EVALUATION OF RUTTING RESISTANCE OF ASPHALT PAVEMENTS BY CIRCULAR ROAD TRACKING TEST

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ABSTRACT

Due to the frequent premature rutting failure in asphalt pavements in Jiangsu, a province in the east of China, a research programme using the circular road-tracking test was initiated. Different asphalt pavement structures were designed and tested to determine the critical factors in the occurrence of rutting, including different aggregate gradations, binder types and combinations of layers. Results show that the middle layer of the pavement plays an important role in rutting development, and an adequate aggregate gradation of the surface layer mix is essential to achieve the desirable rutting resistance. Moreover, asphalt with high viscosity helps to reduce rutting. The environmental influence on the occurrence of rutting is also discussed in the paper, and a pavement type with high rutting resistance, which is appropriate for Jiangsu's climate, is recommended.

1. BACKGROUND

As one of the main economic centres in China, Jiangsu Province takes the lead in freeway construction. Since the construction of the first freeway, the Jiangsu section of the Huning Freeway, freeway construction has undergone an upsurge in the Province. Since then the Nanjing Airport Freeway, Ning-yan, Lian-xu, Jing-fu, Xu-su, Ning-hang and Su-jia-hang freeways have been built or are currently under construction (Jiangsu Freeway Construction Headquarters, 2003). After opening to traffic, however, many pavement sections have experienced premature rutting to different extents, primarily due to the rapidly increasing traffic, overloaded trucks and possibly the rainy weather during the summer season in this region (Zhang Zhixiang et al., 2004). In 2003, an investigation was begun by the Jiangsu Freeway Construction Headquarters to determine the rutting resistance of some freeways that were opened to traffic in 2001. The results of the investigation are shown in Table 1.

Proceedings of the 26th Southern African Transport Conference (SATC 2007) 9 - 12 July 2007
ISBN Number: 1-920-01702-X Pretoria, South Africa
Produced by: Document Transformation Technologies cc Conference organised by: Conference Planners

Table 1. Rut depth of some freeway sections in Jiangsu in 2003

<table>
<tr><th rowspan="2">Highway name</th><th rowspan="2">Section number</th><th colspan="3">Types of pavement material</th><th rowspan="2">Base material</th><th rowspan="2">Subbase material</th><th rowspan="2">Rut depth (mm)</th></tr>
<tr><th>Surface</th><th>Middle layer</th><th>Bottom layer</th></tr>
<tr><td rowspan="4">Lian-xu (*1*)</td><td>1</td><td rowspan="3">AK13A</td><td rowspan="9">AC20I</td><td rowspan="9">AC25I</td><td rowspan="9">Fly-ash and limestone-treated macadam</td><td rowspan="9">Fly-ash and limestone-treated soil</td><td>9.6</td></tr>
<tr><td>2</td><td>6.4</td></tr>
<tr><td>3</td><td>6.6</td></tr>
<tr><td>4</td><td>SMA13</td><td>7.8</td></tr>
<tr><td rowspan="5">Ning-jing-yan</td><td>1</td><td>AK13A</td><td>6.7</td></tr>
<tr><td>2</td><td>SMA13</td><td>3.4</td></tr>
<tr><td>3</td><td>AK13A</td><td>6.0</td></tr>
<tr><td>4</td><td>SMA13</td><td>5.2</td></tr>
<tr><td>5</td><td>AK13A</td><td>3.8</td></tr>
<tr><td rowspan="4">Lian-xu (*2*)</td><td>1</td><td rowspan="4">AK13A</td><td rowspan="2">AC20S</td><td rowspan="2">AC25S</td><td rowspan="4">Cement-treated macadam</td><td rowspan="4">Fly-ash and limestone-treated soil</td><td>6.5</td></tr>
<tr><td>2</td><td>4.7</td></tr>
<tr><td>3</td><td>Sup20</td><td>Sup25</td><td>7.0</td></tr>
<tr><td>4</td><td>AC20S</td><td>AC25S</td><td>9.1</td></tr>
</table>

Notes: "Sup" means asphalt mixture design based on the Superpave method.
"AK" means a type of asphalt mixture always used in the surface layer with high skid resistance.
"SMA" means stone matrix asphalt.
"AC" means asphalt concrete.
The 13, 20, 25 denote the nominal maximum aggregate size (NMAS) and AIS denotes the aggregate gradation type.

