STUDY OF FLEXIBLE BASE AND SEMI-RIGID BASE ASPHALT PAVEMENT PERFORMANCE UNDER ACCELERATED LOADING FACILITY(ALF)

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ABSTRACT

This paper presented performance analysis of asphalt pavements with semi-rigid base and flexible base on the test results from the field full scale Accelerated Loading Facility(ALF) in HangZhou city, Zhejiang province, China.

The author compared and evaluated the performances of various semi-rigid (cement stabilized crushed stone) base asphalt pavements and flexible (graded crushed stone) base asphalt pavements under the test of Accelerated Loading Facility (ALF) . The performance of asphalt pavement is mainly monitored in several areas, such as the rutting properties, bearing capacity(BB and FWD), strength(strain gage), fatigue characteristics and environment effects on the pavement structure. This paper discussed these data collected from a field study with the Accelerated Loading Facility (ALF).

The high temperature stability of asphalt pavement in the t different structures was analyzed.

0 Introduction

In recent years, the construction of Chinese expressways is quickly developed, and typical pavement structures are semi-rigid base asphalt pavements and flexible base asphalt pavements.

Semi-rigid base structures have high strength and good plank as well as high load bearing capacity. But it is easy for semi-rigid base materials to shrink to cause reflective cracks; and low water stability leads to early failure of asphalt pavement structures. Flexible base structures have high water stability which can decrease the cracking of pavements and improve long-term performance of pavements; and have the advantages (disadvantages) of bigger early rutting and high early cost. Only the surfaces are improved, can the flexible structures be used during the maintenance, while semi-rigid base structures usually need repair through all the layers. Therefore, flexible base structures embody better economical benefits in consideration of the life cycle cost of pavements[1].

The article presented the evaluation of the performances of pavements with the semi-rigid base and the flexible base by field full-scale accelerated loading tests.

1 Introduction of test

By the controllable actual wheel load, the actual layered pavement system is loaded based on or beyond the normal allowed load, the repetitive loading is done under the comprehensive conditions such as defined loading conditions, climate factors (eg. temperature, water content), and so on, the failure of pavements are accumulated in a compact period to complete the accelerated failure of pavements. Each index of characteristic pavement performance can be observed by accelerated loading tests of pavement projects constructed by normal processes or special test roads to obtain the change rule of pavement performance. [2]

1.1 Accelerated loading facility

ALF (Accelerated Loading Facility) is a large-scale, movable field linear full-scale comprehensive accelerated loading facility which can simulate the actual traffic status on the spot. It can make impose accelerated loading on the full-scale pavements and load in a short time by controllable axle loads to simulate the failure of pavement structures by actual traffic loads in the long time, as shown in Fig.1-1.

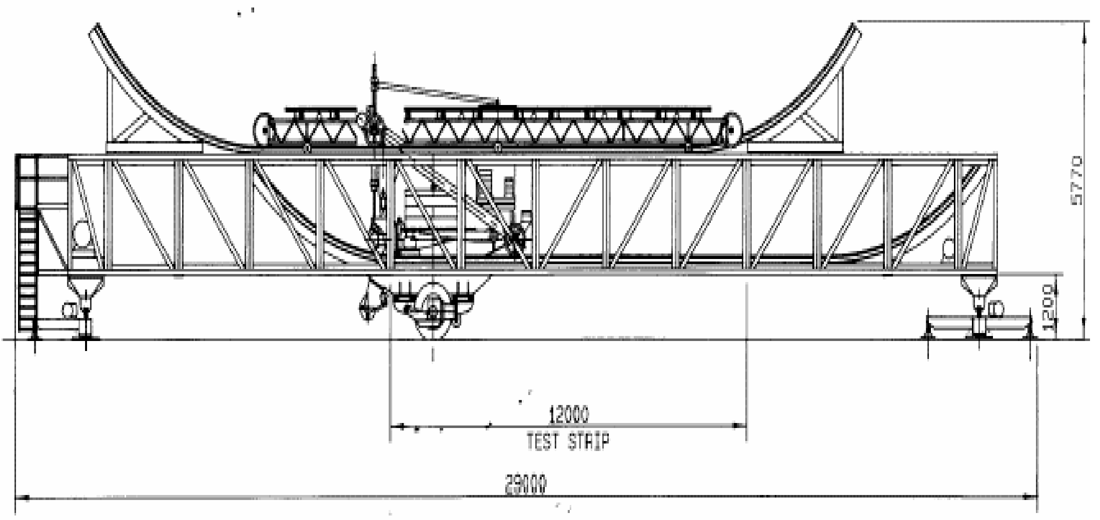

Figure1-1 ALF(Accelerated Loading Facility)

