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Design and Construction of Pavement: Introduction of New Approaches in Roads and Highways Department

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Abstract

Roads and Highways Department, Bangladesh was long been using AASHTO Guide for Design of Pavement Structures 1993 for designing flexible pavement which uses Empirical formula. It was not possible to set the limiting criteria of pavement deterioration such as rutting and cracking in this design process. Recently a number of software have been developed to analyze stress, strain and deflection in pavement layers which are now being used to check the adequacy of the Empirical Design. Use of Polymer Modified Bitumen (PMB) as a Performance Grade Bitumen has added benefit against rutting and cracking. Construction of Continuously Reinforced Concrete Pavement (CRCP) is giving better riding quality with limited maintenance and longer life.

1 Introduction

Not very far, all the major roads, including the national highways, under Roads and Highways Department (RHD) were being designed by following the 'AASHTO Guide for Design of Pavement Structures 1993'. This is an empirical method developed in the USA long before in 1960's. Considering the local conditions, the designs were compared with Indian Road Congress (IRC) and Overseas Road Note (ORN) catalogues. After the concept of stress-strain in pavement structures became clearer, many countries have already switched over to either full Mechanistic Design or Mechanistic-Empirical Design. RHD has also endeavored to these methods. It has also moved to Continuously Reinforced Concrete Pavement (CRCP) from Jointed Reinforced Concrete Pavement (JRCP) in Rigid pavement design. Apart from that, Polymer Modified Bitumen (PMB) in wearing course is used to prevent rutting. The following paragraphs describe the reasons behind adopting these methods in pavement design..

2 Mechanistic-Empirical Design

The Empirical Method (AASHTO 1993) uses the fallowing formula in designing of flexible pavement:

$$\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07$$

When the values of W_{18}, Z_R, S_0, ΔPSI, $M_R$etc. are inserted in the above formula then Structural Number (SN) appears which is solved with the following formula:

$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3+\ldots..$

Here the layer thicknesses (D_1, D_2, D_3etc) are selected based on the layer coefficients (a_1, a_2, $a_3$etc) and drainage coefficients (m_1, m_2, $m_3$etc).
But in this design method the designer remains in dark about the two critical strains in pavement:

1. Horizontal tensile strain at the bottom of asphalt layer and
2. Vertical compressive strain on the surface of subgrade.

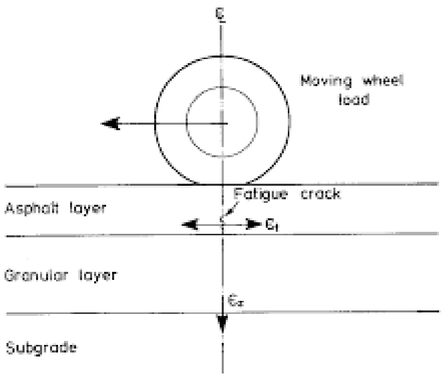

Fig 1: Critical strain in flexible pavement

The horizontal tensile strain occurs maximum at the bottom of asphalt layer. When this tensile strain exceeds its threshold value, cracking initiates and propagates upwards. This is called fatigue cracking. On the other hand, when the vertical compressive strain on the subgrade exceeds a certain level rutting occurs. Therefore, the designer should proportion the pavement structure in such a way that the above two critical strains do not exceed in design life. If the asphalt thickness is not enough to take the tensile stresses in the upper layers, then thicker aggregate layers in the bottom will be of very little use. The Mechanistic-Empirical Design takes account of these two critical strains.

As its name implies, Mechanistic-Empirical Design is a combination of Mechanistic and Empirical Design. AASHTO already have released Mechanistic-Empirical Pavement Design Guide 2008.Austroads also have published their latest edition on this design method in 2017. Both Guides generally follow the following 4 steps:

1. Prepare a Trial Design
2. Set the threshold values of critical strains
3. Analyze the Trial Design by software to check its adequacy against cracking and rutting
4. Revise the Trial Design if required.

