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ALTERNATIVE OPTION FOR ROAD MAINTENANCE MANAGEMENT IN BANGLADESH UNDER CLIMATE CHANGE CONDITION

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ABSTRACT: Bangladesh is one of the worst climate-vulnerable countries in the world. It is predicted that the temperature of the country will increase 1^0- 3^0 Celsius and precipitation 20% by 2050. Bangladesh being a flood-prone country, roads in the lowlying areas will likely to be flooded more frequently than before due to increased rainfall. The study has developed a methodology by Mechanistic-Empirical (M-E) method to find out the effect of moisture and temperature on the pavement. It has also provided solutions to minimize the additional damage due to traffic movement on the affected pavement. It is found that damage by a standard axle load during saturation period of 30 days is almost 3 times than that in dry condition. However, during 30 days of saturation if the axle is overloaded by 6 ton, the damage is 20 times than that of a standard axle at the dry condition. By M-E method it is found that imposing 30 % restriction on standard axle load during pavement saturation condition will minimize the additional damage. It has suggested using improved materials to fight against temperature rise. The outcome of the study will support road engineers of Bangladesh to combat the climate change effect by adopting axle load restriction.

Keywords: Climate change, Mechanistic-Empirical method, Pavement saturation, Axle load restriction

1. INTRODUCTION

Climate change adaptation becomes more critical developmental issues for Bangladesh. According to the scientists, it is predicted that temperature will increase 1^0-3^0 Celsius and precipitation 20% by 2050 in Bangladesh [1]. Bangladesh is a flood-prone country and floodwater causes enormous damage to the road infrastructure of the country. Flood records indicate that approximately 21% of the country is subject to annual flooding and an additional 42% is at risk of floods with varied intensity [2].

Although the road agency of Bangladesh specifies 4-days soaked CBR value for the design of pavement [3] but usual flooding duration is more than 4 days in Bangladesh and may increase in future. Due to the increase in precipitation and flooding duration pavement will remain in saturated condition for a longer time. Saturated layers of the pavement cannot bear the wheel load of the vehicle. So, pavement life will be reduced and road maintenance and rehabilitation cost will be increased. Moreover, an increase in pavement temperature will affect the functioning of the Hot Mix Asphalt (HMA) layer and will reduce the pavement life.

However, it is important to quantify the pavement damage done by moisture. If quantification of the damage can be done it will be possible to show the severity of the problem. Since road infrastructure is the main mode of transport of goods and passengers in Bangladesh, it should be safe against adverse climate change effect. Moreover, a developing country like Bangladesh has a limited budget allocation for road construction and maintenance. So, road design, materials selection, and traffic loading should be such that road construction and maintenance become economic and durable.

The study has attempted to quantify the effect of moisture and temperature for a typical national highway and district road with consideration of vehicle overloading. In Bangladesh, vehicle overloading is common as mentioned in the Road Master Plan [4].To predict the life of the flexible pavement due to changes in the saturation period, the study has adopted the mechanistic-empirical (M-E) approach. However, the dynamic effect of entrapped water due to vehicular movement is not considered in the study. In this study, the mechanistic analysis is done with software GAMES (General Analysis on Multi-layered Elastic system). GAMES provides strain values at the critical location of the pavement. Pavement life is then predicted by using the empirical model of the Asphalt Institute with critical strain values. Finally, it has suggested probable solutions to fight against the moisture effect.

2. METHODOLOGY

2.1 Pavement in Saturation Condition

The study determines the damages caused by axle load for predicting moisture effect on pavement. Stiffness values of pavement layers reduce due to the presence of moisture. With the reduced stiffness values of layers, fatigue and rutting life of the pavement will be reduced. It is reported that the reduction of the strength of pavement due to the saturation effect can be 1.5% to 50% within a short time [5]. This means damage caused by a vehicle during and shortly after the flood will be higher than the normal situation.

It is found that Marshall stability value decreases and flow value increases with the increase of the inundation period [6]. Marshall stability-flow ratio decreases to approximately 38% of the initial after 30 days of inundation as shown in Fig. 1. Stability-flow ratio is proportional to the resilient modulus (M_r) of asphalt concrete [7]. Table 2 shows M_r value of HMA for different saturation period. In this study, M_r for the dry condition is assumed to reduce according to the stability-flow ratio for different saturation period.

Fig. 2 shows, if the saturation period is 30 days, subgrade CBR value reduces to 89% - 69% of the 4-days soaked CBR value depending on the condition of compaction [6]. CBR value for subgrade is linearly correlated with the resilient modulus [7]. So, resilient modulus of the subgrade modulus also decreases with the inundation period. Additionally, resilient modulus for the base and sub-base layer is assumed to be decreased with the same rate as that of subgrade value.