The facility consists of an accelerated loading system, a data collection system, and the loads are equivalent to 80KN to 200kN of single-axle double-wheel axle loads, which are freely selected by taking 20KN as a rank. The loading speed is about 20Km/h，the length of the loading trip is 12m，and 9000 unidirectional selected wheel loads can be imposed on the pavements every day. The facility can automatically simulate the transverse distribution of actual traffic loads. The transverse distribution includes wide distribution and narrow distribution, which are both standard normal distribution, as shown in Fig.1-2. The data collection system can timely monitor various parameters and status of the pavements (including surface deflection, interlayer displacement in pavement structures, surface deformation such as rutting, stress and strain of each layer in pavement structures, etc.). In addition, cracks and breakages on the surfaces of pavements can also be observed and natural conditions around the test (for example, daily maximum temperature, surface maximum temperature, temperature field in pavement structures, daily rainfall, etc.) can be recorded manually. The quantitative relationship between the status of pavements and accelerated loading times can be established to study, discuss and verify the rule of development and change of pavement structures under continuous loads. [3]

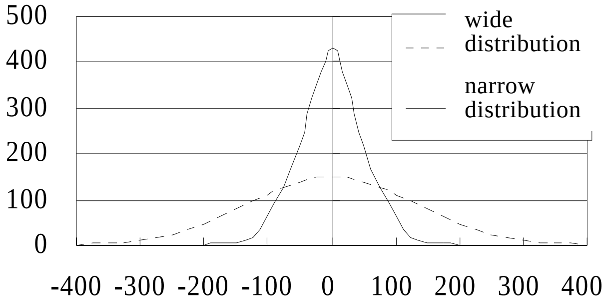

Fig.1-2 accelerated loading transverse distribution

1.2 Purpose of test

The purpose of accelerated loading test is continuously observing the related performance indices which can reflect the pavement structures, quantitatively establish the relationship between the related performance indices of pavement structures and accumulated axle loads; to compare service life, rutting-resistance, load bearing capacity and stability to the environment (temperature, water) of asphalt pavements with different structures; to evaluate the performance and the applicability of different pavement structures.

1.3 project description

The test roads were located in Hangzhou city, Zhejiang province, southeast China. The pavement structures were divided into four modes and different material were selected as design models and composited structure design models. SN-A was the most common semi-rigid base combined mode used for asphalt pavements of Chinese expressways nowadays, wherein, the base adopted cement stabilized macadam and the thickness of the asphalt layer was 18cm. SN-B was a pavement structure added with the grading macadam, wherein, the transition layer of grading macadam was added between the asphalt layer and the semi-rigid base to improve the water-resistance performance of the asphalt pavement and the thickness of the asphalt layer was 20cm. SN-C and SN-D were all flexible base structures which adopted grading macadam base materials and the thickness of the asphalt layer was 26cm，wherein, the bottom base of the SN-C adopted cement stabilized macadam. For SN-A and SN-B, the total thickness of the pavement was both 72cm, for SN-C and SN-D, the total thickness of the pavement was both 66cm, and more details are shown in Fig1-3.

