

# Semi-rigid Asphalt Pavement's Premature Failures on Chinese Motorway Network

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**ABSTRACT:** Over the past 20 years more than 30,000 km motorways have been built in China. On the motorway network, semi-rigid asphalt pavement is widely used, which is composed of 15cm or so asphalt concrete layer and cement or lime-flyash bounded aggregate base layer. It has been observed that many premature failures occur 2-3 years after the motorways' open to traffic. Moreover, most of the motorway asphalt pavements' actual service life is about 7-8 years, comparing with their design life of 15 years. In the paper, asphalt pavement design method of China is given first. Then, the premature failure types as rutting and transversal cracking are presented. The impact of these failures on the pavement is discussed as well. It reveals that currently prevailing semi-rigid asphalt pavement technique in China need to be further improved.

**KEY WORDS:** Motorway, semi-rigid asphalt pavement, premature failure.

## 1 INTRODUCTION

Efficient transport infrastructure plays an important role in economic activity for a country. That is why so many countries attach great importance to the planning and building of transport infrastructure. The construction of an adequate and effective road network system, especially a national motorway system represents a huge investment on the part of governments and taxpayers in many countries.

Since 1990s, road construction in China has undergone a rapid development, especially after the implementation of central government's active financial policy in 1998. In the 14 years starting from 1990 to 2003, the accumulated investment for road construction in China has reached approximately 2 trillion RMB yuan and the investment in 2003 one alone hit 371.5 billion RMB yuan. By the end of 2004, 34,000 km of expressway have been in use on the mainland.

In 2005, the central government mapped out a 85,000 km national expressway network plan, of which 40,000 km yet to be built, with 32,000 km to be built in central and western regions. The national expressway network will combine five vertical and seven horizontal national trunk lines and eight western major highways to forming a nationwide road network by

getting the national capital to be connected with provincial capitals, provincial cities to communicate with each other, local cities and regions linked up with major counties and cities to be covered up by the network. As a result, most large and medium-sized cities, national and regional economic center, transportation hubs as well as key foreign trade ports will be directly linked by that time.

Road will degrade under traffic, environment impact. Pavement, as the immediate interface between road and traffic and outer environmental loading, begins to deteriorate first. Generally, pavement tends to deteriorate very slowly during the first few years after placement and very rapidly when they are aged. In China, motorway pavement's premature failure is gaining more and more attention. It has been observed that a number of premature pavement failures occur 2-3 years after the motorways' open to traffic. And most motorway asphalt pavements' actual shorter service life is about 7-8 years, comparing with their design life of 15 years.

The author gives a review of asphalt pavement design method of China, which is an analytically based method. Then the pavement premature failure types are presented, which are rutting, moisture distress and transversal cracking. Some simplified mechanical analyses are also conducted to a typical motorway pavement structure. It seems that semi-rigid asphalt pavement technique needs further improvement.

## 2 ASPHALT PAVEMENT DESIGN IN CHINA

Pavement design is a process intended to find the most economical combination of layer thickness and material types for the pavement, taking into account :(1) the traffic to be carried during the service life of the road; (2) the characteristics of the selected construction materials; and (3) The properties of the soil foundation.

In China, an analytically based method is used in pavement design. A linear, multi-layer elastic model is used to calculate the tensile stresses at the bottom of each pavement layer, and also the vertical displacement at the top of the pavement surface induced by an standard axle load of 100kN. The thicknesses of the layers are chosen so that the calculated stresses do not exceed the allowable values, and the allowable displacement at the top of the surface. These allowable stresses take into account the fatigue behaviour of the material, the risk of failure of the pavement, and a fitting coefficient.

### 2.1 Conversion of Mixed Traffic to ESALs

To use the asphalt design method, mixed traffic must be converted to an equivalent number of 100kN single standard axle load. The standard design load used in China is a 50 kN dual wheel load (based on the legal axle load of 100 kN allowed on public roads) at 319.5 mm spacing between centers and a uniform contact pressure of 700 kPa. According to Chinese 《Specifications for design of highway asphalt pavement》 (JTJ014-97) , the criteria are obeyed when converting a specific axle load to ESALs:

1)When calculating pavement surface deflection and stresses of HMA layers, for the axle load of more than 25kN, the ESALs can be calculated as follows:

$$N_s = C_1 C_2 N_i (P_i / 100)^{4.35} \quad (1)$$

Where

$$N_s = \text{ESALs (100 kN)}$$

$N_i$  = number of a specific axle load

$P_i$  = the magnitude of a specific axle load (KN)

$C_1$  = factor of axle number, if the spacing between two axles is beyond 3 meter, they should be treated as two single axle respectively; when the spacing is less than 3 meter,  $C_1$  can be calculated as follows:

$$C_1 = 1 + 1.2(m - 1)$$

where

m = number of axle

$C_2$  = factor of wheel combination, 6.4 for single axle with two wheels, 1 for single axle with four wheels, 0.38 for single axle with eight wheels

