The State of Pavement Technologies in Japan

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Summary *Japan has constructed more than five hundred thousand kilometers length of pavements for these twenty years. The design and construction of them mainly followed the "Manual for Design and Construction of Asphalt Pavement" published by the Japan Road Association. Based on the English version of the manual, this paper desctribes the principle of asphalt pavement design method in accordance with a brief summary of the "Low Cost Road Pavement Manual" and "Portland Cement Concrete Pavement Manual".*

Pavement technologies in Japan have remarkably developed for these several years, but there are some problems still unsolved. The following topics are introduced here.

(1) High speed measurement of pavement condition
(2) Semi-blown asphalt resistant to plastic flow
(3) Wearing problem
(4) Field recycling of asphalt pavement

Introduction

Japan has a public road network approximately 1.1 million kilometers in total length, out of which 0.57 million kilometers are paved. Practice of pavement design and construction of public roads generally follows the publications from the Japan Road Association.
They are :

(1) "Manual for Design and Construction of Asphalt Pavement."[1]
(2) "Low Cost Road Pavement Manual" dealing with asphalt pavement for local roads with light traffic.[2]
(3) "Portland Cement Concrete Pavement Manual."[3]

In Japan, asphaltic pavements account for as much as 90% of the total length of pavements (Table 1) due to their advantage including low initial cost, suitability for paving roads in operation and low cost repair.

The number of vehicles exceeded 37 millions in 1983 and is increasing. The principal characteristics of road traffic are the high percentage of cargo trips and the high percentage (as high as 30%) of large size vehicles, including a considerable volume of vehicle having an axial load of 20 tons or more. Consequently, pavement failures have remarkably increased these several years and an urgent countermeasure is required.

This paper describes the principles of pavement design according to the manuals mentioned above and recently developed technologies on pavement maintenance and rehabilitaion.

Table 1 Public Roadways in Japan, as of April 1.1982 **(km)**

	Road Length	Paved Roads				
		Total	Portland Cement Concrete Pavement	Asphaltic Pavement		
				Total	High Quality Pavement	Low Cost Pavement
National Expressways	3,011	3,011	127	2,884	2,884	0
Ordinary National Highways	46,275	44,064	2,224	41,840	35,380	6,460
Prefectural Roads	126,229	105,383	2,104	103,279	47,013	56,266
Municipal (City, Town and Village) Roads	947,515	416,547	32,019	384,528	70,544	313,984
Total	1,123,030	569,005	36,474	532,531	155,821	376,710

1. High Quality Asphalt Pavement

(1) Design Principles

The Japanese method of asphalt pavement design is largely based on domestically developed technology, incorporated with principles of the AASHO Road Test and the CBR Design Cureve methods. It was established in 1967 and has been accepted as reasonable up to the present.

The required thickness for the asphalt pavement is derived from the following equations :

$$H = \frac{28.0 \cdot N^{0.1}}{CBR^{0.6}} \cdots\cdots (1)$$

$$T_A = \frac{3.84 \cdot N^{0.16}}{CBR^{0.3}} \cdots\cdots (2)$$

where H : The pavement thickness (cm)

T_A : The design thickness (i. e. the required thickness of a full depth hot mix asphalt pavement having an equivalent strength) (cm)

N : The number of equivalent 5 ton wheel-loads in one direction to be expected during the 10 year period following construction

These equations are described only in the appendix of the "Manual for Design and Construction of Asphalt Pavement", because they are not so easy to use for designers. The design method of the manual is introduced in the following paragraphs.

(2) Classification of Roads by Traffic

The one-way daily traffic volume of heavy vehicles, which is an average value during design period, is first estimated to choose the traffic classification from Table 2. "Heavy vehicles" refers to cargo trucks, buses and special vehicles such as truck cranes. The average relationship between traffic classiffication and N is also shown in Table 2, which is derived experimentally from traffic weight surveys.

Table 2 Traffic Classification[1)]

Traffic Classification	One Way Daily Traffic of Heavy Vehicles	Number of Eqiovalent 5-ton Wheel-loads $N(\times 10^4)$
L	Less than 100	3
A	100 to 250	15
B	250 to 1,000	100
C	1,000 to 3,000	700
D	More than 3,000	3,500

(3) Determination of the Design CBR

The design CBR is determined based on CBR values of individual locations within the road section to be constructed with a uniform thickness by the following formula :

$$\text{Design CBR} = \left[\begin{array}{l}\text{Average value of CBR} \\ \text{of individual locations}\end{array}\right] - \frac{(\text{Max. CBR}) - (\text{Min. CBR})}{C}$$

where C is a coefficient given in Table 3.