In preparing the Trial Design, AASHTO Guide for Design of Pavement Structures 1993 can be followed. Different agencies such as AASHTO, Asphalt Institute (AI), Austroads have developed different failure criteria for cracking and rutting among which 2 formulas given by Austroads are given below:

a. For Fatigue Cracking:

$$N = \frac{1}{n} * \frac{SF}{RF}\left[\frac{6918(0.856Vb + 1.08)}{E^{0.36}\mu\varepsilon}\right]^5$$

b. For Rutting:

$$N=\left[\frac{9150}{\mu\varepsilon}\right]^7$$

Here N is the number of repetitions of load (ESALs) a pavement can take before it fails in cracking and rutting respectively.

AASHTO and Austroads use MEPDG and AustPADS software respectively. These two software require a number of inputs collection of which need long time. However, two other software- KENPAVE and GAMES are easily available without any cost. KENPAVE and GAMES have been developed by Yang H. Huang and Japan Society of Civil Engineers (JSCE) respectively. These two software need minimum number of inputs to analyze the stress, strain and deflection in the pavement structure. So, RHD used these software to develop Mechanistic-Empirical Design.

The following Table is the summary of a new flexible pavement designed for ESALs of 58 million in 20 years. The initial thicknesses were selected following the AASHTO Guide for Design of Pavement Structures 1993.

Then critical strains - tensile strain at the bottom of asphalt layers (142 and 167 micro strain) and compressive strain at the top of subgrade (712 micro strain) were calculated as per Austroads formula. Finally, the critical strains were checked by KENPAVE software and the initial thicknesses were revised to make the design safe.

Table 1: Summary of Obtained Strain, Allowable Load Repetitions & Design Life using KENPAVE software

	Pavement Composition (mm)	SN		Fatigue Criterion			Rutting Criterion		Design Life in years, should not be less than	Remarks
		Required	Provided	Tensile Strain at bottom of (WC+BC) layer, µ-strain, should not to exceed	Tensile Strain at the bottom of ATB layer, µ-strain, should not to exceed	Allowable Load Repetitions, MSA, should not be less than	Compressive Strain at Top layer, µ-strain, should not to exceed	Allowable Load Repetitions, MSA		
				142	**167**	**58**	**712**		**20**	
INITIAL THICKNESS	WC 50 BC 60 ATB 100 AB 100 SB 170 ***Total 480***		4.69	115.4	210.1	18.5	271.8	9.11E+10	6.4	Design is unsafe
Trial 1	WC 50 BC 70 ATB 100 AB 100 SB 150 ***Total 470***	4.64	4.75	112.6	198.6	24.51	270.8	9.34E+10	8.49	Design is unsafe
Trial 2	WC 60 BC 100 ATB 100 AB 100 SB 150 ***Total 510***		5.41	96.4	158.9	74.73	224	3.62E+11	25.87	**Design is safe**

WC = Asphalt Wearing Course
BC = Asphalt Binder Course
ATB = Asphalt Treated Base Course
AB = Aggregate Base Layer
SB = Aggregate Sub Base Layer

The above Table shows that the trial pavement designed after following AASHTO Guide for Design of Pavement Structures1993 was not enough to satisfy the failure criteria for cracking and rutting during its design life. The 2nd trial meets both the criteria. Therefore, it was selected as final design.

3 Performance Grade Bitumen

Bitumen what we use in flexible pavement is a viscoelastic material. At high temperature it behaves as a viscous fluid while at low temperature it behaves as an elastic solid and rebounds to its original shape when load is relieved. In between two extreme temperatures such as that is found in most pavement structures, it shows both characteristics of viscous fluid and elastic solid. This unique characteristic has made the bitumen suitable as a binder material in flexible pavement.