Table 1 shows that rutting occurred in many freeways in Jiangsu and in some sections the problem is especially severe. The factors identified in this investigation that lead to distress include: (1) high percentage of overloaded trucks, (2) long periods of high temperature in the summer, (3) mixtures of AC20I and AC25I, which are both suspension-dense structures that are prone to rutting, were used in the middle and bottom layers.

2. CIRCULAR ROAD TRACKING TEST

The circular road-tracking (CRT) test is a kind of full-scale test that falls between indoor tests and large field tests. It is well able to simulate the entire process of rutting development under field loading. It has been shown that the results of the CRT test are consistent with those of indoor tests and field tests (Metcalf, 1996; Hugo et al., 1998; Hosfra et al., 1972; Jia, 1999). The CRT test therefore has an obvious advantage for evaluating the rutting resistance of asphalt mixtures.

The CRT test has been used in several countries to study the rutting resistance of asphalt mixtures, and many results have been published (Metcalf, 1996; White, 2002; Hugo et al., 1998; Hosfra et al., 1972; Gokhale et al., 2005; Huang, 1999; Li et al., 1998). It must be noted, however, that in different countries the climate and traffic conditions may be very different. Moreover, differences in the test procedure, test temperature, test load, tyre type, and wheel moving pattern may also lead to different test results. The CRT results achieved in one country therefore may not be applicable to another country.

After the investigation of the general condition of freeway pavements in Jiangsu, a full-scale circular road-tracking test was planned and carried out to evaluate the rutting resistance of typical pavement structures used in Jiangsu, and then to determine which were the correct pavement structures to use and feasible solutions to reduce rutting.

2.1 Pavement structures used in the circular road tracking test

In recent years, the disadvantages of pavement with a semi-rigid base have been gradually revealed, and more and more preference is being given to thicker asphalt pavement with a flexible base (Huang, 1999). Accordingly, in the circular road-tracking test different bases and pavements were designed to determine the differences in their performance. The detailed information is shown in Table 2. Details of the mix gradings and engineering properties are given in Tables A1 and A2 in Appendix A.

Table 2. Pavement structures tested in the circular road tracking test

Pavement types	A	B	C	D	E	F
Surface layer (4 cm)	SMA13 (SBS, P_f)	SMA13 (SBS, C_f)	SUP13 (SBS)	AK13A (SBS)	AK13A (SBS)	AK13A (SBS)
Middle layer (6 cm)	AC20S (SBS)	AC20S (SBS)	SUP20 (SBS)	AC20S (AH-70)	AC20S (SBS)	AC20S (SBS)
Bottom layer (8 cm)	AC25S (AH-70)	AC25S (AH-70)	SUP25 (AH-70)	AC25S (AH-70)	AC25S (AH-70)	AC25S (AH-70)
Base (36 cm)	Cement-treated macadam	Cement-treated macadam	Cement-treated macadam	Cement-treated macadam	Asphalt-treated macadam (18 cm)+ Cement-treated macadam (18 cm)	Cement-treated macadam

Notes: P_f means asphalt modified with 2‰ polyester fibre.
C_f means asphalt modified with 3.5‰ cellulose fibre.
SBS means SBS-modified asphalt; AH-70 means the type of asphalt typically used in heavily loaded roads classified by the penetration grade.