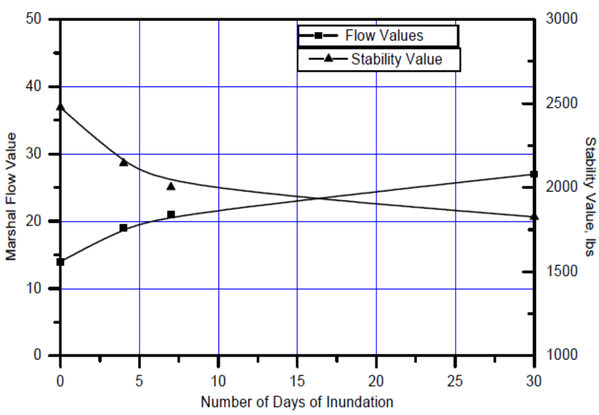

Fig. 1 Effect of inundation on CBR of subgrade [6]

In this study, M_r values for dry granular layers are determined from CBR values by using correlation charts developed by Van Til. et al.[8].Table 1 shows the resilient modulus (M_r) values for different saturation period. Table 2 shows the typical layer thickness values for a national highway of Bangladesh.

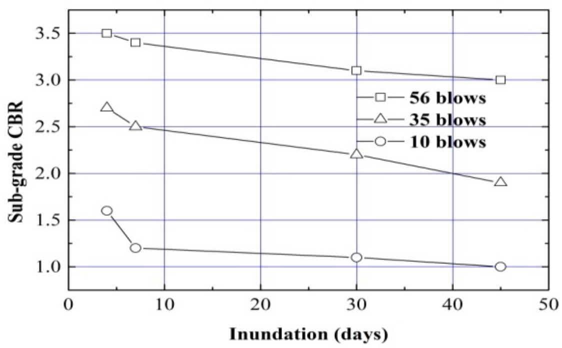

Fig. 2 Effect of inundation on flow and stability of bituminous surface layer [6]

Table 1 Values of Resilient Modulus (M_r) at saturated conditions

Layer	M_r (Mpa) for saturation period of			
	0 day	4 days	7 days	30 days
HMA	2760	1762	1488	1055
Base	210	210	158	144
Sub-base	140	140	105	96
ISG	83	83	62	57
Sub grade	62	62	47	43

Table 2 Layer properties of the highway

Layer	Layer thickness(cm)	Poisson's ratio
HMA	12.5	0.30
Base	15	0.35
Sub-base	18	0.35
ISG	20	0.40
Sub grade	200	0.40

2.2 Pavement at Elevated Temperature

For predicting temperature effect by M-E analysis the change of resilient modulus of HMA layer due to an increase in temperature is considered as the factor. It is found that resilient modulus of asphalt layer decreases with rising in temperature [9] [10] as shown in Fig. 3. Resilient modulus of asphalt concrete is decreased by 121 Mpa per degree Celsius rise in temperature [9]. For determining temperature effect a typical section and properties of a district road is selected. The input values for finding temperature effect on the pavement are shown in

Table 3. The resilient modulus for the HMA layer is decreased considering 1-5 degree Celsius rise in temperature and the other values are kept constant.

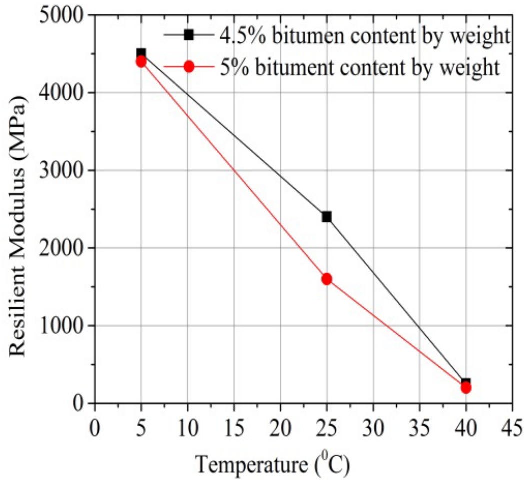

Fig. 3 Relationship between resilient modulus and temperature [9]

Table 3 Input value for temperature effect

Layer	Layer thickness (cm)	CBR	M_r (Mpa)	Poisson's ratio
HMA	5.2	-	1379	0.35
Base	20	80	862	0.4
Sub-base	20	30	104	0.4
ISG	20	7	72	0.45
Sub grade	200	5	52	0.45

3. AXLE LOAD

Standard single axle load for Bangladesh is 80 kN. However, to simulate overloading effect axle load of 100 kN, 120 kN, and 140 kN consecutively are also considered. Since overloading is a common practice in Bangladesh, it is taken into consideration while simulating moisture and temperature effect. Tire pressure for the study is considered to be 0.5 Mpa.