When load is applied to a flexible pavement 2 primary stresses are developed in the asphalt – vertical compressive stress within the asphalt layer and horizontal tensile stress at the bottom. Therefore, the asphalt must be strong enough to withstand both the stresses. If it fails to take the compressive stress, permanent deformation, called rutting, occurs. Similarly, failure to withstand horizontal tensile stress leads to fatigue cracking.

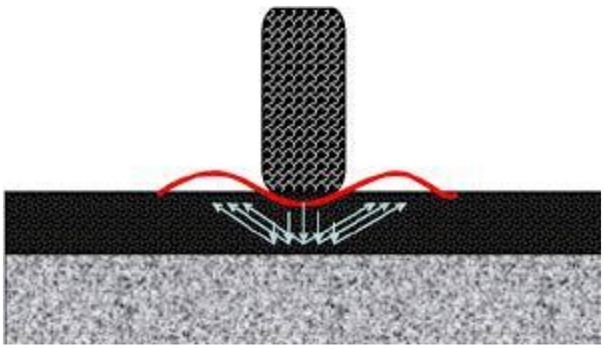

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Fig 2: Rutting from weak mixture

Fig 3: Fatigue cracking

To get rid of these two failure criteria, Asphalt Institute has developed Superior Performing Asphalt Pavement, commonly called "Superpave." It prescribes an improved system for specifying aggregate, binder and mix design. This system has the unique nature that it is a performance-based specification system.

RHD was using Penetration Grade (60/70) bitumen as binder for long time. This type of bitumen is specified by its penetration, viscosity and ductility which are mostly empirical. For example, penetration test represents the stiffness of the asphalt and has very little relationship with the performance in the field. Moreover, these tests do not reflect the pavement temperatures in the field, that is, not a performance-based specification.

The main objective of a performance-based specification of bitumen is to represent the field conditions at different stages of life of bitumen. Initially bitumen is selected based on the 7-day maximum pavement temperature 20 mm beneath the surface. Then it is adjusted to reflect the vehicle speed and loading conditions. This bitumen is denoted by PG 64-10, PG 76-22 etc. PG means Performance Grade. The upper value next to it represents the maximum pavement temperature (adjusted) bitumen can exhibit its required properties. The lower value such as -10 or -22 represents the low temperature the bitumen can withstand. The maximum temperatures have been specified as 46, 52, 58, 64, 70, 76, 82 while the lower temperatures have been specified as -10, -16, -22, -28 and -34 ^{0}C

It is assumed that the pavement will be subjected to fast vehicles. If there are substantial number of slow vehicles the bitumen grade has be stepped up by one notch. For standing design load the grade has to be stepped up by 2 notches. An additional shift is also prescribed for extraordinarily high numbers of heavy traffic loads, especially if it exceeds 30 million ESAL.

The asphalt mix production and construction stage is simulated by aging the bitumen in a rolling thin film oven (RTFO). It exposes the thin films of bitumen to heat and air during hot mixing conditions. After the construction, asphalt has to endure heat and pressure from the wheels for long years in service. This condition is simulated by a pressure aging vessel (PAV). The conditioned bitumen then tested in Dynamic-Shear Rheometer (DSR).

Performance Grade (PG) bitumen is prepared by adding polymer with the Penetration Grade Bitumen. The commonly used polymer is SBS (Styrene-Butadyne-Styrene). As polymer is used to modify the base bitumen (Penetration Grade), it is also called Polymer-Modified Bitumen (PMB). It is available both as pre-mixed material or SBS can be mixed at site.

3.1 Use of PMB in Roads and Highways Department

In Roads and Highways Department, PMB was first used in the wearing course on the Kanchpur, Meghna and Gumti 2nd Bridges in 2019. Due to unavailability of testing facilities, premixed PMB was imported, properties of bitumen just like Penetration Grade bitumen were tested and used in wearing course. The following table shows a comparison of results of Penetration Grade Bitumen and that of PMB.

After the availability of RTFO, PAV and DSR equipment in RHD labs, SBS was mixed with 60/70 Penetration Grade Bitumen at site and is being used in the wearing course of the project corridor at Dhaka Hazrat Shahjalal International Airportto Gazipur. The mixing and testing procedures are described in the following paragraphs.

