Proceedings of the International Conference on Civil, Structural and Transportation Engineering
Ottawa, Ontario, Canada, May 4 – 5, 2015
Paper No. 327

Effect of Climate Environmental Conditions on Pavement Overlay Thickness

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***Abstract*-** The main objective of this research is to study the effect of hot climate environmental condition on overlay thickness of asphalt pavement. An experimental and analytical approach was implemented to carry out this investigation. Field measurements included the minimum and the average and the maximum pavement temperature during the various months of the year. Pavement temperatures at various depths in summer days were observed. The analytical approach involved the application of a multi –layer elastic system (shell) program that considers the temperature of the pavement layers and the asphalt mix properties. Results of the analysis indicated that the pavement temperature in summer is about 2.5 times the pavement temperature in winter. While the air temperature in summer exceeds four time the air temperature in winter. The calculated overlay thickness increases when summer temperature conditions are considered. Results also indicated that the overlay thickness reaches about 14 cm if the air temperature 35c. The study concluded that the pavement temperatures are directly related to major climate factors of air temperature and solar radiation.

***Keywords*:** Overlay, pavement temperature, pavement cracking, damage mechanism.

1. Introduction

1. 1. Background

Pavement damage is considered one of the worthy attention issues by the specialists in highway industry (Alexander and Noureldin, 2003), as the roads and airports which are established by using asphalt pavement are considered the main artery of raising countries economy and developing them through the easiness of travelling inside and outside these countries, and subsequently moving and bringing goods, marketing products and exchanging all kinds of economic and cultural benefits among their peoples. Caring for this damage and determining its causes and finding ways of treatment is an inevitable necessity for the safety of paved establishment and keeping them for as long time as possible, this is to benefit from them and to make the best use.

Many studies prove that the difference between the temperature of the air and the temperature of the pavement may reach about 20-25 degrees which leads to a big difference in pavement temperature according to the temperature of the air. The surface layer of the asphalt pavement is affected by the sun radiation too. As the solar radiation in this area is more than in any other area (Haroun, 2005)

Hot dry regions are characterized by their very high service pavement temperature and substantial daily temperature fluctuation, sometimes fluctuating between the maximum of 70 degrees to the minimum of 10 of pavement surface temperature, hardening of bitumen binders in these regions takes place due to the action of different reactions that occur in service and result in loss of its desirable properties. These reactions include: oxidation, volatilization, and polymerization (SHRP 1993),

1. 2. Literature Review

Pavements subjected to hot environmental conditions are characterized by their substantially high maximum temperatures and low precipitation rate. North Africa and Middle East are typical examples of regions experiencing this climatic type. In Libya, where most of its area lies within this region, a large network of highways and numerous airfields were constructed during the last four decades using asphalt concrete.

The most common type of pavement rehabilitation is the asphalt concrete (AC) overlay. An understanding of the factors affecting the long-term performance of overlays should enable pavement engineers to build overlays with longer service lives. Original pavement conditions overlay thickness, mix properties, traffic characteristics, and weather conditions can all affect the long-term performance of AC overlays. There are some models that were developed to evaluate the performance of the overlay. One of these models was developed to predict the service life of the overlay mat in Ontario. In 1989, the Canadian Long-Term Pavement Performance (C-LTPP) project was established with a main objective of identifying the best procedure for pavement rehabilitation. Overlays with different characteristics were constructed over the existing pavement and their surface conditions were monitored.

The overlay service life increases with the increase of overlay thickness. However, within the range of the data used in the analysis, the economic value of the increase of expected service life due to the use of thicker overlays may be questionable. Such a finding affirms the conclusion by Behest et al which was based on quantitative economic analysis (Ying-Haur Lee (2009). Using recycled AC under the favourable conditions of low traffic level and dry pavement conditions yields almost the same service life for a virgin AC.

Several mix design method can be found in the technical literature, all of which focusing on producing high performance dense bituminous mix. Never the less, most of these methods do not seem to directly address the unique conditions of the performance of dense bituminous mixes in hot arid regions. Cracking and disintegration of road pavements still appear in different sections of the recently constructed road.