4. DAMAGE BY A STANDARD AXLE

Two failure mechanisms are considered to determine the damage done by a standard axle load. One is fatigue and another is rutting failure. To measure the pavement life, critical strain values are determined by general analysis of multi-layered elastic system (GAMES) software. Following steps have detailed the approach:

1. Resilient modulus (MR), Poisson's ratios, layer thicknesses and layer interface slip values, wheel load and tire pressure are needed as inputs to run GAMES.

2. To determine the fatigue and rutting life of the pavement, tensile strain value at the bottom of the asphalt layer and compressive strain value at the top of the subgrade layer as shown in Fig. 4 is calculated first by GAMES. After getting the strain values for the critical location of the pavement layers, life was predicted by the Asphalt Institute model [11], [12].

$$N_{f_1} = 0.0796\varepsilon_t^{-3.291}E_1^{-0.854} \quad (1)$$

$$N_{f_2} = 1.365E-07\varepsilon_v^{-4.477} \quad (2)$$

Where N_{f_1} = allowable number of load repetition to prevent fatigue cracking, N_{f_2}= allowable number of load repetition to prevent rutting cracking, ε_t= tensile strain at the bottom of Asphalt layer, ε_v= compressive strain at the top of sub-grade layer, E_1= elastic modulus of asphalt layer.

Moreover, the damage (D_i) caused by each application of axle load is given by:

$$D_i = 1/N_i \quad (3)$$

Where N_i is the minimum number of load repetitions required to cause either fatigue or rutting failure.

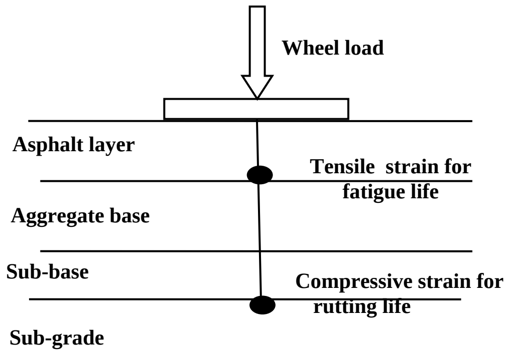

Fig. 4: Critical location of strain values for analysis

5. RESULTS AND DISCUSSION

5.1 Moisture Effect on Pavement

From the Mechanistic-Empirical (M-E) analysis it is found that fatigue failure governs for the typical pavement of the national highway of Bangladesh as shown in the Fig. 5. Fatigue damage by a single axle is considered for making a critical decision in this study as it is higher than that of rutting.

Fig. 6 shows damage by a standard and overloaded axle for different saturation periods.

Here, the values are normalized by the damage value of a standard axle load during the dry period. It is found that damage by a standard axle during 30 days of saturation period is approximately 3 times than that of the dry period. Other study reveals that the relative damage due to a single axle load for wet sections varies from 5 to 70,000 times in comparison to drained sections [13]. In this study, it is found that if the axle is overloaded by 6 ton the damage is approximately 20 times higher than that of the dry period.

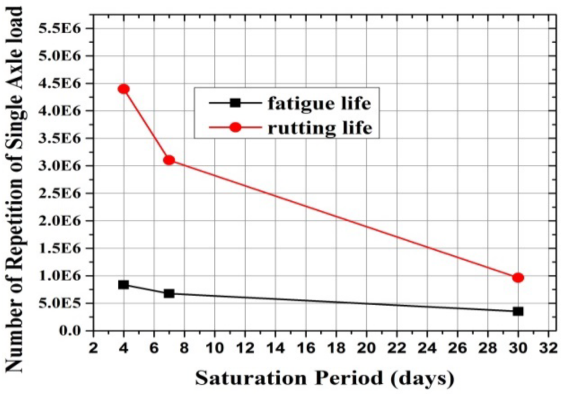

Fig. 5 Comparison between fatigue and rutting life of the pavement.