Table 3 Values of C for Calculating Design CBR[1)]

No. of Values Available (n)	2	3	4	5	6	7	8	9	10 or more
C	1.41	1.91	2.24	2.48	2.67	2.83	2.96	3.08	3.18

(4) Design of Pavement Thickness

Pavement thickness is designed based on the design CBR and traffic classification given in Table 2 so that each individual course does not fall below the target value of T_A shown in Table 4, and that the total pavement thickness does not become smaller than the target total thickness in Table 4 by 1/5 or more. These values of Table 4 are the calculated ones using equations (1), (2), and values of N in Table 2.

Table 4 Target Values for Ta and for the Total Pavement Thickness H, cm.[1)]

Design CBR	Traffic Classification									
	L		A		B		C		D	
	T_A	H	T_A	H	T_A	H	T_A	H	T_A	H
2	17	52	21	61	29	74	39	90	51	105
3	15	41	19	48	26	58	35	70	45	83
4	14	35	18	41	24	49	32	59	41	70
5	12	27	16	32	21	38	28	47	37	55
6	11	23	14	27	19	32	26	39	34	46
12	–	–	13	21	17	26	23	31	30	36
20 or more	–	–	–	–	–	–	20	23	26	27

(5) Determination of Pavement Structure

In determining the pavement structure, a tentative design is first made and T_A is calculated applying the formula

$$T_A = a_1 T_1 + a_2 T_2 + \cdots\cdots + a_n T_n$$

where $a_1, a_2, \cdots\cdots, a_n$: Coefficient of relative strength given in Table 5

$T_1, T_2, \cdots\cdots, T_n$: Thickness of individual layers of pavement, cm

Coefficients of relative strength in Table 5 indicate in cm the thickness of hot aspahlt mix used in constructing binder and surface course, having a strength equivalent to 1cm layer of pavement of other materials and methods of construction.

2. Low Cost Asphalt Pavement

The "Low Cost Asphalt Pavement Manual" was first issued in 1964. In those days only 4% of road length was paved and a pavement manual for local roads with light traffic was desired eagerly.

The roads to be designed by the manual have less than 60 heavy vehicles per day. Pavements consist of

Table 5 Coefficients of Relative Strength for Calculating TA[1)]

Pavement Course	Method and Material of Construction Used	Conditions	Coefficient
Binder and Surface Course	Hot Asphalt Mix for Binder and Surface Course		1.00
Base	Bituminous Stabilization	· Hot-mixed, Marshall Stability : 350 kg or more	0.80
		· Cold-mixed, Marshall Stability : 250 kg or more	0.55
	Cement Stabilization	· Unconfined Compressive Strength (7 days) : 30 kg/m^2	0.55
	Lime Stabilization	· Unconfined Compressive Strength (10 days) : 10 kg/m^2	0.45
	Mechanically Stabilized Gravel and Slag	· Modified CBR : 80 or more	0.35
	Hydraulic Mechanically Stabilized Slag	· Modified CBR : 80 or more	0.55
	Penetration Macadam	· Unconfined Compressive Strength (14 days) : 12 kg/m^2	0.55
Subbase	Crusher-run, Slag,	· Modified CBR : 30 or more	0.25
	Sand, etc.	· Modified CBR : 20 or more, less than 30	0.20
	Cement Stabiliztion	· Unconfined Compressive Strength (7 days) : 10kg/m^2	0.25
	Lime Stabilization	· Unconfiend Compressive Strength (10 days) : 7kg/m^2	0.25

Note : Layer coefficient for any construction method or material other than those listed in table 5 should only be adopted when based on established engineering experience.

base course and surface course with 3~4cm thickness. Design life of the pavement is estimated as 4~5 years.

For the design of pavement, CBR test is first required. Then design CBR is determined by the same formula mentioned before. Total thickness of surface, base and subbase course is given in Table 6 according to design CBR, and standard thickness of base course in Table 7.

Materials and methods used in constructing surface course include hot asphalt mix, cold asphalt mix and penetration macadam. A standard cross section of penetration macadam using asphalt emulsion as binder is shown in Fig. 1.

