Cause Analysis of Asphalt Pavement Rutting on Section N5 in Pakistan

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ABSTRACT: It was well known that rutting is one of the most common types of pavement distress for asphalt pavement under heavy vehicle loading in hot climate. In this study, the cause of rutting on highway N5 in Pakistan was reviewed in detail, mainly including climate conditions, pavement materials and traffic control. It was concluded that local conditions should be carefully considered for projects either designed or constructed by Chinese companies during the implementation of ‘One Belt, One Road’ strategy.

Keywords: Asphalt Pavement; Rutting; High Temperature; Pavement Design

BACKGROUND

Rutting as a surface depression in the wheel path is one of the primary pavement distress modes. There are normally two types of rutting, mixing rutting and subgrade rutting, of which the mixture rutting is a result of compaction/mix design problems. Rutting can cause severe safety concerns for vehicles travelling on pavements with ruts since ruts filled with water can cause vehicle hydroplaning. It is extremely hazardous because ruts tend to pull a vehicle towards the rut path as it is steered across the rut.

In 2010, Pakistan suffered a severe flood, infrastructure including highways were severely damaged. Chinese Government decided to provide assistance to Pakistan for the rehabilitation of the N5 and N55 road. The highway section from Halato Moro Section of N5 with a total length of 82Km is located in the province of Sindh in Pakistan is selected for analysis in this paper. The standard of this highway is equivalent to the first class of China. It is in the open lowland of alluvial plain of India River. The project corridor belongs to the subtropical climate with the characteristics of monsoon climate. The annual average temperature is between 24°C and 28°C with high temperature at around 46°C and low temperature at around 5°C. Due to the possible reasons such as extreme high temperature and overloaded heavy trunks etc., severe pavement rutting was found after some sections were open to public for a short time. A lot of lab tests were conducted for the new pavement structure of SAC (Stone Asphalt Concrete) and Superpave and trial road was paved as well to test the adaptability of the new pavement structure to avoid pavement rutting. While the cause of the rutting needs to be thoroughly studied.

PAVEMENT STRUCTURE

This section of the N5 highway is a rehabilitation/ reconstruction project. The pavement structure in the original design is as follows:
Table 1. The Original Pavement Structure.

<table>
<thead>
<tr>
<th>Measured Deflection(Ls)</th>
<th>Ls ≤ 50 (0.01mm)</th>
<th>50 &lt; Ls ≤ 95 (0.01mm)</th>
<th>95 &lt; Ls (0.01mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Course</td>
<td>19cm AC-16C</td>
<td>19cm AC-16C</td>
<td>19cm AC-16C</td>
</tr>
<tr>
<td>Base Course</td>
<td>/</td>
<td>20-34cm 5% Cement Stabilized Crushed Stone</td>
<td>34cm 5% Cement Stabilized Crushed Stone</td>
</tr>
<tr>
<td>Subbase Course</td>
<td>/</td>
<td>/</td>
<td>17cm 3.5% Cement Stabilized Crushed Stone</td>
</tr>
</tbody>
</table>

Since serious rutting problems were reported on constructed pavement, totally 2.8 kilometers test road section was constructed to verify the new pavement structure including Stone Asphalt Concrete (SAC in short) and Superpave (SUP in short). The proposed new pavement structure was adjusted to two options as follows:

**Option1:**

Table 2. Test Road Pavement Structure with Superpave as the Binder Course.

<table>
<thead>
<tr>
<th>Measured Deflection(Ls)</th>
<th>Ls ≤ 50 (0.01mm)</th>
<th>50 &lt; Ls ≤ 95 (0.01mm)</th>
<th>95 &lt; Ls (0.01mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Course</td>
<td>5cm SAC-16(Modified Asphalt)+6cm SUP20(Modified Asphalt)+8cm SUP25(Modified Asphalt)</td>
<td>5cm SAC-16(Modified Asphalt)+6cm SUP20(Modified Asphalt)+8cm SUP25(Modified Asphalt)</td>
<td>5cm SAC-16(Modified Asphalt)+6cm SUP20(Modified Asphalt)+8cm SUP25(Modified Asphalt)</td>
</tr>
<tr>
<td>Base Course</td>
<td>/</td>
<td>20-34cm 5% Cement Stabilized Crushed Stone</td>
<td>34cm 5% Cement Stabilized Crushed Stone</td>
</tr>
<tr>
<td>Subbase Course</td>
<td>/</td>
<td>/</td>
<td>17cm 3.5% Cement Stabilized Crushed Stone</td>
</tr>
</tbody>
</table>

**Option2:**

Table 3. Test Road Pavement Structure with SAC as the Binder Course.

