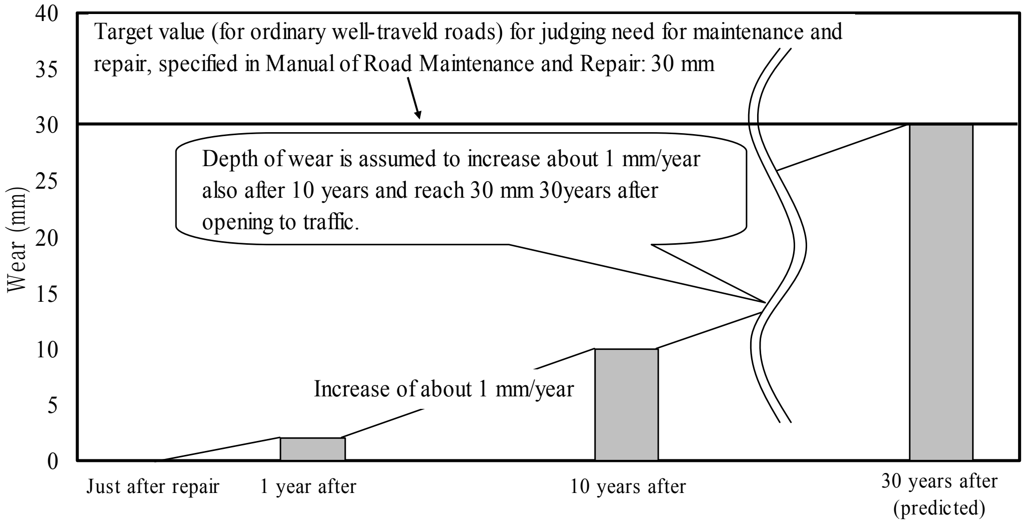

Fig 5: Estimation of Time to Repair from Wear

thin layer overlay with SFRC and for overlay-after-scarification with the polymer-modified asphalt type II mixture. The tentative calculation was done, referring to the method of Mr. Taniguchi et al. 2003.

4.4.1 Test conditions

The test conditions are shown in Table 6. On the concrete pavements in the tunnels in the neighborhood of the said tunnel, motor vehicles are regulated to run with tire chains removed, so the numbers of service years under the same running conditions are unaccounted for. Therefore, we contemplated making the tentative calculation, assuming a lifetime of 30 years for the bright-colored epoxy asphalt mixture and 25 years for the SFRC on the basis of the results of the rotating raveling test (epoxy asphalt mixture: 4.9 cm^2, SFRC: 6.7 cm^2) shown in Table 3. In this study, however, the tentative calculation was made, assuming the lifetime of 30 years for both of them.

Table 6: Test Conditions

Item	Test Conditions		
Repair Method	Overlay with bright-colored epoxy asphalt	Thin layer overlay with SFRC	Mill and Overlay with modified asphalt
Classification by traffic volume	From 1,000 to less than 3,000 units/day/way		
Paving length	600m		
Paving width	6.5m (3.25m * 2 lanes)		
Bypass	Not provided (alternate one-way traffic)		
Number of service years	30 years		5 years*1
Direct construction cost	¥10,000/m^2	¥ 13,000 /m^2	¥ 2,000 /m^2
Number of days subject to traffic regulation	5 days	7 days	5 days
Traffic regulation time	9 hours (8:00-17:00)	All day (24hours)	9 hours (8:00-17:00)
Analysis period	40 years		

*1 Same repair repeated every 5 years

4.4.2 Performance curve

The repair pattern images (performance curves) used for the tentative calculation(Taniguchi et al. 2003) are shown in Figures 6 and 7. Further, the repeir pattern images is based on the number of service years shown in Table 6.

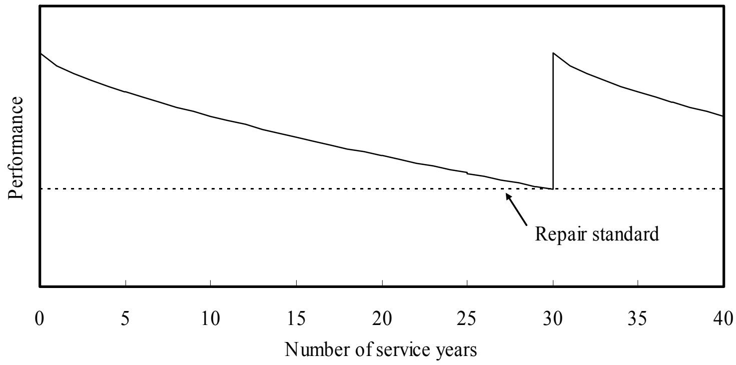

Fig 6: Performance Curve (bright-colored epoxy asphalt mixture, SFRC)