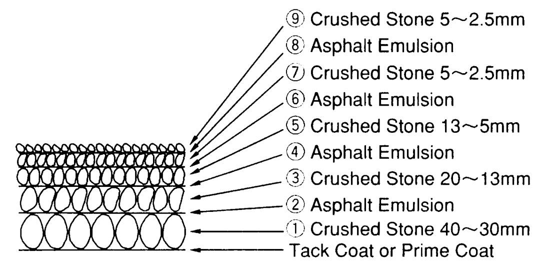

Fig. 1 Standard Cross Section of Penetration Macadam (Surface Thickness 4cm) [2)]

Table 6 Design CBR and Standard Thickness of Pavement[2)]

Design CBR	1.6~2.0	2.1~3.0	3.1~5.0	5.1~7.0	7.1~10.0	10.1~20.0	20.1~60.0	60.1 or more
Pavement Thickness (cm)	50	40	30	25	20	15	10	leveling

Table 7 Standard Thickness of Base Course[2)]

Method and Material of Construction Used	Thickness (cm)
Mechanically Stabilized Gravel, Crusher-run	7~12
Cold-mixed Bituminus Stabilization	7~12
Hot-mixed Bituminus Stabilization	5~6
Cement Stabilization	12~15
Lime Stabilization	10~15

3. Portland Cement Concrete Pavement

The design principle of portland cement concrete in Japan is based on Westergaard's edge formula and thermal stress analysis experimentally derived by the Public Works Research Insitute, Ministry of Construction.

Though this method of pavement had been mostwidely used until 1960s, asphaltic pavement increased year by year and only 5~10% of newly constructed road has been paved by portland cement concrete since 1970s.

One of the main reasons for this trend was that thickness of portland cement concrete slab was limited to 25cm (for A, B, C traffic) or 30cm (for D).

In 1984, the manual was revised and we have been able to choose thickness of slab from Table 8 according to traffic classification.

Table 8 Thickness of Cement Concrete Slab[1)]

Traffic Classification	Thickness of Cement Concrete Slab (cm)
L	15
A	20
B	25
C	28
D	30

4. Maintenance and Rehabilitation

The percentage of paved length to total road length is about 50% as stated before. Fig. 2 shows prefectural distribution of pavement. Though many prefectures need more pavements, most of all prefectures have to make considerable efforts to maintain and repair the pavements in service. If the overlay is needed every 5 years for high quality asphalt pavement (after 10 years initial life) and 3 years for low cost asphalt pavement (after 5 years initial life), required length of overlay per year will be estimated as shown in Fig. 3.

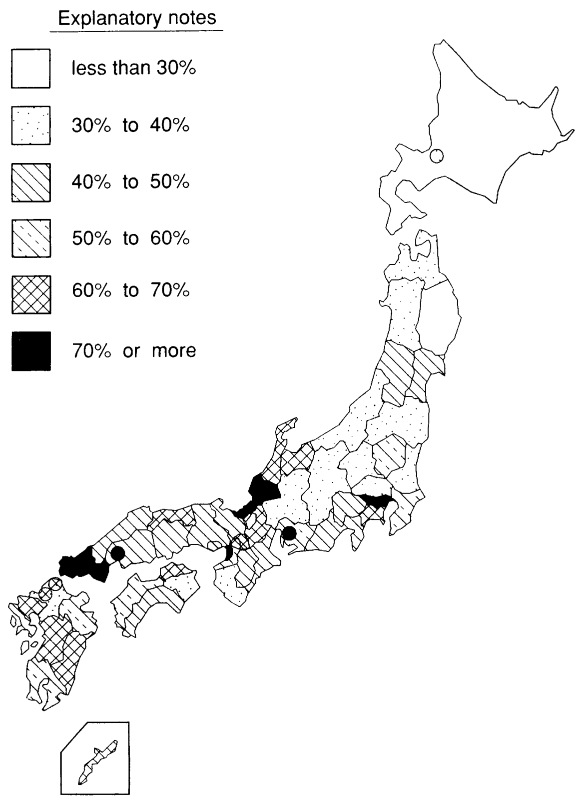

Fig. 2 Ratio of Paved Roads (April 1,1982)

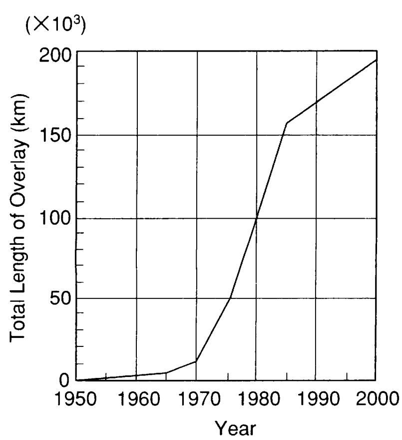

Fig. 3 Estimated Total Length of Overlay

Recent pavement technologies in Japan have been focused on the pavement evaluation and rehabilitation.