The problem comes from the fact that the substantial daily temperature fluctuations increase the bituminous mix stiffness which makes the pavement surface vulnerable to thermal cracking. In such a situation, only lower viscosity binder or reducing the hardening rate of the bitumen binder will be beneficial in reducing the potential of thermal cracking. It is generally accepted that bitumen hardening is a good relative measure of asphalt durability .many researchers have reported the poor quality of bituminous pavement due to premature aging problems in hot and dry regions in different parts of the world (FHWA 2004).

2. Data Collection

2. 1. General

Since the temperature of the pavement surface layer is affected by solar radiation more than the temperature of the atmosphere , so when the atmosphere temperatures are equal, the pavement temperature and its fluctuation increase in the hot dry areas in comparison with other areas as a result of the great amount of solar radiation which affects the pavement in these areas. The pavement in hot areas , damp areas is characterized by the least change of temperature over one day, and that happens because clouds blocks the solar radiation in the intervals, so the effect of the environmental conditions on the pavement in the hot dry areas is greater than it is in other areas. Hot areas are classified as follows:

Hot, dry areas characterized by:

- The maximum temperature is ≥ 32 degrees
- The rainfall rate is < 250 mm annually.

Hot, damp areas characterized by:

- The maximum temperature is ≥ 32 degrees
- The rainfall rate is ≥ 250 mm annually.

2. 2. Air and Pavement Temperature

This part is depending on measuring the asphalt pavement temperatures with different depths. Holes about 3/4 inch in diameter where bored in the asphalt concrete by using a special drill down to depths of 5, 10, 15, 20, and 25 cm from the surface. The holes where then filled with a light bituminous cutback. The laboratory glass thermometers with a temperature range of (-10 to +110) C. with an accuracy of ±1 c, where inserted in the holes to the depth required for the surface temperature measurements the mercury bulb of the thermometer was painted asphalt cement and laid on the surface and held there by a thin coat of asphalt cement.

Temperature readings where started for recording about one day after the thermometers had been fixed in positions. The temperature measurements where taken at 6:00 am, 10:00 am, 2:00 pm, and 6:00 pm on a certain days of the year, which represent the range of the various weather conditions. For measuring surface pavement temperatures, a mercury thermometer was used with asphalt - coated bulb resting in the surface. Half of surface area of the bulb was touching the pavement surface, and the other half was exposed to the air. The temperature recorded where concerned representative of the month of solar radiation absorbed by the asphalt – filler coating film and not that of the surface of the exposed course aggregate on the surface, which is of lower temperature. Table 1 presents a summary of the minimum, average and maximum temperatures measured for this investigation.

Table 1. Minimum, Average and Maximum Air Temperature for Sabha Airport

Months	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Min. Air Temp. (c)	-1	2	3	6	15	14	14	13	4	5	4	-1
Min. Pavement Temp.(c)	17	19	20	22	28	27	26	25	20	17	15	14
Average Air Temp. (c)	23.2	30.3	36.4	42.5	45.3	40.4	42.6	39.6	30	24.3	19.8	19.3
Average Pavement temp.(c)	33.5	41	51	61	65.5	58	62	54.5	39	34	29	28
Max. Air Temp. (c)	32	41	44	48	49	47	47	45	39	29	25	24
Max. Pavement temp. (c)	50	60	63	68	70	69	67	65	59	48	43	40

3. Analytical Approach - Shell Design Analysis

The Shell Pavement Design Manual (SPDM) enables the designer to introduce the effects of temperature, traffic density. On the pavement, the asphalt mixes being characterized with respect to stiffness and fatigue behavior, and bitumen type. The SPDM represents the first practical, analytically based design method for asphalt (road) pavements.

The computer program package fully reflects the Shell philosophy on the thickness design of flexible pavements. Thus the package essentially follows the methods and procedures of the SPDM. The SPDM-PC guides the user through the calculation procedures by means of user friendly menus and panels. The user is advised, though, to use the Shell Pavement Design Manual and its Addendum as references in order to fully understand the philosophy, the system, the assumptions, and their implications.

The SPDM-PC program consists of three parts:

1. Structural thickness design for new (asphalt) road pavements
2. Estimation of permanent deformation (rutting) in the asphalt layers.
3. Structural thickness design for (asphalt) overlays on existing road pavements.