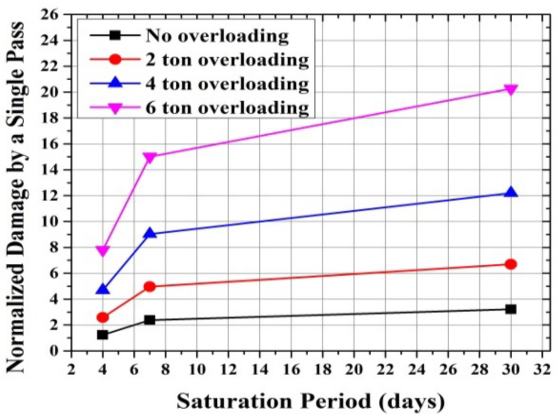

Fig. 6 Effect of saturation and overloading on pavement

Fig. 7 shows a standard axle in saturation period causing additional damage to the pavement. Actually, layer's stiffness reduces during saturation condition and hence the standard load causes additional damage. As a result, even if a standard axle load is allowed to pass during saturation condition pavement life will be reduced drastically. However, we can prevent the pavement from losing its life by allowing a load less than the standard axle load so that it does not cause additional damage to the pavement.

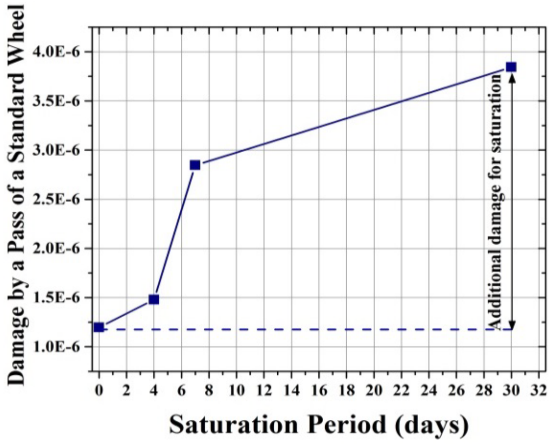

Fig. 7 Damage done by a single pass of a standard wheel load.

Fig. 8 shows the relationship between wheel load and damage for different saturation period of the pavement. By using the fitted equation shown in Fig. 7, it is found that for a saturation period of 30 days a wheel load of approximately 28 kN causes the same damage as that of a 40kN wheel load in dry condition. If 70% of the standard axle load is allowed for the pavement with 30 days saturation period, it will not create additional damage. Fig. 9 shows the allowable axle load for different saturation period. If axle load is restricted to the allowable limit until the dry back period of the pavement, its life will not reduce at all.

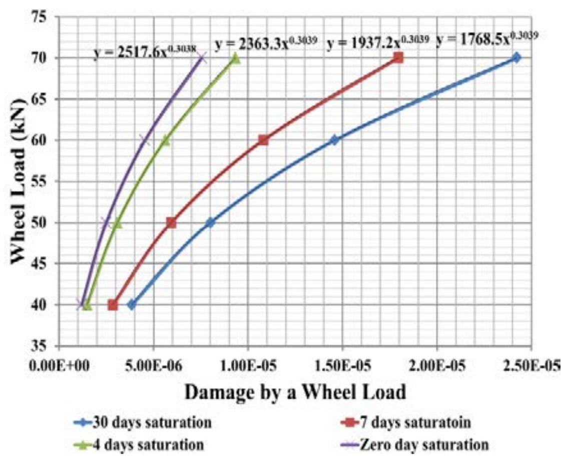

Fig. 8 Load damage correlation for different saturation periods

5.2 Temperature Effect on Pavement

For predicting temperature effect by M-E analysis change of resilient modulus of the HMA layer due to an increase in temperature was considered as the variable. From the M-E analysis, it was found that rutting failure governs for the typical district road of Bangladesh. Damage by the different single axle loads were determined and normalized by the standard axle damage. It was found that with the rise in pavement temperature, damage done by a single pass of axle load increases as shown in Fig. 10. However, damage was more severe once temperature effect was combined with overloading. As a remedy for temperature effect on pavement polymer modified asphalt having temperature resistance should be used.