3. INVESTIGATION OF RUTTING RESISTANCE

Two phases of the test were defined to evaluate the rutting resistance of different pavements. In the initial test, the test temperature was set at 45 – 50 °C, but after 220 000 wheel passes a large deformation occurred in the surface layer of AK-13A, which made resurfacing necessary to allow the loading wheels to run smoothly. The test temperature was set at 60 °C after the resurfacing, and the test was afterwards defined as the second phase.

3.1 Test preparation

3.1.1 Test machine

The track loading facility of the Transportation College of Southeast University was used for this test. It has a 240-cm-deep circular trough with an outer diameter of 10 m and an inner diameter of 5 m. The rotating system applies the load by two arms with a group of standard axles of actual size and dual tyres on the outer end of the arms. A weight block is mounted on the loading arm so that the load value can be adjusted. The moving speed can be adjusted automatically up to a maximum tangential speed of 60 km/h. In order to simulate a 100 kN load applied through a single axle with dual tyres, the axle load of each side was set at 50 kN. The tire pressure was 0.7 MPa, and the wheel speed was 25 ± 5 km/h.

3.1.2 Heating mode

To obtain the actual temperature of the pavement surface, infrared radiation was used to heat the pavement in the circular road track (see Figure 1).

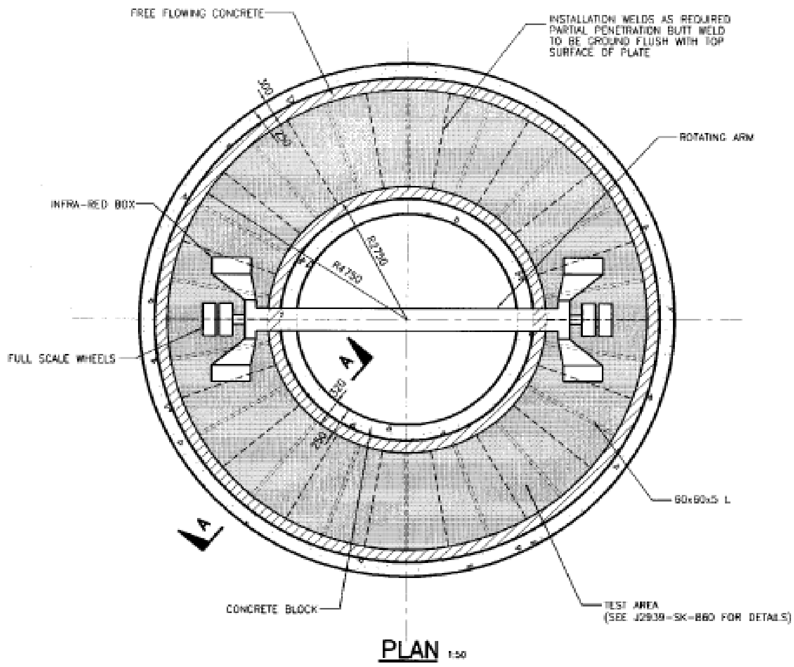


Figure 1. Sketch diagram of the placement of the heating equipment

3.1.3 Measurement of permanent deformation

Dial gauges fixed to a beam were used to measure the vertical deformation in the test. Their positions are shown in Figure 2(a). Each pavement structure had a similar temperature gradient.

The absolute rut depth and the relative rut depth were calculated from the dial gauge readings. Absolute rut depth is defined as the depression from the original surface level, while the relative rut depth means the distance between the bottom point of rutting and the top point of the mixtures along the rutting track. Both definitions are illustrated in Figure 2(b).