Table 2: Comparison of properties of Penetration Grade Bitumen and PMB

Biner Properties	Unit	Penetration Grade Bitumen (60/70)	PMB
Softening Point (Ring and Ball Method)	^{0}C	54.9	87.3
Penetration at 25℃	0.1 mm	60.0	51.3
Penetration of Residue after Heating for 5 hours at 163℃ to Original	%	71.67	93.57
Stability	Kg	1390	1570

3.2 SBS blending in laboratory

- SBS sample was sourced from China with Styrene-Butadyne ratio around 30:70. Itwasa lineartri block copolymer and came as white pellets.
- Heated base bitumen (Malaysian, 60/70 pen-grade) gradually up to 120 °C.
- Took1kgbitumensamplein a cylindricalpotwith5-inchdiameter and 6-inch height.
- Covered the pot using heating jacket.
- Increased heating temperature of the sample gradually to reach 170-1800C.
- Added SBS (YH-791H) gradually to base bitumen which was between 4.5-5.5% wt. of the blend.
- Three blends were made in the same process, from which optimized dosage was selected for plant trial.
- Blended SBS at speed of 3000-4000 rpm for aduration of two hours.
- Smear test done during blending to check smoothness of the blend.
- Added sulfur to the blend which was 0.05% to 0.1% wt. of base bitumen.
- Allowed the mixture to blend using a slow shear mixture for one and half hours at speed of 500to600 rpm while maintaining a temperature of 120°C to 130°C depending on viscosity. After that, the prepared sample was stored in an airtight container.
- After blending and cross-linking to prepare three variants of PMB, standard tests were conducted to evaluate the PG gradation of the bitumen.
- After several blends of PMB were prepared and tested, decision was made to use 4.75% w/w SBS content with base bitumen.

3.3 SBS manufacturing at plant

- Base bitumen was heated to 160°C or above to ensure sufficient fluidity.
- A weighted loader was filled with SBS and a screw-style dosage controller enabled controlled dosing of SBS to Base bitumen.
- Base bitumen was mixed with required amount of SBS in the premixing tank for absorption of lighter bitumen compounds and general softening of SBS in preparation of blending.
- The SBS and Base bitumen mixture, that was in the premixing tank, is the pumped through a rotor-stator type Colloidal Mill. The output was checked to ensure fineness of SBS-Bitumen mixture.
- The prepared suspension ist hen pumped into PMB holding tank with agitation capacity.
- To stabilize the SBS-Bitumen suspension and encourage cross-linking, small amount of powdered sulfur is added to bitumen-SBS blend which essentially tum it to Polymer Modified Bitumen (PMB). However, the tank is kept at elevated temperature to ensure proper fluidity and cross-linking. On the other hand, too high temperature may damage to SBS and reduce PMB quality.
- To ensure that sufficient cross-linking was achieved, samples were taken for softening point test to match to expected range of values. When the softening point reached adequate level, the temperature was lowered to reduce oxidation and storage instability.
- The sample was thus made ready for usage and was only reheated when it was required for application to the site.

3.4 Testing for performance grade verification

Samples created in the laboratory and plant was tested to identify their Performance Grade. As the required criteria wsa PG 76 or higher grade bitumen, PG tests were mostly conducted at 76°C, except for MSCR tests, when done, was conducted at 64°C.

Dynamic Shear Rheometer machine at BRRL-Mirpur (Rheotest) was primarily utilized for testing for measurement of G*/Sinδ parameters. AASHTO T315 procedure was followed for operation of the DSR and measurement of G*/Sinδ parameter.

Short-Term aged bitumen was produced using a Rolling Thin Film Oven (RTFO), located at BRRL-Meghna Lab.35g of unaged PMB sample was placed on a glass bottle which was then raised to 163°C and rotated for 85 minutes at specific rates. The resultant bitumen was tested in DSR again for G*/Sinδ parameter using AASHTO T315 parameter.