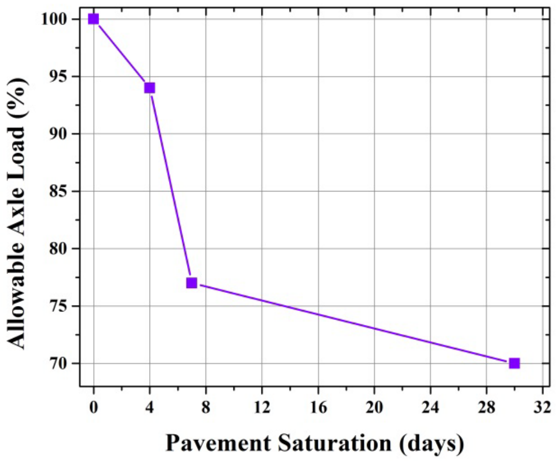

Fig. 9 Allowable axle load during saturation period

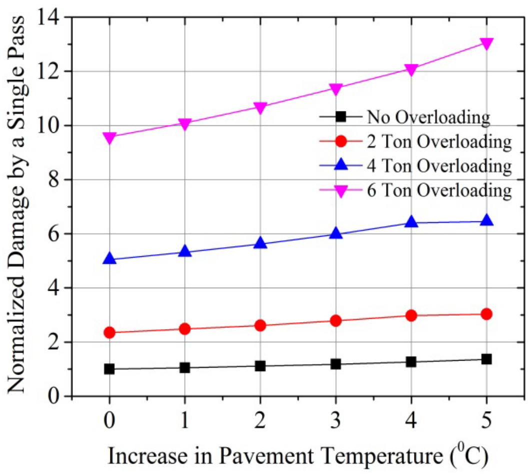

Fig. 10 Temperature and overloading effect on pavement

6. CONCLUSION

The study has made an attempt to simulate the effect of climate change on the roads of Bangladesh. It has developed a methodology for finding the effect of moisture by M-E method. It has also proposed a methodology to impose axle load restriction on the pavement to minimize the moisture effect. The study concludes with the following findings :

1. Damage by a standard axle load to the 30-days saturated pavement is approximately 3 times of damage to the dry pavement.
2. However, damage by a 6-ton overloaded axle to the 30-days saturated pavement is 20 times of that by a standard axle to the dry pavement.
3. Reduction of the standard axle load will be necessary during the saturation period to keep the pavement design life unaffected. For a sturation period of 30 days, a vehicle should be loaded with 70% of the standard axle to minimze the damage.
4. Moreover, overloading should be totally restricted during pavement saturation period.
5. Temperature in combination with the overloading will cause significant damage to the pavement. The damage by a single axle with 6-ton overloading and with a temperature increase of 5^0C would be 13 times than that of a standard axle load without an increase in temperature.

REFERENCES

[1] The World Bank, "The cost of adapting to extreme weather events in a changing climate", Bangladesh Development Series, Paper No. 2, executive summary, pp. xiii, 2011.

[2] Dasgupt, S. , Huq, M, Khan, Z. H., Masud,M. S. Ahmed, M. M. Z., Mukherjee, N. and Pandey , K., "Climate proofing infrastructure in Bangladesh: the incremental cost of limiting future flood damage",Journal of Environmental & Development, 20 (2),pp.167-190.

[3] Ministry of Communication, "Technical specifications," Bangladesh Roads and Highways Department, Vol. 7, 2011.

[4] Ministry of Communication, Bangladesh, "Road master plan", Roads and Highways Department, Vol. 1, 2007

[5] Sultana, M. et al. "A review of the structural performance of flooded pavements", in the proc. 26th ARRB, 2014, pp.1-11, Sydney, New South Wales, Australia

[6] Alam, M. J. B. and Zakaria M., "Design and construction of roads in flood affected areas", Engineering Concerns of Floods a1998 Perspective. Directorate of Advisory, Extension and Research Services, BUET, Dhaka, Bangladesh, pp91-99, 2002.

[7] Ahmad H. Al-Zassar et. al., "Using Marshall test to assess asphalt-concrete modulus for mixes used in Kuwait", Kuwait J. Sci. Eng. 30(2), pp169-182, 2003.

[8] Mamlouk, M.S. "Design of flexible pavements", The Handbook of Highway Engineering edited

by Fwa, T.F, Boca Raton, T& F groups, , 2006, ch.8, pp. 8.1-34.

[9] S.A Tabatabie, H. Ziari and M. Khalili, 2008. Modeling temperature and resilient modulus of asphalt pavements for tropic zones of Iran, Asian Journal of Scientific Research, 1(6):579-588, ISBN1992-1454, pp 579-588.

[10] Aschuri, I., Yamin, R. A. and Haryanto, D., "Temperature and time loading influence of asphalt concrete mixture and design life using analytical method on Indonesian tropical condition", Proceedings of the Eastern Asia Society for Transportation Studies, Vol.4, October, 2003, pp. 426-435.

[11] Huang, Y.H., Pavement Analysis and Design, Pearson Education, Inc., 2nd edition, 2004, ch. 11.

[12] Salem, H.M.A., "Effect of excess axle weights on pavement life", Emirates Journal for Engineering Research, 13 (1), 21-28, 2008.

[13] Gartin, R.S., Raad, L., "Mechanistic behavior of saturated cohesionless layers in pavements", Report no. INE/TRC 92.06, Transportation Research Center, Institute of Northern Engineering, School of Engineering, University of Alaska Fairbanks, AK 99775:1- 2, 1992