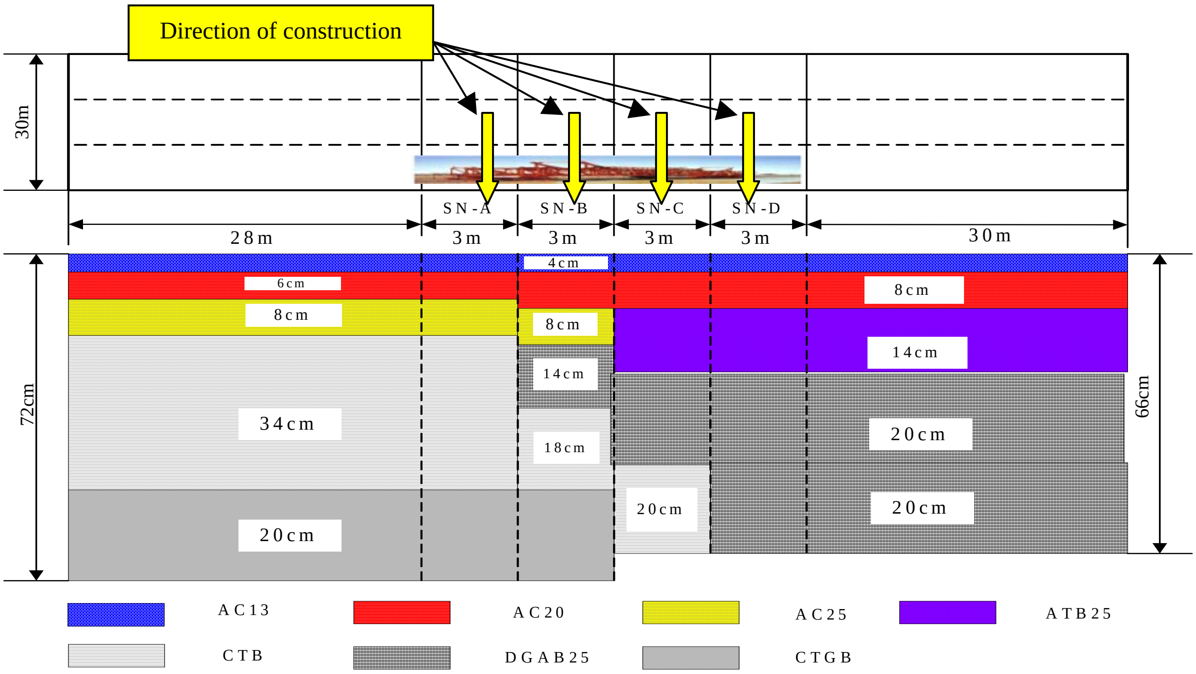

Fig 1-3 Arrangement plan and structure for accelerated loading test sections of full-scale pavements

All the raw materials were local road materials, and all performance indices met the national standard requirements. Test data for mixing design of materials in all layers is shown in Table 1-1；the test result of on-site strength parameters in all layers is shown in Table 1-2。

Table 1-1 Test data for mixing ratio design

Design index	Cement mixture (%)	Design strength (Mpa)	7 days of unconfined compression strength (Mpa)	Maximum dry density (g/cm^3)	Best water content (%)
Cement stabilized gravel bottom base	3.5	2.5	3.2	2.31	6.50
cement stabilized macadam bottom base	3.5	2.5	3.5	2.27	6.50
cement stabilized macadam base	5.0	4.0	4.2	2.28	6.00
designed grade aggregate				2.28	5.65

Detected projects	Best asphalt dosage (%)	Stability (KN)	Flow value (0.1mm)	Voidage rate (%)	Asphalt saturation (%)	Remaining stability (%)
AC-13	4.8	6.76	29.8	7.1	61.5	80.3
AC-20	4.6	11.56	34.6	4.3	70.8	89.0
AC-25	4.4	11.82	35.1	4.2	70.6	80.5
ATB-25	4.0	28.76	47.0	6.2	55.8	75.5

Table 1-2 Detection data for deflection and resilient modulus in all layers

Surface deflection	Top surface of road base		Top surface of bottom base		Top surface of base		Top surface of surface layer	
	material	$\bar{l}$ （0.01mm）	material	$\bar{l}$ （0.01mm）	material	$\bar{l}$ （0.01mm）	material	$\bar{l}$ （0.01mm）
SN-D	slag	135.6	designed grade aggregate	108.4	designed grade aggregate	86.8	AC-13	23.8
SN-C	Slag	157.2	Cement stabilized aggregate	49.2	designed grade aggregate	67.2	AC-13	23.3
SN-B	slag	163.6	Cement stabilized aggregate	52.0	designed grade aggregate	41.6	AC-13	11.3

SN-A	slag	133.6	Cement stabilized gravel	32.0	Cement stabilized aggregate	5.6	AC-13	3.6
Resilient modulus	Top surface of road base		Top surface of bottom base		Top surface of base		Top surface of surface layer	
	material	$\overline{E}$（Mpa）	material	$\overline{E}$（Mpa）	material	$\overline{E}$（Mpa）	material	$\overline{E}$（Mpa）
SN-D	Slag	111.0	designed grade aggregate	116.7	designed grade aggregate	125.3	AC-13	391.1
SN-C	Slag	95.4	Cement stabilized aggregate	285.9	designed grade aggregate	163.5	AC-13	399.5
SN-B	Slag	107.2	Cement stabilized aggregate	229.1	designed grade aggregate	181.1	AC-13	823.7
SN-A	slag	97.5	Cement stabilized gravel	185.9	Cement stabilized aggregate	637.2	AC-13	2585.6

1.4 Scheme of test

The scheme included two parts, wherein, the first part was comparing long-term performances of full-life asphalt pavement structures; and the second part was comparing the adaptability of different structures under high temperature and comparing the rutting-resistance capacity. As shown in Table 1-3.