The BISAR program is included as a subroutine to calculate strains at critical points in the pavement structure. The individual sub-layers of the pavement (sub grade, sub-base, asphalt and overlay) are characterized by Young's modulus of elasticity, the Poisson ratio and the layer thickness. Within the BISAR model the structure is assumed to have the following characteristics:

- The pavement and the sub base consist of horizontal layers of uniform thickness resting on a semi-infinite subgrade
- The layers are homogeneous and extend infinitely in the horizontal direction.
- All the materials are isotropic, purely elastic and have a linear stress-strain relationship.

4. Analysis and Discussion

Figure 1 shows the relationship the thickness overlay and the elastic modulus of the asphalt layer. The overlay thickness decreases as the elastic modulus increases. It was found that the maximum overlay thickness ($H_{overlay}$) value was (240 mm) at an elastic modulus ($E_{overlay}$) value of (660 Mpa). The elastic modulus of the asphalt concrete mix depends on mix properties and service temperature. It could be noted that the AASHTO pavement design method considers the elastic modulus of the asphalt concrete mix in determining the layer thickness. The reduction in overlay thickness is dramatic for elastic moduli values less thatn 5000 MPa (the slope of the curve is almost for Elastic moduli values greater than 5000 MPa). Due to complexity of determining the elastic modulus of an asphalt concrete mix and its sensitivity to the test boundary conditions, the pavement design methods consider wide ranges of elastic moduli as input variable for design procedures (Carlos 2005).

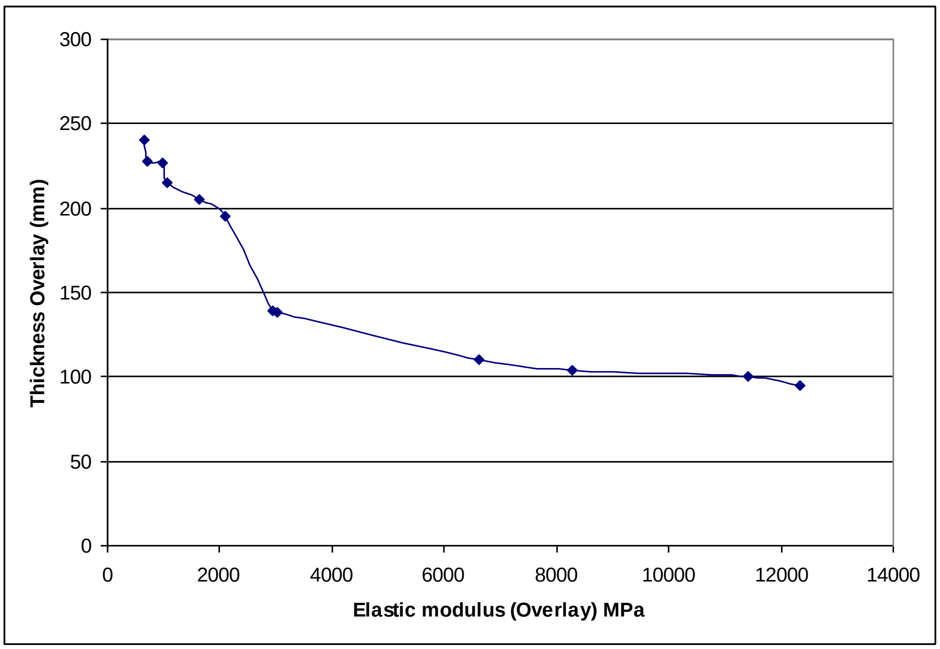

Fig. 1. Relationship Between Overlay Thickness ($H_{overlay}$) and the Modulus of Elastic($E_{overlay}$)

The relationship between air temperature and the thickness $_{overlay}$, is illustrated in Figure 2. The thickness of overlay course increases as the air temperature increases. Field data collection for this investigation indicated that the maximum air temperature in summer is about 50 C. However, the pavement temperature is usually much higher that the air temperature. Table 1 above indicates that the site air temperature is 50 c and the corresponding pavement is 70 C. This means that the required overlay thickness would be higher than winter condition requirements.