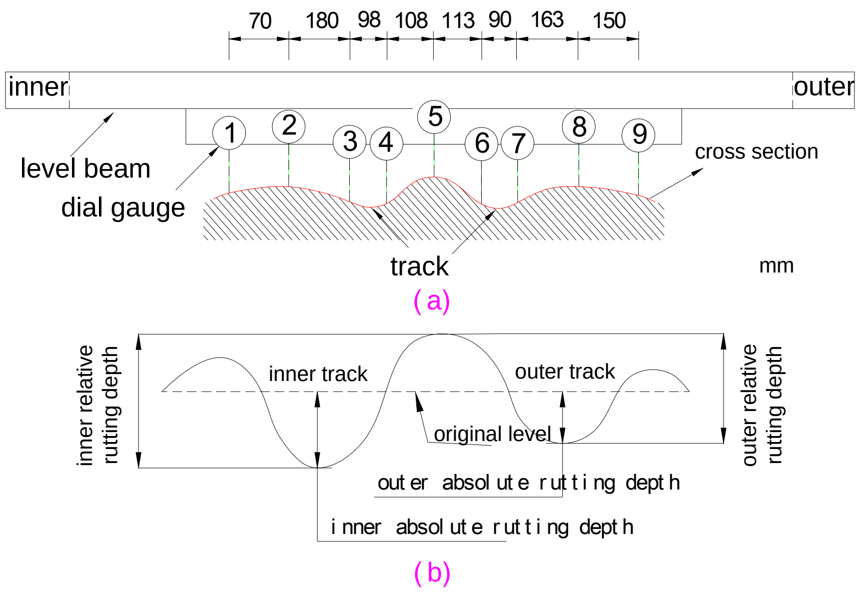


Figure 2. Sketch diagram of the measurement of permanent deformation

In a real road, traffic wanders, roughly following a normal distribution. The middle part of the track is always subject to the most load passes, so this is where the deepest rutting is detected. The circular road tracking test did not take traffic wandering into account, so it simulates severer conditions than would be caused by normal traffic on an actual road.

3.2 Deformation in the first phase of the test

The rut depths of different pavement structures were measured with dial gauges after 20, 50, 80, 110, 140, 170, 200, and 220 thousand passes. The average absolute and relative rut depths are shown in Figures 3 and 4 respectively. A, B, C, D, E and F denote the pavement types as listed in Table 2.