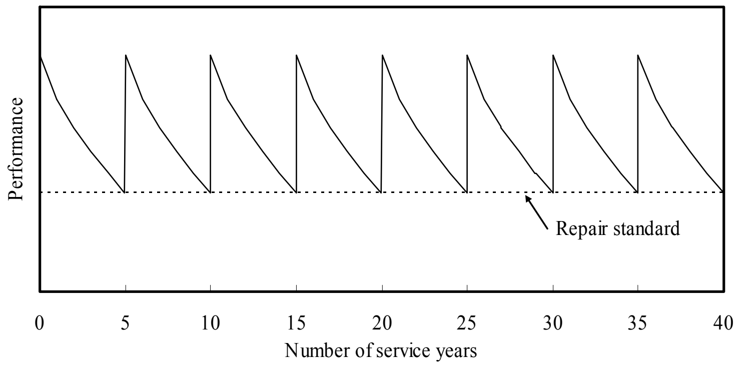

Fig 7: Performance Curve (polymer-modified asphalt type II mixture)

4.4.3 Test results

The test results obtained in the analysis period of 40 years are given in Table 7. With the bright-colored epoxy asphalt mixture, the road administrator costs for maintenance and repair may decrease about 17% as compared with the SFRC, but increases about 51% as compared with the polymer-modified asphalt type II mixture. On the other hand, with the bright-colored epoxy asphalt mixture the road user costs, which comprise the cost of time-loss by work regulation and vehicle running cost may decrease about 17% as compared with the SFRC and about 27% as compared with the polymer-modified asphalt type II mixture.

As a result, the total cost calculated by subtracting the residual value from the total of the road administrator costs and road user costs is about 80% of that for thin-layer overlay with the SFRC and about 73% of that for overlay-after-scarification with the polymer-modified asphalt type II mixture.

Therefore, the application of the bright-colored epoxy asphalt mixture for repair of concrete pavements in tunnels is considered effective in shortening work periods and cutting down costs.

5 CONCLUSIONS

[Characteristics of the developed epoxy asphalt mixture]

(1) The epoxy asphalt mixture can be manufactured and applied in the same way as conventional asphalt mixtures.

(2) Even just after application, this material has the same level of resistance to rutting and wear as the polymer-modified asphalt type II mixture, so the pavement can be opened to

Table 7: Tentative Calculation Results

Item	Cost (million yen)		
Repair method	Bright-colored epoxy asphalt	SFRC	Polymer-modified asphalt type Ⅱ mixture
Road administrator costs	210.8	254.0	138.9
Maintenance cost	23.6	23.6	23.7
Repair cost	187.2	230.4	115.2
Road user costs	427.5	514.7	594.6
Cost of time loss by work reguration	46.5	130.7	186.1
Vehicle running cost	381.0	384.0	408.5
Vehicle running cost for passing through work reguration	1.7	4.7	6.8
Vehicle running cost due to degradation in surface properties	379.3	379.3	401.7
Residual value	59.3	73.0	0.0
Total cost	579.0	695.7	733.5

traffic, as is the case with conventional asphalt mixtures.
(3) After opening to traffic, the reaction of this mixture still continues to progress in the normal temperature region until the final strength is attained.

[Bright-colored epoxy asphalt mixture applied for repair of concrete pavements in tunnels]
(1) According to the results of the follow-up survey carried out 10 winters after repair under conditions of 1,000 to less than 3,000 (units/day/way) in design traffic volume and 16% in ratio of tire chains installed, the depth of wear (maximum rut) is 9.9 mm, the surface roughness 1.86 mm and the cracking ratio 0.0%, which proves a good serviceability.
(2) The brightness after the lapse of 10 years is 35, which is inferior as compared with the brightness of the nearby concrete structures, but higher by 12 than the brightness of 23 for asphalt pavements.
(3) According to the comparison of the lifecycle cost in the analysis period of 40 years, the total cost with the bright-colored epoxy asphalt mixture is about 80% of that with the overlay-after-scarification with the SFRC and about 73% of that with the polymer-modified asphalt type II mixture. Therefore, cost reduction is promising.

6 CLOSING REMARKS

The present epoxy asphalt mixture has been applied for repair of plural tunnels, in addition to the tunnel presented herein, and all of them show a good serviceability. It is hoped that this report will be beneficial to shortening work periods and reducing costs for repair of pavements in tunnels.

By the way, it goes without saying that the present bright-colored epoxy asphalt mixture can also be applied for repair of asphalt pavements in tunnels.

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