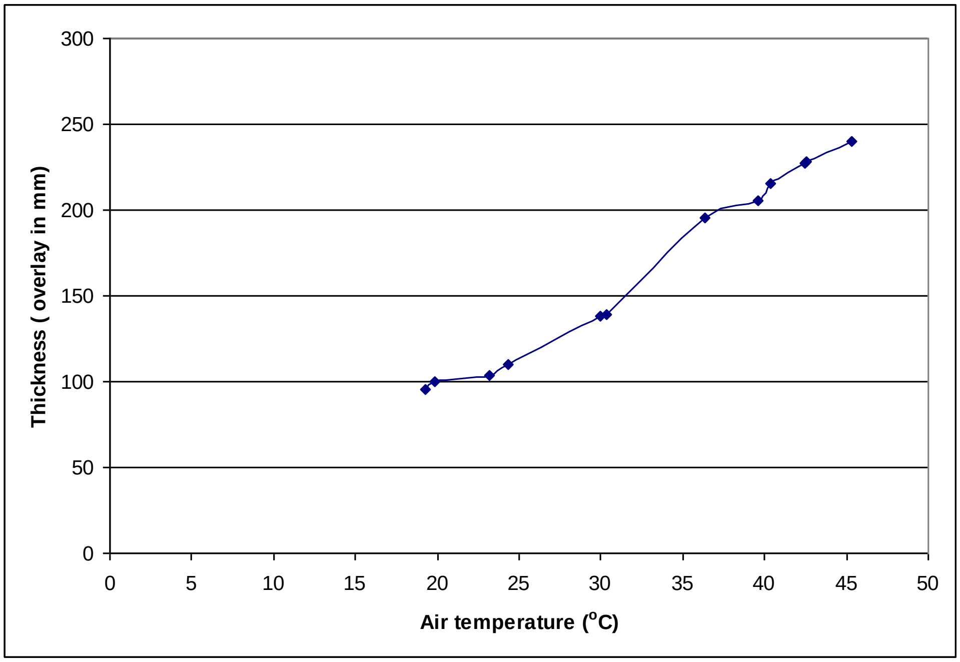

Fig. 2. Effect of Air Temperature on Overlay Thickness ($H_{overlay}$)

To investigate the combined effect of both air temperature and elastic modulus of the overlays asphalt concrete mix, the relationship between the air temperature and elastic modulus is illustrated in Figure 3. It could be noted that the elastic modulus decreases as the air temperature increases. This means that if both conditions exist (i.e., both high temperature and low elastic modulus value), the required overlay thickness will be extremely high to withstand both effects. In other words, low elastic modulus requires high overlay thickness and high air temperature also requires high overlay thickness.

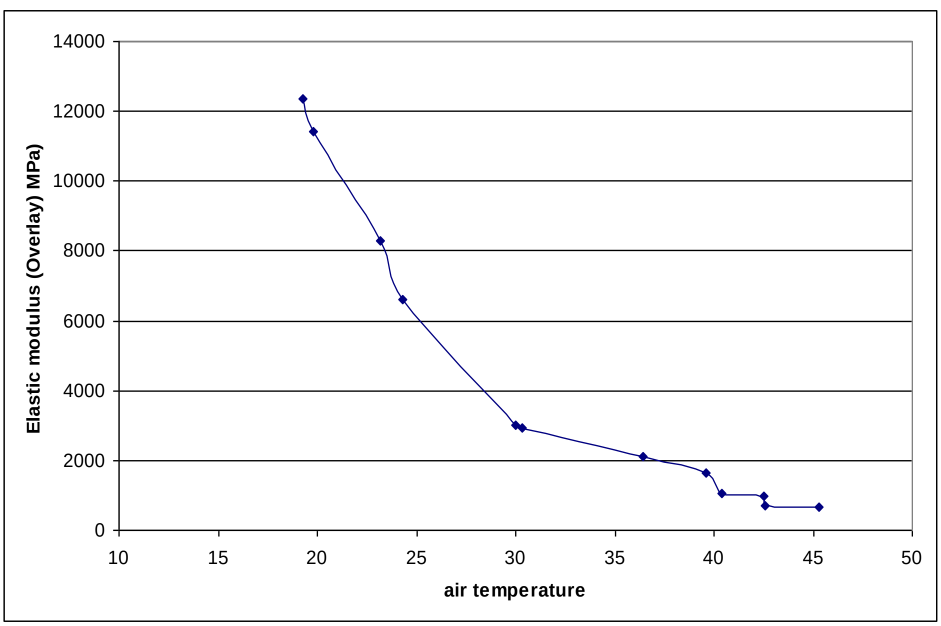

Fig. 3. Effect of Air Temperatures on Elastic Modulus $_{overlay}$

Figure 4 illustrates the effect of base course thickness on required overlay thickness, It was found that the maximum H overlay (240 mm) occurs at an existing surface course thickness of 70 mm. However, most of the existing surface course layer thickness is usuall greater than 80 mm which means less overlay thickness requirements.