<table>
<thead>
<tr>
<th>Measured Deflection(Ls)</th>
<th>Ls ≤ 50 (0.01mm)</th>
<th>50 &lt; Ls ≤ 95 (0.01mm)</th>
<th>95 &lt; Ls (0.01mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Course</td>
<td>5cm SAC-16(Modified Asphalt)+6cm SAC-20(Modified Asphalt)+8cm SAC-25(Modified Asphalt)</td>
<td>5cm SAC-16(Modified Asphalt)+6cm SAC-20(Modified Asphalt)+8cm SAC-25(Modified Asphalt)</td>
<td>5cm SAC-16(Modified Asphalt)+6cm SAC-20(Modified Asphalt)+8cm SAC-25(Modified Asphalt)</td>
</tr>
<tr>
<td>Base Course</td>
<td>/</td>
<td>20-34cm 5% Cement Stabilized Crushed Stone</td>
<td>34cm 5% Cement Stabilized Crushed Stone</td>
</tr>
<tr>
<td>Subbase Course</td>
<td>/</td>
<td>/</td>
<td>17cm 3.5% Cement Stabilized Crushed Stone</td>
</tr>
</tbody>
</table>
SAC-16 is selected as the surface wearing course in both option 1 and option 2 due to its good resistance to the deformation and the comparatively lower cost. For option 1, Sup-20 and Sup-25 are chosen to be the binder course. While in option 2, SAC-20 and SAC-25 are selected to be the binder course. SAC has a high percentage of the coarse aggregate and has a good anti-rutting ability, while the anti-rutting ability relies on the property of the coarse aggregate (See Figure 1). On the other hand, Superpave design method can take thorough consideration of the actual physical and traffic condition, which will contribute to a good adaptability to the anti-rutting ability.

![Figure 1. SAC Particle Skeleton.](image)

**SURVEY OF RUTTING CONDITIONS**

To understand the rutting type, rutting development and rutting distribution, a detailed survey was performed on the construction site, including the construction site laboratory, asphalt mix plant, mixing equipment of cement stabilized soil, gravel and crushed stone stockpile. In addition, coring, cutting, milling, settlement monitoring, deflection measurement, temperature measurement, extraction and sieving were performed for sections with serious rutting to investigate the cause of rutting and measures to control it.

1) K568+940~K576+000 (7.06km)

The highway was open to traffic before the top surface layer was placed to cope with the traffic pressure. Asphalt mixture segregation was observed on the surface of middle surface layer not long after it was open to traffic. Slight rutting was observed on the pavement with surfaced fine aggregates and shoved coarse aggregates. The pavement was cored at location K575+783.5, which was relatively dense (See Figure 2). The thickness for middle asphalt surface layer, lower asphalt surface layer and cement stabilized crushed stone base layer are, 6cm, 8cm and 25cm, respectively. The cored sample has a good bond between layers.
2) Sections with cement stabilized crushed stone base layer sealed with crushed stone
These four sections include K548+000~K548+380(0.38km), K549+860~K550+000(0.14km), K552+000~K555+650(3.65km), K561+475~K568+940(7.465km), which has a total length of 11.635Km. These four sections were open to traffic directly on the seal layer with crushed stone (See Figure 3). No reflective cracking from the cement stabilized crushed layer was observed on the seal layer. However, light rutting was observed on the seal layer.