2) When calculating tensile stresses at the bottom of hydraulic treated base (or subbase) layer, axle load of more than 50kN, the ESALs can be calculated as follows:

$$N_s = C_1' C_2' N_i (P_i / 100)^8 \quad (2)$$

Where

$N_s$  = ESALs (100 kN)

$N_i$  = number of a specific axle load

$P_i$  = the magnitude of the axle load (KN)

$C_1'$  = factor of axle number, if the spacing between two axles is beyond 3 meter, they should be treated as two single axle respectively; when the spacing is less than 3 meter,  $C_1$  can be calculated as follows:

$$C_1' = 1 + 2(m - 1)$$

where

m = number of axle

$C_2'$  = factor of wheel combination, 18.5 for single axle with two wheels, 1 for single axle with four wheels, 0.09 for single axle with eight wheels

3) the formula above is only correct for axle load that is less than 130kN.

From formula (1) and (2), the relationship between the axle load and the damage caused to the road can be quantified conveniently. For example, a single four-wheel axle load which is only 25% over the legal load limit of 10 tons, i.e. 12.5 tons, is equivalent to the loads of 2.6 standard axles for HMA material and of 6 standard axles for hydraulic material treated layers. An axle carrying twice the legal load (10 tons for single axle load) has 256 times the damaging effect of a legal axle load on the hydraulic material treated layers. In other words, the passage over the road structure of one such overloaded axle is equivalent to the passage of approximately 256 legally loaded axles.

## 2.2 New Asphalt Pavement Design

When designing a new pavement structure, the criteria to be checked out are:

--that tensile stress  $\sigma_t$  (the maximum of stress value at point 1,2,3,4, see figure 1) at the base of the asphalt layers and layers treated with hydraulic binders remains less than a limit value.

--that the surface deflection  $I_s$  (calculated at point 5, see figure 1) is less than a limit value

$I_d, I_d$  can be calculated as follows:

$$I_d = 600 N_e^{-0.2} A_c \cdot A_s \cdot A_b \quad (3)$$

where

$l_d$  = design deflection (0.01mm)

$N_e$  = cumulative number of ESALs, it may be calculated using following formula

$$N_e = \frac{[(1 + \gamma)^t - 1] \times 365}{\gamma} N_1 \eta$$

where  $t$  = analysis period(years), 15 years for asphalt pavement;

$\gamma$  = annually traffic growth rate(%)

$N_1$  = cumulative ESALs on the design lane at the initial year

$A_c$  = factor of highway class, 1.0 for expressway, 1.1 for class two highway

$A_s$  = factor of pavement surface layer, 1.0 for asphalt concrete surface

$A_b$  = factor of base, 1.0 for a pavement with a hydraulic base of not less than 20 cm thickness

The structural analysis will be a linear elastic, static analysis of the multi layer system from which the pavement response to the loading condition is calculated in terms of stresses ( $s$ ) and strains ( $e$ ) at critical positions in the pavement structure. These critical positions are determined by the material type used in each layer of the pavement structure. The pavement surface deflection and tensile stress calculation scheme is shown in figure 1. A software has been provided to do all the calculations.

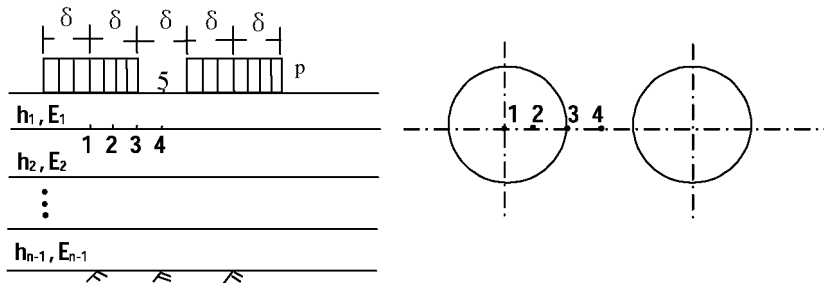


Figure 1: Pavement surface deflection and tensile stress calculation scheme

(where:  $\delta$  = the radius of the circular contact area of a standard tire, i.e. 106.5 mm;  $p$  = contact pressure, i.e. 0.7 Mpa;  $h_i$  = thickness of layer  $i$ ;  $E_i$  = elastic modulus of layer  $i$ ; the spacing between point 1 and point 2 equals to  $0.5\delta$ ; point 3 is on the circle; point 4 is on the centerline of two circles)

Typical asphalt pavement structure of Chinese motorway network is given in Table 1.