In addition, MSCR test was conducted for one plant mix sample at 64°C, which is the estimated site pavement temperature according to PG specification. It was done to verify that specification currently being used (AASHTO T320) with two-grade bumps to accommodate higher traffic (PG76inplace ofPG64)correspondstonewerAASHTOM332 grade which should be PG 64 with Extreme Traffic (E) grade. This test was done at 64°C using AASHTO T350 specification. The test results are summarized below:

Table 3: Test result of Performance Grade Bitumen

Characteristic Test	Test Method	Ref. Value	Result	Comment
Dynamic Modulus (Fresh) (@.76°C, G*/Sinδ	AASHTOT31S	>1.0kPa	1.91kPa	**Ok**
RTFO Aging PMB	AASHTOT240	NIA	**NIA**	
Dynamic Modulus (RTFO) (@.76°C, G*/Sinδ	AASHTOl115	>2.2kPa	3.87kPa	Ok
Non-Recoverable Creep Compliance@64"C,J.,,Extreme Heavy Traffic 'E' Grade	AASHTOl150	<0.5kPa·'	0.139kPa·'	Ok

4 Continuously Reinforced Concrete Pavement

There are 3 types of rigid pavement –Jointed Plain Concrete Pavement (JPCP), Jointed Reinforced Concrete Pavement (JRCP) and Continuously Reinforced Concrete Pavement (CRCP). Among these, JRCP was constructed several locations after the independence of Bangladesh. Later, after a long break, JRCP was again constructed particularly at urban locations in Dhaka-Chittagong, Dhaka-Mymensingh and other local roads. Focuses were mainly to construct flexible pavement. But construction of flexible pavement mainly depends on imported materials such as stone and bitumen. The required volume is also very huge. Due to unavailability of these material in sufficient quantity, many projects have suffered a lot in the past. Moreover, frequent maintenance burden, lower design life and the changed climatic condition have raised questions about the sustainability of flexible pavement. For the first time, RHD decided to construct a rigid pavement in a long stretch on Dhaka-Rangpur Highway. Considering the volume of construction, riding quality and maintenance of joints, Continuously Reinforced Concrete Pavement (CRCP)was selected and it is now under construction. It gives better riding quality and has long design life. The following figures show the typical sections of CRCP under construction at Dhaka-Rangpur Highway.

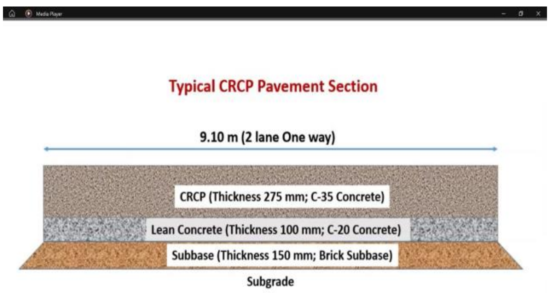

Fig 4: CRCP Pavement Section

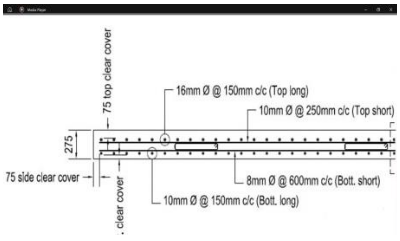

Fig 5: Details of Reinforcement in CRCP

5 Conclusion:

Flexible pavement designed by AASHTO Guide for Design of Pavement Structures 1993 does not guarantee against cracking and rutting. If the trial pavement prepared by following the above guide is analyzed by software available and compared with the failure criteria then it gives satisfactory result. Use of Performance Grade Bitumen on important highways has reduced the tendency of rutting. Moreover, construction of Continuously Reinforced Concrete Pavement (CRCP) is giving better riding quality, low maintenance, fit for all weather and a long-expected life.

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