Table 1-3 Scheme for accelerated loading test

Project	Test for comparison of long-term performance of full-life asphalt	Test for comparison of rutting on pavements and surfaces of pavements under high temperature
Test conditions	Natural conditions	Heat the pavements，control the temperature5cm deep below the surfaces of asphalt pavements to 60℃
Axle load for test	axle load：160KN tyre pressure：0.8Mpa	axle load：160KN tyre pressure：0.8Mpa
Loading structures	SN-A、SN-B、SN-C、SN-D	SN-A、SN-B、SN-C、SN-D
Loading distribution	Narrow distribution（normal distribution）	Narrow distribution（normal distribution）
Simulating rainfall	Yes	No
Loading times	2,645,000	79,000
Detection indexes	Rutting, deflection（Benkelman）, FWD, flexural-tensile at bottom, surface damage, weather conditions	Rutting, temperature field of the asphalt layer

2 Results of test

The whole full-life accelerated loading test was taken 15 months all the time, which contained two winters. The number of accumulated loading was 2,645,000，and loading times at each month are shown in Fig2-1. During loading, the general average air temperature was 14.4℃，maximum monthly average air temperature was 29.3℃，minimum monthly average air temperature was 3.2℃; and natural rainfall added up to 1239mm. Natural conditions during loading, namely temperature and rainfall are shown in Fig.2-2.

The temperature control test was concentrated in 8 to 9 month, which included highest temperature in the year. The loading times rose high up to 79,000. The temperature fields of asphalt pavements during the temperature control test are shown in Table 2-1.

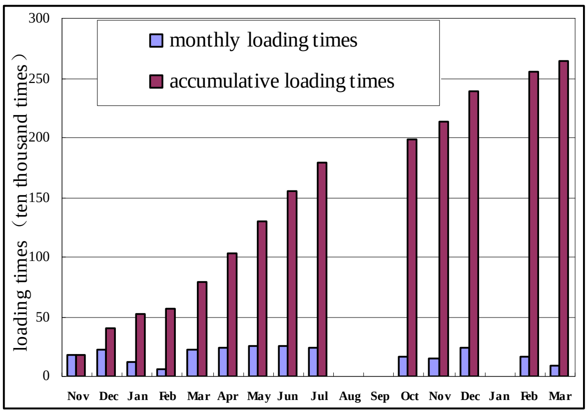

Fig. 2-1 Statistics of loading times at each month and accumulated loading times

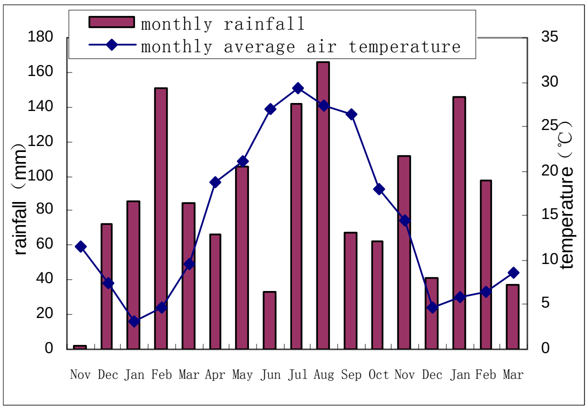

Fig.2-2 Statistics of monthly average temperature and rain fall during loading

Table 2-1 Temperature fields of asphalt layers during heating

Item	Structure	Depth from surfaces of pavements（cm）						Regression equation
		3	5	10	15	20	25	
Average temperature (centigrade)	SN-A	60.5	59.4	56.9	54.0	51.9	/	$y=-0.516x+62.011$ $R^2=0.9973$
	SN-B	60.5	60.0	57.2	54.6	51.8	/	$y=-0.521x+62.327$ $R^2=0.9974$
	SN-C	60.9	60.1	57.4	54.4	51.9	50.3	$y=-0.505x+62.127$ $R^2=0.9982$
	SN-D	60.5	59.8	57.0	54.5	52.3	49.3	$y=-0.503x+62.374$ $R^2=0.9923$

The loading trip of accelerated loading sections had a total length of 12 meters. The widths of four pavements were all 3 meters. Seven cross-sections were allocated on the surface of each structure for the measurement of related performance indices, as shown in Fig.2-3. The cross-sections marked by three red long dash lines were cross-sections for the test of deflection and FWD， and the cross-sections marked by three red long dash lines and four red short dash lines were cross-sections for the test of rutting.