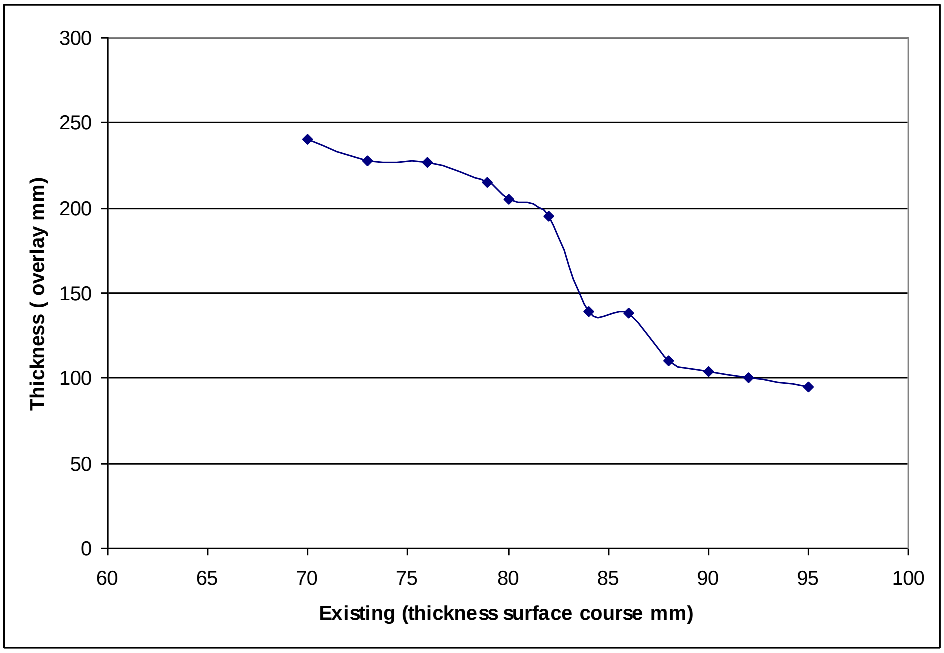

Fig. 4. Effect of Existing Surface course Thickness on Overlay Thickness

The effect of the existing base course thickness on required overlay thickness is illustrated in Figure 5. It can be noted that base course thickness has a little effect on overlay thickness as most of the base course thickness are greater than 100 mm after which the slope of the relationship is almost flat.

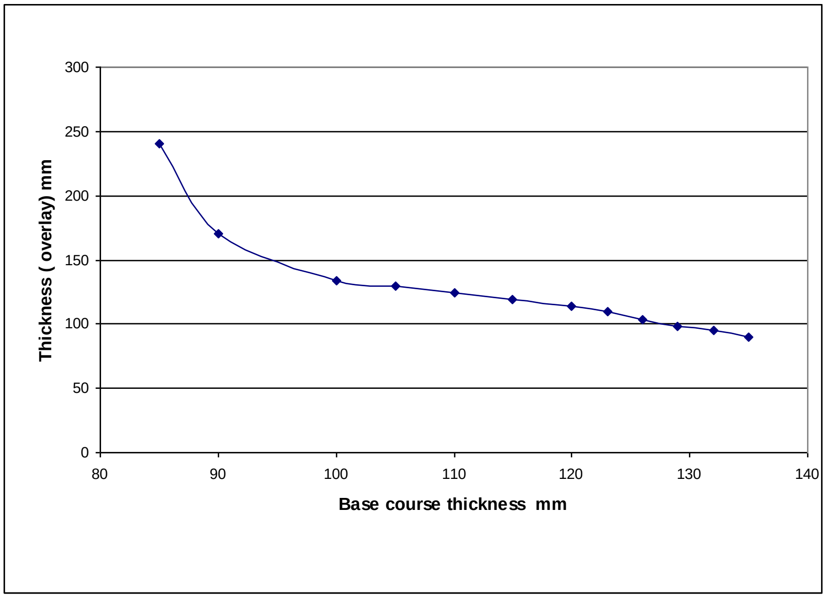

Fig. 5. Effect of Base Course Thickness on Overlay Thickness

Figure 6 indicates the relationship between the air temperature and the crack width observed in the pavement surface layer. High air temperature will lead to less crack opening due to the expansion of asphalt pavement in summer environmental conditions. Max crack width can be observed in winter condtion where the air temperature is about 15 C.