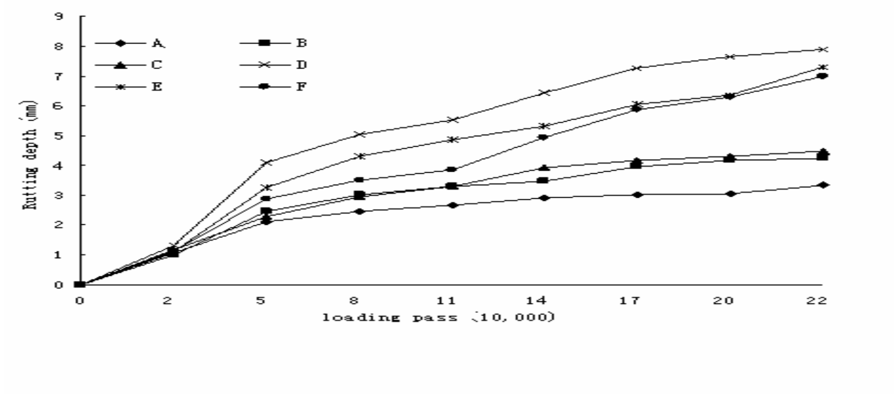


Figure 3. Average absolute rut depths after different wheel passes

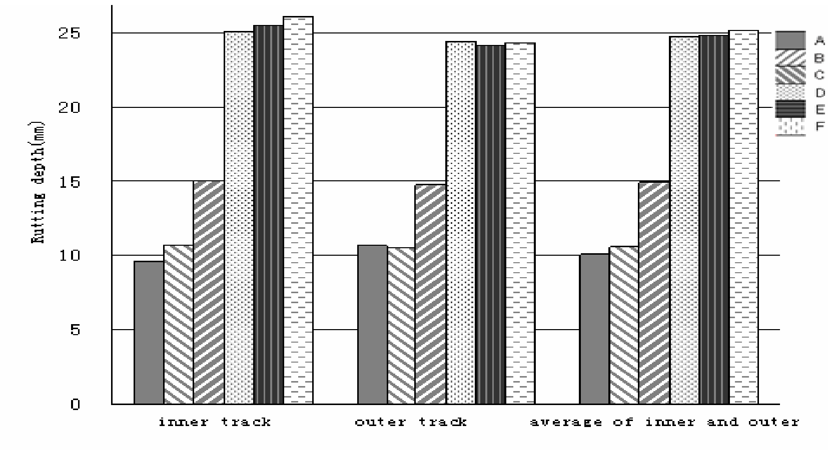


Figure 4. Relative rut depths after 220 000 loading passes

From the results in Figures 3 and 4, it was found that the rutting in structures D, E and F was quite similar and severer than in other structures. Structure A had the smallest rut depth, which was similar to that of Structure B.

3.3 Deformation in the second phase of the test

After 220 000 wheel passes, huge deformation developed in the section where AK13A was used as the surface layer, which stopped the loading machine from moving normally. Resurfacing therefore had to be done. After resurfacing, the test temperature was set at 60°C and the test was continued with all other test conditions remaining unchanged.

In the latter period of the test, the upward bulge between the two tracks was so large on some sections that the data could only be read on some of the dial gauges. For structures C and B, the rut depth could only be measured before 80 000 and 100 000 passes respectively, while the No. 5 dial gauge could not be read at all.

Figure 5 shows the development of the average outer absolute rut depth of different structures with loading passes.

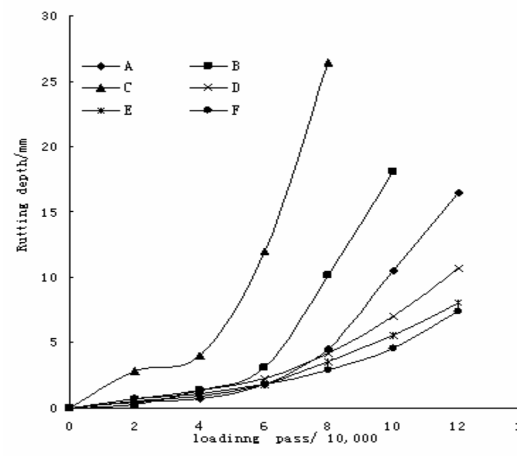


Figure 5. Average outer absolute rut depths of different structures

Because of the rapid failure of structures B and C during the second phase of the test, a small number of data were obtained in the tracks and the place between them. Therefore, for structures B and C, only the relative rut depth before 60 000 and 40 000 passes respectively were measured. The results, plus the readings on structures A, D, E, and F after 120 000 wheel passes, are shown in Table 3.

Table 3. Relative rut depth during the second phase of loading

Structure / Item	A $1.2*10^5$	B $6*10^4$	C $4*10^4$	D $1.2*10^5$	E $1.2*10^5$	F $1.2*10^5$
Inner average (0.01 mm)	2 775	1 583	1 751	2 487	1 935	1 940
Outer average (0.01 mm)	3 663	1 625	1 817	2 826	2 187	2 092
Inner, outer average (0.01 mm)	3 219	1 604	1 784	2 656	2 061	2 016
Number of cross-section	4	4	4	4	4	3

Note: $1.2*10^5$, $6*10^4$, $4*10^4$ are the loading passes.

From the results in Figure 4 and Table 3, it was found that amongst structures A, B, C, structure C had the highest rate of rutting development in terms of both relative and absolute rut depths, B was second and A had the lowest. As regards D, E, and F, structure D developed rutting quickly, and E and F were quite similar except that the outer absolute rut depth of E was slightly larger than that of F.