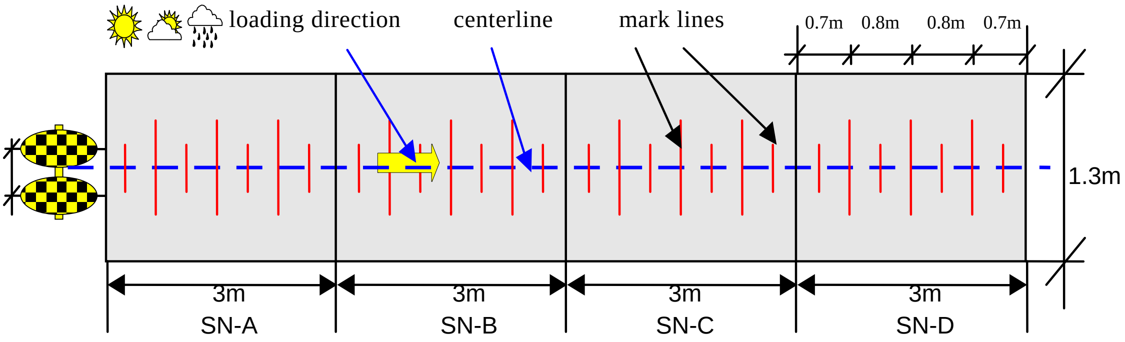

Fig.2-3 Allocation of cross-sections of the accelerated loading test

The related parameters of pavement performance (including surface deflection, rutting, stress in pavement structures, surface damage, etc.) were tested during loading, and the result of the test is as follows：

2.1 Performance of rutting

Due to excessive overload of vehicles and continuous high temperature, the failure caused by rutting has become the main failure inside national asphalt pavements. It was proved that the rutting on asphalt pavements are mainly produced by compact deformation and shear deformation of asphalt layers and accumulated deformation of all structures. The main interior factors are compaction, mechanical deformation or shear rheology arising from irrational structural design or inadequate performance of asphalt mixing, while the main exterior factors are high temperature and overload. Fig.2-4 and Fig. 2-5 show the relationship curves of maximum average depths of rutting and loading times under ambient temperature and high temperature respectively.

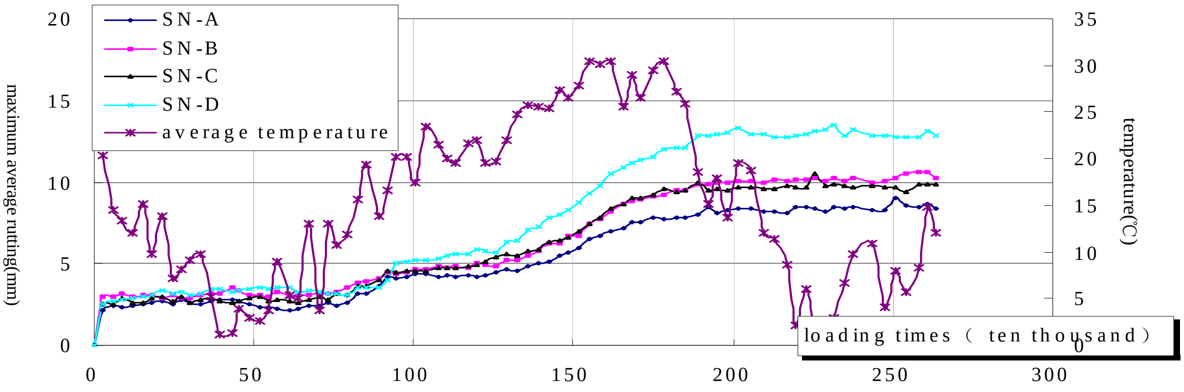

Fig. 2-4 Relationship of maximum average rutting and accumulated loading times under natural conditions

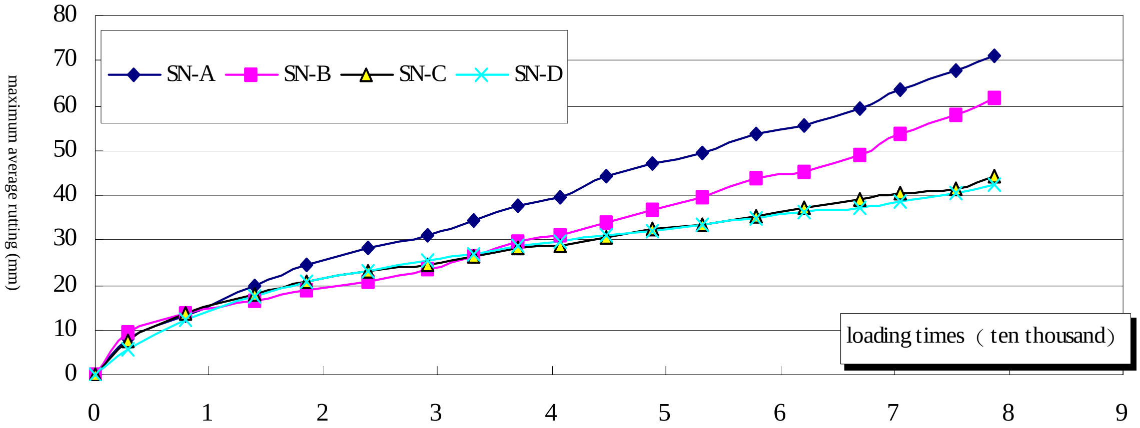

Fig. 2-5 Relationship of surface ruttings and loading times under constant high temperature