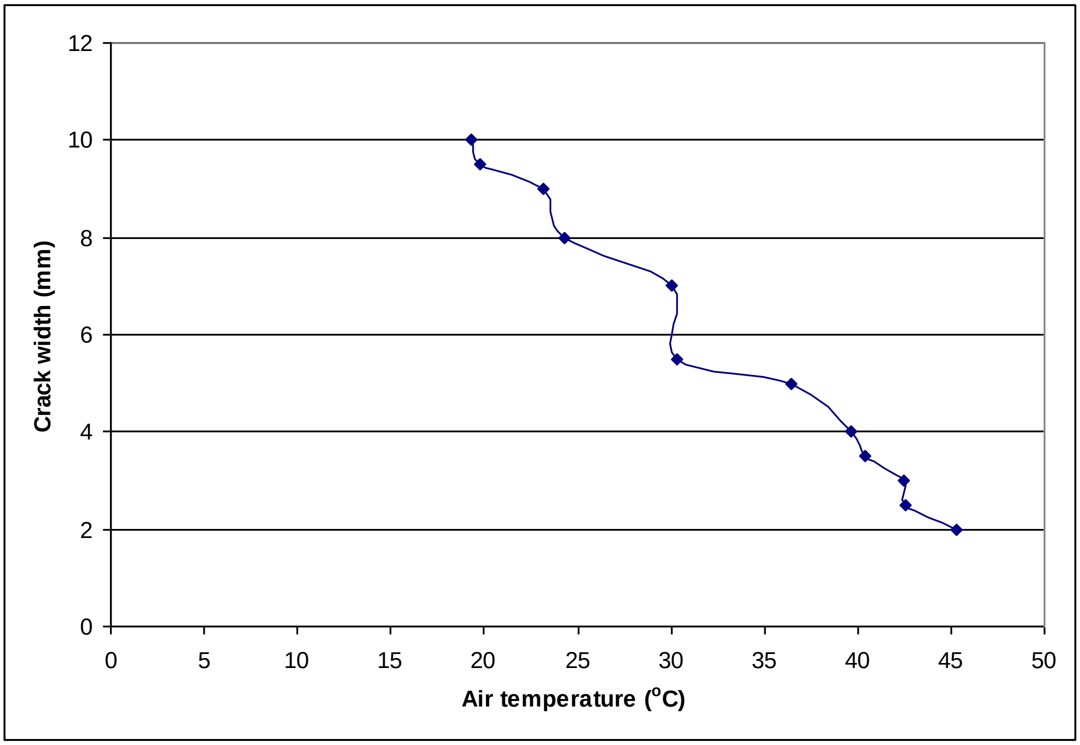

Fig. 6. Effect of Air Temperature on Crack width

5. Conclusions

Through the analysis and discussion of results, the existing asphalt mix can not resist the high and low temperature requirements. It is required to improve the binding asphalt material to enhance its physical and mechanical properties and improve its flexibility at the lower temperatures (to prevent the shrinkages cracks) and increase the solidity of asphalt mix at the high temperatures (to prevent distortions) and because asphalt is not able to fulfil the higher and lower temperature requirements, so suitable bitumen should be selected according to an advanced design method such as the Superpave system which consider temperature susceptibility in mix design.

- The pavement temperature is directly related to major climate factors such which are air temperature and solar radiation. The pavement temperature is higher than the air temperature by 20 degrees centigrade.
- High air temperature requires greater overlay thickness to resist pavement deformation take place in summer conditions.
- Low asphalt concrete elastic modulus requires greater thickness of overlay. The combined effect of air temperature and elastic modulus of asphalt concrete mix leads to maximum requirements of overlay rehabilitation.
- The thickness of the existing base course has a little effect on required overlay thickness isas most of the pavement structures have base course thicknesses greater than 100 mm.

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