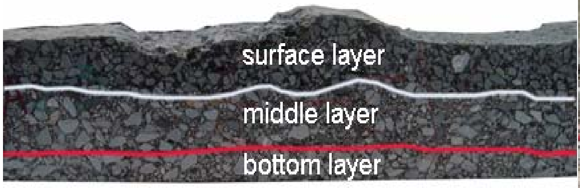
3.4 Contribution of different layers to deformation (White et al., 2002)

After testing, four slab specimens of 100 cm x 20 cm x 18 cm were sampled from each structure. The rut depths of both the surface and the middle layers of 13 cross-sections were measured. The results are summarised in Table 4 and illustrated in Figure 6, from which it was found that there was little change in the thickness of the bottom layer of the pavement. Thus only the deformations of the surface and middle layers were measured, which were converted to the percentages of the total depression.

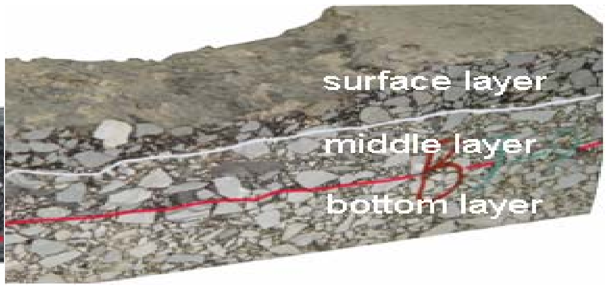
From the results in Table 4 it was found that in most structures the deformation in the middle layer contributed much more to the total deformation than the surface layer, except in structure E, where the bottom layer and asphalt-treated macadam layer also exhibited slight deformation, which can be disregarded. It is therefore important to design the middle layer to improve the rutting resistance of the entire pavement. In structures D and F, which differ only in the middle layer, the middle layer of D contributed more to the total deformation. Based on this observation, it can be concluded that the rutting resistance can be significantly improved by the use of polymer modifier in the asphalt of the middle layer.

Table 4. Contributions to the deformation of different layers and different structures

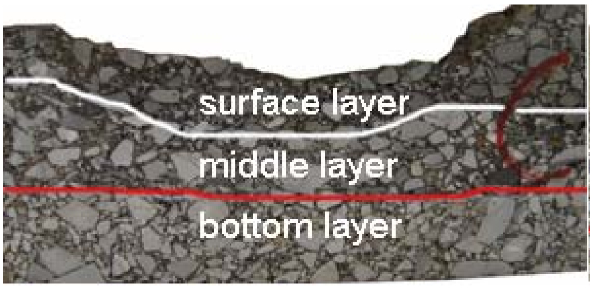
Location	Percentage of contribution (%)					
	A	B	C	D	E	F
Surface layer	27.5	35.8	36.1	23.3	66.1	35.3
Middle layer	72.5	64.2	63.9	76.7	33.9	64.7



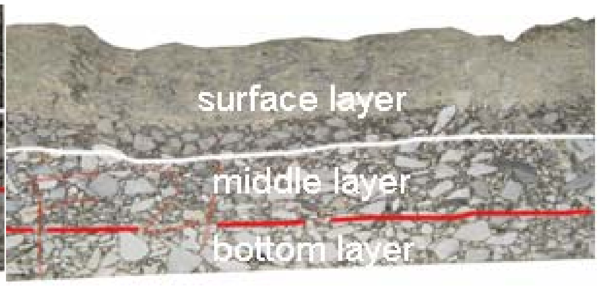
a)



b)



c)



d)

Figure 6. Core samples from the pavement in the circular road-tracking test

4. CONCLUSIONS

From the field study and the laboratory tests on the contribution to rutting of the pavement structure, bitumen type, aggregate gradation, bitumen additive and external environment, the following conclusions can be drawn:

1. From the results of the circular road-tracking test, it was found that structure A was the best in terms of rutting resistance. Structure B proved to be second best. Structure D was the worst. Based on all these observations and the conditions of high temperature and heavy traffic volume in Jiangsu, it is highly recommended that B be used as a typical structure in this region.
2. Compared to the rut depth of pavement with a semi-rigid base, the rut depth of pavement with an asphalt-treated macadam base was slightly greater, which mainly occurred in the densification phase, while rutting due to shear deformation was nearly the same.