It can be seen from the test that the rutting were formed by compact deformation or shear deformation under high temperature of asphalt layers and were susceptible to the temperature for an accelerated loading test in a shorter time.

For the test at ambient temperature, the rutting developed very slowly under low temperature less than ten degrees (centigrade). The rutting of four structures presented a change rule from growth to stability, moreover, the rutting depths of the flexible SN-C and D structures were larger than that of the semi-rigid SN-A structure, but finally all the rutting were less than 15mm. These results show that, under natural conditions, the formation of the rutting on asphalt pavements was mainly divided into two phases: the first stage--viscous deformation stage，the deformation of asphalt layers showed strong viscosity, thereby, producing viscous strain and deformation, so the rutting at early days were increased very quickly, meanwhile, the void rate was decreased due to the compaction of asphalt pavements under the action of loads arising from no complete compaction during the construction. So the rutting during this period was quickly increased and the actual rutting was larger than predicted results. The second phase：the viscous deformation phase was the middle-term phase of rutting formation; the asphalt mixing had an increasing “resistance” to the deformation，which made the further deformation more difficult，namely the appearance of “consolidation effect”; the asphalt layers entered relatively steady viscous deformation phase; the deformation of the rutting was relatively slow; the actual rutting were smaller than predicted ones.

Under high temperature, the rutting on asphalt pavements had apparent double logarithm relationship with accumulated loading times (see Formula 1-1)；the parameters producing prediction models of the rutting on different structures are shown in Table 2-2.

$$\lg(RD) = a \times \lg(N) + b \qquad \text{(Formula 1-1)}$$

wherein：RD —depth of rutting(mm)，N —loading times(ten thousand)，a 、b —regression coefficient

Table 2-2 Prediction models of the ruttings on different pavement structures

Structure	a	b	R^2
SN-A	0.6729	1.2104	0.9927
SN-B	0.5896	1.1753	0.9224
SN-C	0.5016	1.1711	0.9942
SN-D	0.5645	1.1252	0.9864

For high temperature tests, the rutting developed very quickly, moreover, the main reasons the rutting appeared were shear flow of asphalt layers and dis-stabilization of structural layers. For semi-rigid SN-A structure, the rutting was largest; the second is SM-B structure; the rutting of SN-C and SN-D structures were basically equal and were smaller.

Seen from the change rule of the ruttings on four structures under natural conditions and high temperature conditions, the ruttings were mainly produced in middle asphalt layers, namely 4cm to 10cm away from the surfaces; the thicknesses of asphalt layers of four structures were different, but compaction deformation of asphalt layers under loading had a small difference; seen from shear deformation, the thickness of each asphalt layer was also not a main factor, on the contrary, the structural type had an apparent effect on shear deformation. Seen from the results of the whole rutting tests of flexible structure and semi-rigid structure, it is much easier for the asphalt pavement with semi-rigid base to cause the rutting under high temperature conditions the reason was that the strength of semi-rigid base got smaller influence from the temperature, but the modulus change of asphalt layer could lead to asphalt layer to bear larger shear stress.

2.2 Deflection test

The design guide of national asphalt pavements takes the surface deflection as design criteria to control and reflect the strength of pavements. The change of surface deflection reflects the change of strength reduction of pavement and road materials, and establishes the relationship of maximum pavement deflection and loading times and can reflect strength performance and fatigue life of different structures of pavements under long-term loading.(strength performance and fatigue life of different structures of pavements under long-term loading can be reflected by establishing the relationship of maximum pavement deflection with loading times) Fig. 2-6 shows the relationship curve of surface deflection (measured by Benkelman beam) of all structures corrected by temperature and loading times.

All of four pavement structures had an obvious deflection hiberarchy under the same conditions, which completely reflected the whole rigid characteristic of the pavement structure combined by different structures; the surface deflections of four structures had small increases, then the deflections of SN-B, SN-C and SN-D structures began to decrease, then, with the increase of loading times, the deflections of four structures were steady in a degree until the end of the test; the deflections of four structures had no apparent abruption, which indicated that there was no structural failure inside pavement structures during loading and the four structures had higher load bearing capacity.