Table 1 Typical motorway asphalt pavement structure in China

layer	thickness (cm)
Asphalt concrete upper surface layer	4
Asphalt concrete medium surface layer	5-6
Asphalt concrete lower surface layer	6-8
Cement treated aggregate, or lime fly-ash treated aggregate base layer	20-40 (1 or 2 layer)
Lime treated soil, or cement, fly-ash treated soil subbase layer	15-35 (1 or 2 layer)

### 3 RUTTING AND TRANSVERSAL CRACKING ON CHINA MOTORWAY PAVEMENT

The traffic of China's motorway network has a unique characteristic, e.g. that more than 70% traffic is commercial vehicles and the estimated overloaded vehicles can be up to 80%. As research revealed, the damage that vehicles do to a road depends very strongly on the axle loads of the vehicles. And light vehicles such as cars and light commercial vehicles, make a relatively small contribution to the structural damage of a road pavement compared to that of heavy vehicles. Extensive research in South Africa, using the Heavy Vehicle Simulator (HVS), revealed that some kind of roads are sensitive to overloading, such as those with shallow-structured pavements with thin cemented bases.

From its first motorway open to traffic in late 1980s, By the end of 2004, 34,000 km of expressway have been in use in China. While celebrating the great achievement in transport infrastructure, motorway pavement premature failure is gaining more and more attention within the field. It has been observed that a number of premature pavement failures occur 2-3 years after the motorways' open to traffic. And most motorway asphalt pavements' actual shorter service life is about 7-8 years, comparing with their design life of 15 years.

The premature failure of motorway pavement has two major forms, e.g. rutting and transversal cracking. Rutting is a major distress form found in asphalt pavements, especially when the ambient temperature is high. Rutting is caused by the accumulation of irreversible (or permanent) deformation in all pavement layers under the action of repeated traffic loading. Among the contributions of rut depth by the various pavement layers, the cumulative permanent deformation in the surface course of asphalt pavement is known to be responsible for a major portion of the final rut depth measured on the pavement surface. Studies recently performed in China, show that, the rutting mainly derives from the upper and medium surface HMA layers. Structural rutting originating in the subgrade is seldom observed. Figures 2 and 3 present the rutting observed on a Chinese motorway pavement. In Figure 3, it is clear that rutting originates mainly from upper and medium surface HMA layer.

Transverse cracking is very common on motorway semi-rigid asphalt pavement. Study shows that most of them are reflective cracking, which start at the hydraulically treated base layers, and progress towards the surface. The transverse cracking spaces 50 to 100 meter apart statically. Figures 4 and 5 present a transverse cracking observed on motorway pavement. The crack forms weak zone of pavement where water seeps into the road structure and becomes the starting point for other degradations.



Figure 2: Pavement rutting on Shijiazhuang-Anyang motorway in China

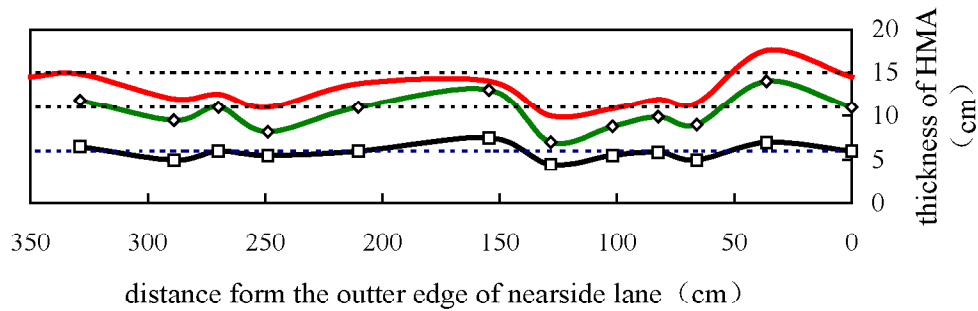


Figure 3: A pavement surface HMA layer profile on Shijiazhuang-Anyang motorway in China (red, green and blue curve represents surface of upper, medium and lower HMA surface layer respectively)



Figure 4: Transverse cracking originating from the hydraulically treated base

#### 4 A SIMPLIFIED MECHANIC ANALYSIS OF SEMI-RIGID ASPHALT WITH CRACKINGS

Transverse cracking is very common on Chinese motorway semi-rigid asphalt pavement. Although it is difficult to quantify its negative impact on the performance of pavement, there are laboratory and analytical proofs that these cracks may have significant impact on the pavement performance, such as bearing capacity and service life.

The cracks form weak zone of pavement where water seeps into the road structure and becomes the starting point for other degradations. As a result of the presence of cracking, the pavement layer is not a continuous layer any more. When a rolling wheel pass the cracked pavement, it will produce bigger pavement deflection near the cracking. The fatigue life will be shortened consequently. Moreover, once water seeps into the road structure through the surface reflective cracking, the pavement layers' interface bounding and road foundation may be seriously weakened.