They are :

(1) High speed evaluation of pavement performance
(2) Rutting caused by plastic flow of asphalt mixtures
(3) Wearing resistance in relation to spike tires
(4) Fiels recycling of asphalt mixtures

These technologies will be discussed in the following chapters.

5. Survey of Pavement Performance

Pavement rehabilitation generally follows the "Manual for Maintenance and Rehabilitation of Asphalt Pavement"[4] issued by the Japan Road Association. In it methods of repairing pavement are classified as in Table 9 in accordance with PSI values calculated by the follwing formula :

$$PSI=4.53-0.518\log\overline{SV}-0.371\sqrt{C}-0.174D^2$$

where PSI : Present serviciceability index
SV : Slop variance
C : Percentage of cracked area
D : Rut depth in cm

So far lot of time and engineers have been needed for the measurement of roughness, cracking and rutting. But recently some measuring devices with high speed (more than 30 km/hour) have been developed and use widely. Gas lasers, highway sensitive acceleration meters and microprocessors are utlized and combined with computers in the devices.

Table 9 PSI and Methods[4]

PSI	Methods
3~2.1	Surface Treatment
2~1.1	Overlay
1~0	Replacing

6. Resistanace to Plastic Flow

Japan has wide climatic variations ranging from sub-tropical to sub-arctic.

The most typical failure of pavement in relatively hot areas in rutting caused by plastic flow of asphalt mixtures. Investigations have been conducted in order to find a mixture resistant to plastic flow and two types of mixtures shown in Table 10 are recommended now.

In designing such mixtures, it has been found that attentuin should be paid to the dollowing points :

(1) The aggregate grading should be taken at the medium value of Table 10, with a small proportion of fines passing a 0.074mm sieve.
(2) The Marshall stability with 75 blows should be greater than 750kg and the ratio of Marshall stability to flow value should be large than 25.

(3) Dynamic stability of a mixture determined by wheel tracking test should be greater than 1500 trips/mm under a 6.4 kg/cm^2 load, where rutting is likely to occur due to plastic flow.

The use of newly developed semi-blown asphalt has been successful for reducing plastic flow. It is produced by blowing air into a straight asphalt to improve its temperature susceptibility, and to increase its viscosity at 60℃. This is a pavement surface temperature occuring successively for 6 to 10 days in a row during summer in Japan. The viscosity of semi-blown asphalt at the temperature is 3 to 15 times as high as that of usual pavement asphalt. The specifications adopted by the Japan Road Association for semi-blown asphalt are as shown in Table 11.

Table 10 Types of Asphalt Concrete[1)]

		Dense Grade Aspahlt Concrete		Dense-and-gap Graded Asphalt Concrete
Compacted Thickness od a Lifted Layer		3~5		3~4
Max Particle Size (mm)		20	13	13
Weight Percent Passing Sieve	25 mm	100		
	20	95~100	100	100
	13	75~90	95~100	95~100
	5	45~65	55~70	35~55
	2.5	35~50		30~45
	0.6	18~30		20~40
	0.3	10~21		15~30
	0.15	6~16		5~15
	0.774	4~8		4~10
Asphalt Content (%)		5~7		4.5~6.5
Penetration Grade of Asphalt		40~60 60~80 80~100		

7. Wear Resistance

The snowy road length accounts for 38% of the total length in Japan. As most of those roads are opened to traffic even in winter removing the snow, wear resistance of surface materials is extremely important. Table 12 shows recommended mixtures for snowy regions. The wear resistant property of asphalt mixtures is generally determined by the following factors :

(1) Asphalt content. The larger the asphalt content, the greater the wear resistance.
(2) Aggregate The harder the aggregate and the smaller the abrasion loss, the greater the wear resistance.
(3) Asphalt type. An asphalt which does not tend to become brittle under low temperature and which maintains strong grip on the aggregate is desirable.