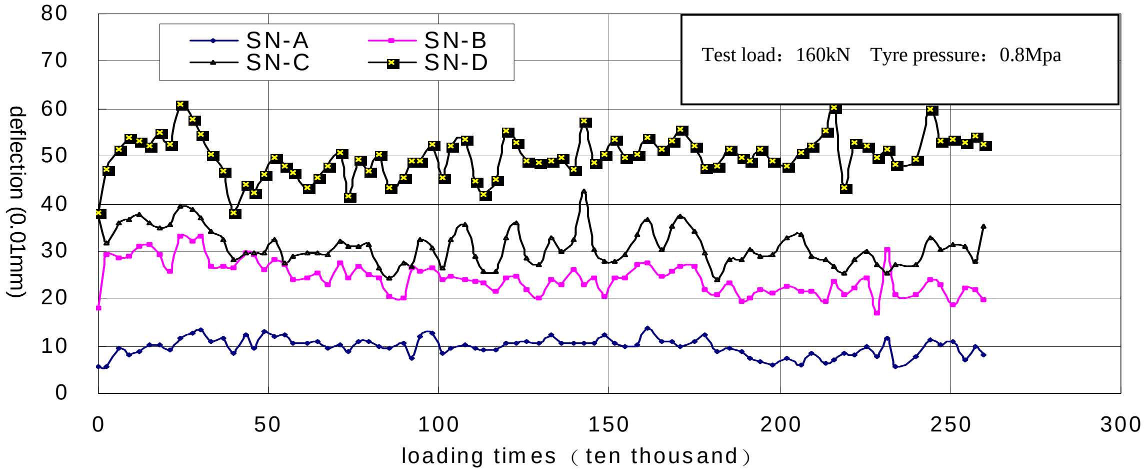

Fig. 2-6 Relationship of deflection of each structure and accumulated loading times （after temperature

2.3 Flexural-tensile stain on the bottom

To obtain the strain of all layers of pavement structures under loading, during the construction of test road, full-bridge resistive H-Bar strain gauges imported from U.S.A were buried in the bottom of asphalt layers of all structures. The result is shown in Fig.2-7.

As shown in Fig.2-7，the flexural-tensile strain at the bottom of asphalt layers decreased along with the increase of loading times and increased along with the loading times. After 600,000 loading times, it reflected that when the structural layers were under loading, asphalt materials were compacted to make the modulus increase to cause the strain decrease of structural layers finally. Then the asphalt layers caused the fatigue to decrease the modulus of asphalt mixings, thereby, making the strain of structural layers increase. Compared with the results of deflection, the surface deflections were not stabilized to a certain degree during loading, but the strength of asphalt layers was always decreasing (the phenomenon is that the strain was constantly increasing) according to the change rule of the strain at the bottom of asphalt layers. From this angle, the strain index of flexible base asphalt pavements could reflect the performance and strength of pavement structures more efficiently for asphalt pavements with flexible bases. With the increase of loading times, one of two strain gauges on the bottom of the asphalt layer of the semi-rigid base structure (SN-A) was kept unchanged, and the other one began to increase when 1,000,000 loading times were loaded; it indicated that the adhesion of the asphalt layer and the base began to change with the constant action of loads.