3. The middle layer contributes more to the total deformation than the surface layer, because this layer withstands most of the shear stress according to the mechanical analysis (Li, et al., 1994). It is therefore important to design the middle layer to improve the rutting resistance of the entire pavement.
4. Asphalt properties have a large impact on rutting associated with shear deformation and it is necessary to use modified asphalt in the middle layer. This conclusion has also been reached in the research by NCAT (Jia, 2006).
5. Good gradation of the aggregates of the surface layer is essential to achieve a desirable rutting resistance. When the same asphalt was used, the rutting resistance of SMA13 proved to be the best, followed by Sup13, with AK-13A being the worst. On the other hand, when the aggregate gradation is the same, asphalt with high viscosity reduces rutting more than asphalt with low viscosity. The CRT by NCAT and actual practice in the USA (Jia, 2006) have proved these conclusions.
6. Fibre is a critical component of an excellent SMA mixture. The test results show that SMA with polyester fibre is better than SMA using cellulose fibre regarding rutting.
7. Temperature is also a critical factor that affects the occurrence of rutting, and similar results were obtained in related research (Huang, 2000, Li et al., 1998). Pavements subjected to high temperature are more likely to experience rutting failure caused by shearing flow. This conclusion has also been verified by performance observations of pavements in the field (Zhang, 2004).

5. ACKNOWLEDGEMENTS

This study was sponsored by the Jiangsu Provincial Communications Department through Project 2003Y002. The generous support of Prof. Deng Xuejun, Chen Rongsheng and Huang Xiaoming from the Transportation College at Southeast University is appreciated. The review of the paper review and the invaluable suggestions by Dr Lu Qing at UC Berkeley are also greatly appreciated.

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APPENDIX A

TABLE A1. Gradations of the aggregates and binder type and content

Mix type	Percentage passing (%) the sieve size (mm)										Binder type and content (%)	
	31.5	26.5	16	13.2	9.5	4.75	2.36	0.6	0.3	0.075		
Asphalt-treated macadam	100	88	47	39	31	25	15	7	7	4	AH-70	3.0
AC25S	100	96	77.9	69	57.1	34.2	25.9	15.1	10.4	6.4	AH-70	3.9
Sup25	100	98	74	67	57	35	20	11	8	5	AH-70	4.0
Sup 20		100	78	64.4	51.2	28	23	11.4	7.4	4.3	SBS	4.5
AC20S		100	83.4	65.7	53.2	41.5	25.7	13.7	9.7	5.7	SBS	4.6
		100	83.3	70	58.4	40.1	25.1	14.3	11.2	5.4	AH-70	4.5
SMA13			100	88	58.4	28	22	15	13	10.5	SBS	6.2
AK13A			100	93.9	65.2	34.7	25.3	11.6	8.6	5.2	SBS	5.2
*Sup 13			100	92	70	42	29	14	10	6	SBS	5.0

Note: * means the aggregate particles between 13.2 and 4.75 mm are basalt while those between 2.36 and 0.075 mm are limestone

TABLE A2. Main properties of asphalt mixes

Type	Density (g/cm^3)	Marshall test		Dynamic stability (cycles/ mm)	Permea-bility coefficient (ml/min)	Core air void (%)
		Stability (kN)	Flow value (0.1 mm)			
AC25S	2.436	10.2	34	1 987	25	5.8
Sup25	2.401	9.2	29	1 183	7	5.0
Sup20	2.451	9.8	35	2 529	20	3.6
AC20S(SBS)	2.419	10.6	34	2 576	25	4.8
AC20S(AH-70)	2.450	9.7	34	1 507	20	3.6
SMA13(P_f)	2.443	7.88	25	4 541	5	3.7
SMA13(C_f)	2.443	7.18	32	4 273	8	4.7
AK13A	2.440	10.72	21.3	3 916	6	4.4
Sup13	2.441	9.07	23.1	2 962	7	4.2