But an excessive attention to the wear resistance may cause plastic flow, because it becomes very hot in summer even in snowy regions. In spite of these long term efforts of developing wear resistant materials, pavement wearing has not been clearly reduced.

Therefore, the Government has been considering some ways to regulate the use of spiked tires.

8. Fiels Recycling

This chapter describes the field recycling of asphalt pavement. There are two kinds of recycling method used in Japan. One is central plant recycling and the other is field recycling. The purpose of these methods is to re-use pavement materials which have become short and expensisve year by year.

Japn has more than twenty sets of field recycling machine. One of the typical sets is illustrated in Fig. 4. Pavement materials are heated first, sculified, covered by fresh mixtures and compacted. About 0.65 million square meters of roads were reconstructed by this method in 1982 and more than 50 papers were published concerning the method.[5)]

Table 11 Requirements for Semi-blown Asphalt[1)]

The semi-blown asphalt shall be homogeneous and free of water, shall not foam when heated to 180°C, and shall satisfy all the following requirements.

	Grade : AC 140
Viscosity at 60°C, poise.	14,000±4,000
Kinematic viscosity at 180°C, max. cSt	200
Mass change by thin-film oven test, max., %	0.6
Penetration at 25°C, 100g, 5 sec., min.	40
Solubility in trichloroethane, min., %	99.0
Flash point, COC, min., °C	260
Specifc gravity at 25°C, min.	1,000
$\text{Ratio} \doteqdot \dfrac{\text{Viscosity at 60°C after thin film oven test}}{\text{Viscosity at 60°C before thin film oven test}}$, max.	6

Table 12 Types of Asphalt Concrete[1]

		Dense Grade Aspahlt Concrete		Fine-and-gap Graded Asphalt Concrete	Fine Graded Asphalt Concrete	Dense-and-gap Graded Asphalt Concrete
Compacted Thickness of a Lifted Layer		3~5		3~5	3~4	3~4
Max Particle Size (mm)		20	13	13	13	13
Weight Percent Passing Sieve	25 mm	100				
	20	95~100	100	100	100	100
	13	75~90	95~100	95~100	95~100	95~100
	5	52~72		60~80	75~90	45~65
	2.5	40~60		45~65	65~80	30~45
	0.6	25~45		40~60	40~65	25~40
	0.3	16~33		20~45	20~45	20~40
	0.15	8~21		10~25	15~30	10~25
	0.774	6~11		8~13	8~15	8~12
Asphalt Content (%)		6~8		6~8	7.5~9.5	5.5~7.5
Penetration Grade of Asphalt		40~60 60~80 80~100				

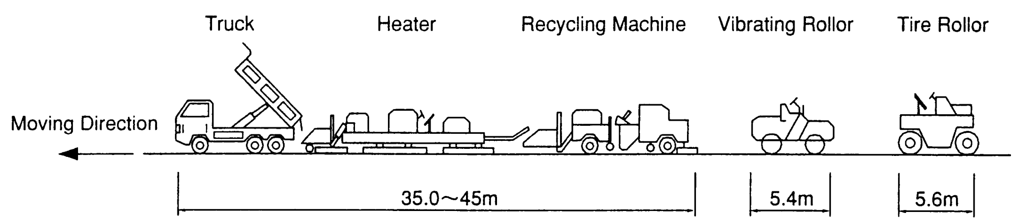

Fig. 4 Field Recycling Machine[5]

9. Postscript

Japan had only 40,000km of paved roads twenty years ago, and now it has 570,000km. This means that more than 500,000km length of pvements have been constructed during these twenty years and their rehabilitation has become an urgent problem. But budget for road has been decreasing year by year. Therefore, pavement engineers are forced to improve cost-effectiveness of investment. This will be one of the most important studies for coming several years in Japan.

References

1) Japan Road Association : "Manual for Design and Construction of Asphalt Pavements", 1978 (in Japanese), 1980 (in English)

2) Japan Road Association : " Low cost Road Pavement Manual", 1978 (in Japanese)

3) Japan Road Association : "Portland Cement Concrete Pavement Manual", 1984 (in Japanese)

4) Japan Road Association : " Manuals for Maintenance and Rehabilitation of Pavement", 1978 (in Japanese)

5) Express Highway Research Foundation of Japan : "A Report on the Surface Recycling", 1984 (in Japanese)