3) Sections with medium rutting
Average rutting depth for section K549+300~K548+30 is 0.5cm with a maximum depth of 1.2cm. Average rutting depth for section K547+700~K542+000 is 0.9cm with a maximum depth of 2.3cm. Average rutting depth for section K535+200~K527+000 is 1.2cm with a maximum depth of 2.9cm. Asphalt mixture segregation and shoving were observed on the pavement surface. Coring at K533+893.5 indicated that the bond between surface layer and base layer was lost (See Figure 4). The surface layer has a thickness of 19.6cm, which was relatively dense.
4) K527+000–K524+000
Serious rutting was observed on this section of the highway with the maximum rutting at 21cm (See Figure 5 and Figure 6). Distortion and serious aggregate shoving was observed on the pavement surface. No cracking was observed in the cement stabilized base layer after the surface layer was milled. Leveling survey indicated that there was no settlement for the base layer.

RUTTING ANALYSIS
1. Coring and binder extraction tests were performed on sections with slight, median and severe rutting, which indicates that the construction quality of all the road sections are fairly good. Meanwhile, the extracted base course is dense, uniform and well-graded and no cracks are found. It can be concluded from the result of deflection test that the rutting on pavement surface layer was not caused by the damage of the base course.

2. For the section from K568+940 to K576+000, medium rutting with deflection about 1-2cm was observed, which was placed with only middle surface layer and lower surface layer. Meanwhile, segregation was observed on the pavement surface, including fine aggregates floating and coarse aggregates shoving. In addition, wearing
was observed on the surface layer. Destruction of aggregate gradation of the asphalt mixture was also observed. In the future, aggregate gradation should be adjusted and asphalt binder should be modified for mixtures of middle and lower surface layer after milling was performed.

3. Medium rutting with 2-4cm was observed on road section from K549+300 to K548+300. Little segregation can be seen while aggregate shoving can be observed on some sections. The cored samples are dense and intact. The modified asphalt in the upper layer is in good condition while the coarse aggregate in the middle and lower surface layer is less than required. Lots of flaky aggregates were observed. There is no clear interface between asphalt layers. Cored samples show that the cement stabilized layer is dense and in good conditions, and no cracks can be found. It is recommended that the upper and middle pavement layer should be milled and an asphalt concrete layer with adjusted gradation and modified asphalt can be overlaid with a thickness of 8-14 cm.

4. Severe rutting of over 10cm was observed on section from K527+000~K524+000. The gradation of the existing asphalt mixture was completely damaged. The existing pavement was determined to be in a bad condition during the field investigation. The existing asphalt layer was recommended to be milled before additional cement stabilized layer and an overlay with gradation adjusted and binder modified asphalt mixture can be constructed.

**CAUSE ANALYSIS**

(1) Extreme climatic condition
The local conditions of N5 section have a negative effect on the pavement deflection and surface layer shear resistance. After construction, there were two entire months with average night time temperature at 30°C and average daytime temperature at 40°C. The extreme high temperature is around 48°C to 50°C with pavement surface temperature over 70°C, which is above the softening point of the asphalt binder. The shear resistance of asphalt mixture is greatly reduced, which will cause the shear-type rutting under heavy vehicle loading\(^5\). Field investigation indicates that severe rutting was also observed on sections repaired by the Pakistan companies after extreme high temperature. See Figure 7 for the extreme climatic condition in June, 2014.

![Figure 7. Extreme high temperature in June, 2014.](image)

(2) Low performance properties for local construction materials
Construction materials purchased from China will be expensive, which will have high price–performance ratio. The locally available asphalt binder has high content of wax, which is close to the allowed up limit in the specification. It is well known that the higher the content of wax, the lower is the high temperature performance. It is known...
that the higher of the wax content is, the lower stability of asphalt in high temperature will be (the Content of Wax was tested to be 1.8%-1.9%). Meanwhile, the strength of local aggregates is relatively low. The crushing value for local aggregates is also high. In addition, the content of flat and elongated aggregates is high. Those values are close the allowed up limit in the specification. Therefore, low performance properties for local construction materials, to some extent, contributed to the severe rutting [7].