As a case study, a pavement structure is selected, which consists of a 150 mm thick asphalt layer as surface layer, a 190 mm thick cement treated aggregate as upper base layer, a 190 mm thick lime and fly-ash treated aggregate as lower base layer, a 200 mm thick lime

stabilized soil as a sub base layer. The material properties of pavement layers are given in Table 2.

Table 2 Layer thickness and elastic material properties

layer	Thickness(mm)	Elastic modulus(Mpa)	Poisson's ratio
Asphalt surface	150	1400	0.25
Upper base	190	1500	0.25
Lower base	190	1500	0.25
Sub base	200	700	0.25
subgrade	---	40	0.35

In Figure 5, when the road foundation's modulus decrease, the surface deflection increase correspondingly. In Figure 6, the existence of smooth interface in pavement structure also result in bigger surface deflection.

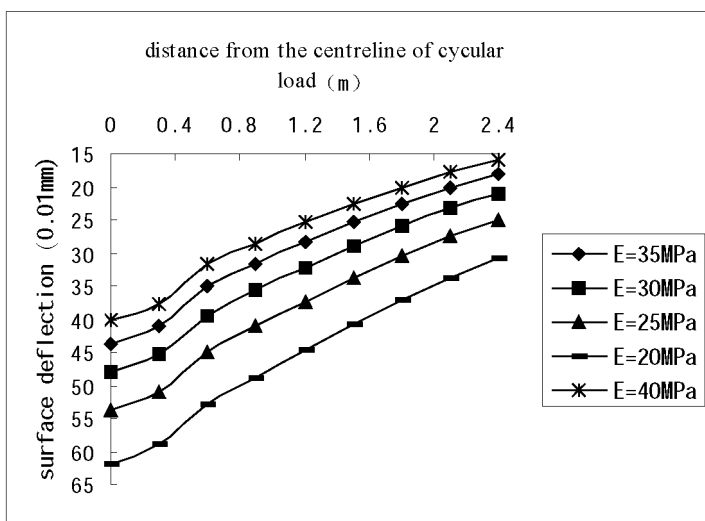


Figure 5: Impact of road foundation on pavement deflection

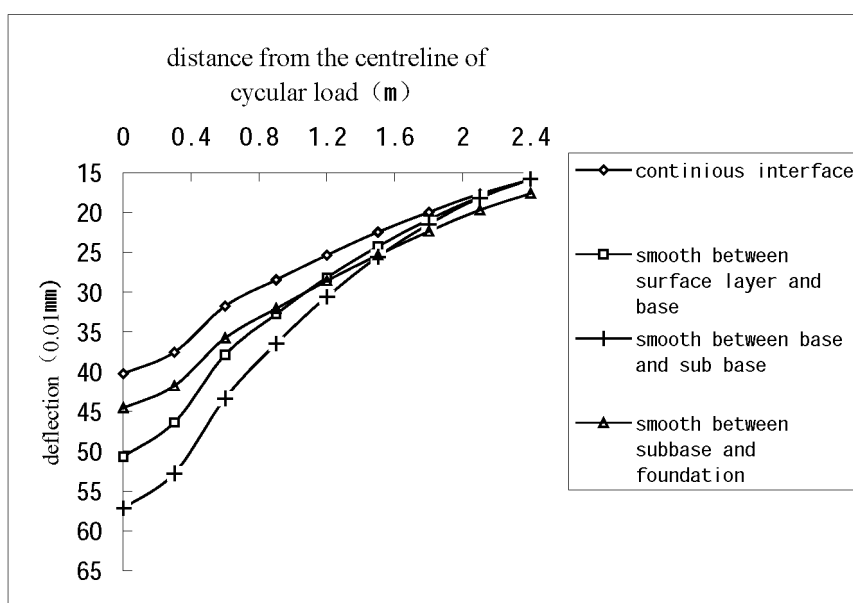


Figure 6: Impact of interface condition on surface deflection

## 5 CONCLUSION AND SUMMARY

Given the result that presented in this paper, we may come to the following summary and conclusions:

1. A number of premature failure have been noticed on Chinese motorway network. Rutting and transverse cracking are major failure pattern.
2. Overloaded heavy traffic caused more damage to the semi-rigid asphalt. The hydraulically treated base is more sensitive to overloading.
3. Due to the stiffness of hydraulically treated base, rutting observed on Chinese motorway pavement is restricted to asphalt surface layer. As to a 3-layer asphalt surface, the rutting mainly occurs in upper and medium asphalt layer.
4. A pavement layer with cracking is no continuous layer in some way. It will produce bigger pavement deflection under load. The fatigue life will be shortened consequently. Moreover, once water seeps into the road structure through the cracking, the pavement layers' interface bounding and road foundation may be seriously weakened.

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