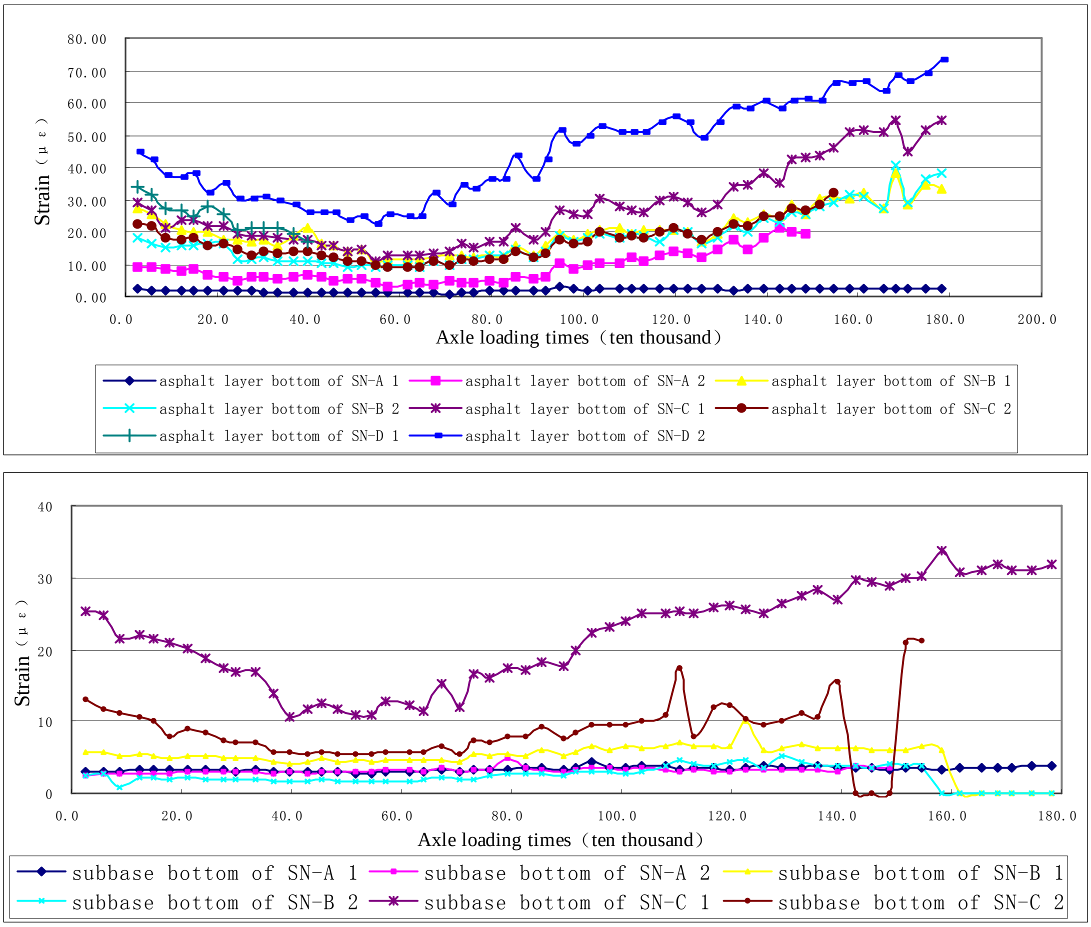

Fig.2-7 Relationship of tensile strain on all bottoms and loading times

3 Conclusions

The test undertook 2,645,000 loading times on four pavement structures, wherein, the axle load was 160kN，the air pressure of the tyre was 0.8Mpa，which was equivalent to 28,580,000 equivalent axle loads (based on deflection index) of standard loading (100kN of axle load, 0.7 Mpa of tyre air pressure) and approached to the design parameters adopted by the structural design of asphalt pavements of Chinese expressways and were equivalent to accumulated traffic loading times on pavement structures within 15 years；in the end of the test, the surface reflections of four pavements didn’t produce apparent abruption points, which indicated that the pavement structures designed in this time all had good load bearing capacity；As seen from the test result of the strain, the strength of asphalt layers of four pavement structures was gradually decreased，while the strain was gradually increased, but the strain level making the asphalt layers crack was still not reached until the end of the test. According to the accelerated loading test, we can make the following preliminary conclusions：

1． The test was accelerated made in a short time, so the test could only to verify and compare the whole load bearing capacity of pavement structures and could not reflect the change of pavement structures arising from the change of pavement materials with time.

2． The flexible base structure increased the thickness of the asphalt layer related with the semi-rigid base structure, but it had a smaller sensitivity to high temperature and had certain advantages in preventing rutting under constant high temperature. The rutting of the flexible base asphalt pavement structure was quickly increased at early loading days, then it was stabilized to a certain degree, which was consistent with the results of creep test of asphalt mixings. For flexible base materials and soil base, the early compaction deformation was also larger, but the late deformation was basically steady.

3. The surfaces of four pavement structures all adopted the same grading improved AC-13 asphalt mixings, and there were no surface cracks and other structural failures at the end of the test, but the good drainage performance of the grading macadam flexible base structure could be found when the pavements for test was excavated.

4. The deflection index was only applicable to the evaluation on the whole load bearing capacity of pavement structures and was not susceptible to the decay of load bearing capacity of structural layers during loading. Especially for the flexible base structures, the flexual-tensile strain on the bottom of asphalt layers was suggested as design index to reflect the performance and strength of pavement structures.

5. The test made a preliminary analysis and evaluation of the performance and applicability of asphalt pavement structures of flexible bases and semi-rigid bases by the verification of the full-scale accelerated loading test. Based on the research of the project, we adopted the same structures to construct long-term test roads for observation in three different areas and developed 5 years of observation and research of long-term performance to evaluate the performance of two pavement structures objectively, systematically and roundly.

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