(3) Instability of the Base Course
The base course of the pavement structure was filled with silty soil which is difficult to compact and with a poor stability and strength (See Figure 8). The lack of stable base course leads to the deformation of the whole pavement structure. A crushed stone base course layer is proposed to replace the existing silty soil base course.

![Figure 8. Existing Base course filled with silty soil.](image)

(4) The pavement was opened to traffic too soon under heavy traffic loading, which also not well controlled. Some sections were open to traffic by opening one and two directions even when the construction of asphalt surface layer was not fully completed at the request of the recipient country. The heavy vehicle has a very high proportion in the traffic (over 60% of the traffic is heavy vehicle, mainly 3-axle to 5 axle oil tanker, container and heavy truck etc. whose load reaches 60 to 100 tones) [6]. Furthermore, to make it worse, the recipient country couldn’t work out effective traffic management policy upon the heavy load vehicles and even overloaded vehicles (See Figure 9), which increased the probability of the rutting and its severity of the rutting.

![Figure 9. Overloaded trucks on the road.](image)

(5) Misconduct after opening to traffic
After the severe rutting occurred, the recipient country requested the contractor to mill the rutted surface layer in order to guarantee the driving safety, which brings damage to the strength of the pavement structure and anti-rutting ability. It accelerated the rutting damage to the road which has been constructed.
(6) All pavement design was conducted according to the Chinese specifications. However, the local high temperature, heavy traffic loading, and bad management of the Pakistan side were not carefully considered. The design was based on the traffic volume provided by the Pakistan side with theoretical deflection as the criteria. The shear resistance of middle and lower surface layer was not considered. Not proper research was conducted in terms of asphalt binder content, filler bitumen ratio and aggregate gradation during the design\textsuperscript{[2]}.

\begin{itemize}[leftmargin=*]
  \item Rutting Depth Survey Result of the Proposed New Pavement Structure in the TestRoad Section:
  \begin{enumerate}
    \item Road section from K525+550-K 525+850, which has a pavement structure with 5cm SAC-16+6cm SAC-20+8cm SAC-25, only one survey point was found to have a slight rutting with a depth of 0.1 cm during this section;
    \item Road section from K526+600-K 526+900, which has a pavement structure with 5cm SAC-16+6cm SAC-20+8cm SAC-25, only two survey points were found to have a slight rutting with a depth from 0.1-0.2 cm during this section;
    \item Road section from K525+900-K 526+550, which has a pavement structure with 5cm SAC-16+6cm SUP-20+8cm SUP-25, only two survey points were found to have a slight rutting with a depth from 0.1-0.2 cm during this section.
  \end{enumerate}
\end{itemize}

It can be seen from the rutting survey (See Figure 10 and Figure 11) result\textsuperscript{[6]} that the more suitable pavement structure shall be selected to adapt to the actual climate and traffic conditions, hence severe road damage e.g. rutting will be reduced to a minimum extent.

\begin{figure}[h]
  \centering
  \includegraphics[width=\linewidth]{figure10}
  \caption{Rutting Depth Survey of the New Pavement Structure.}
\end{figure}

\begin{figure}[h]
  \centering
  \includegraphics[width=\linewidth]{figure11}
  \caption{The proposed Test Road section with new pavement structure is in very good condition after being open to public after 7 months.}
\end{figure}
CONCLUSIONS
Based on the field investigation of pavement rutting combining the lab tests and the trial road observation, early shear damage of surface layer under local extreme high temperature and heavy traffic loading was determined to be main cause. Meanwhile, the fact that the extreme climatic and traffic conditions were not fully considered also contributed to the severe rutting, which was not specifically addressed during design and construction stages. Therefore, a more adaptable pavement structure shall be selected according to the actual physical and traffic condition. Both SAC and Superpave pavement structure are more adaptable to the high temperature area comparing to the AC (Asphalt Concrete) structure. Simultaneously, the Chinese specifications were implemented without consideration of local condition is also a contributing factor to the severe rutting. It was recommended that local conditions should be carefully considered for projects either designed or constructed by Chinese companies during the implementation of ‘One Belt, One Road’ strategy.

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