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A STUDY OF CLIMATE CHANGE EFFECTS ON A TYPICAL PAVEMENT SECTION

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ABSTRACT

Transportation infrastructure today is encountered with threats of climatic vulnerabilities i.e., temperature increase, rise in sea level, increase of rainfall intensity etc. To identify these impacts, KALSHI-ECB CHOTTOR roadway section of 1.8 km is taken as test site. The data of temperature increase of last 10 years (2008-2018) of the test area was collected. A 24 h model is developed to calculate the pavement temperature by an empirical equation using the collected environmental data and is compared with the air temperature to identify the distresses occurred in the pavement. In 2008 average air temperature was 32.2°C and in 2017 it was 34.1°C. In 2008 pavement surface temperature was 47.25°C while in 2017 it is found 50.25°C. It is observed that, for every 2° increase of air temperature, pavement temperature is increased by 3°. Also, the distresses occurred due to climate change is being identified in this paper. Another important climatic effect is reduction of subgrade strength which in turn affects the performance of the pavement. In this study, five soil samples were collected from test site. Various laboratory tests including Atterberg limit, Specific Gravity, Gradation Analysis, California Bearing Ratio (CBR) and compaction were performed on the samples. Various linear relationships between soil properties and CBR of the samples were investigated using simple and multiple linear regression analysis and also predictive equation estimating CBR from the experimental values were developed. Using the CBR values resilient modulus (MR) of the subgrade is determined which is used to calculate Equivalent Single Axle Load (ESAL) by an empirical equation. In traditional design practice in BD the three days soaked CBR value is used but to consider extreme climate change effect seven days soaked CBR value was considered. The result once converted to ESAL shows serious deterioration of pavement strength from 23 to 6.04 million i.e., only 26.26% of estimated ESAL can be carried by the roadway due to prolonged inundation. Besides distress will also occur due to temperature change which will accelerate the distress. GAMES software has been used to determine the fatigue and rutting failure criteria and from the result has been found that after 0.15 million ESAL repetition, there will be fatigue crack on the surface of the pavement. This study aims to mitigate the future losses of pavement structures making the planners cautious about uncertain climate changes.

Keywords: *Climate change, Pavement distress ,24hmodel, Games software, ESAL*

1. INTRODUCTION

Development of transportation system is the prime factor of socio-economic growth of a nation. As a nation of only 48 years, Bangladesh had achieved tremendous success in the road network. Climate change has a tremendous influence on the soil parameters and the pavement components. According to Intergovernmental Panel on Climate Change (IPCC) report, temperature increase, glacial melt and sea level rise have been accelerated faster than predicted. As a result, performance of the pavement and the soil beneath the pavement are degrading day by day. This study explores a relation between the present trend of pavement design in Bangladesh and the climate change effects on the present design system of a typical road including comparing its design ESAL with the calculated one.

2. METHODOLOGY

2.1 Pavement Temperature Determination

Temperature change is having an influence on the structural response of asphalt concrete (AC) pavement. To evaluate the performance, prediction of pavement surface temperature is necessary. Many researchers developed regression-based models to calculate the temperature within the asphalt pavement layers. (Khan et al., 2016; Lukanen et al., 2000; Minhoto et al.,2005; Yavuzturk et al., 2005). Their models are unable to predict the constant variation in temperature over time. Furthermore, the models did not take into account other weather elements such as wind speed, wind direction, and relative humidity (RH), which could have an impact on the prediction of surface temperature. The objective of this study is to develop regression models to determine the asphalt pavement surface temperature. Three types of models namely, 24-h model, day-time model and night-time model were developed based on one-year continuous data. Models were validated using new data which were not used to develop the models. Models' predictions were also compared with the predictions of the recently developed AASHTOW are pavement mechanistic-empirical (ME) design software (ARA Inc., 2007). [Zafrul et al. 2018]. In this experiment pavement temperature is measured using a 24 h model (Zafrul., 2018). For this model wind speed (m/s), air temperature (^{o}F), RH, solar radiation (W/m2) was considered the input variables and asphalt concrete surface temperature was considered the output. When pavement temperature exceeds air temperature it causes severe damages.

2.2 Data Collection

To visualize the temperature variation; monthly air temperature data was collected from CEGIS from the year 2008 to the year of 2017. Using those data. Pavement temperature is determined later.
(The Center for Environmental and Geographic Information Services (CEGIS), 2019)

2.3 Data Analysis of temperature

Monthly temperature values are plotted in graph in order to visualize the change being occurred over the years. The graph showing change of average temperature from 2008 to 2017. This figure shows that temperature increases almost 2^o from 2008 to 2017.A denoting year 2008 with 32.2^{o}c air temperature and J denoting year 2017 with 34.1^{o}c air temperature.

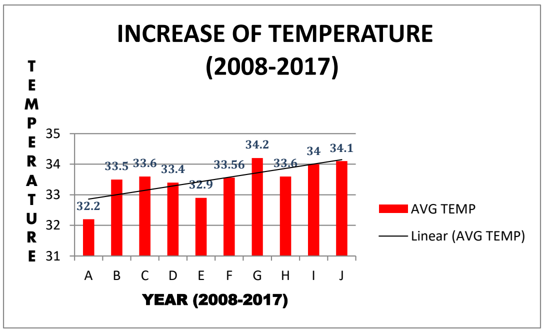

Figure 1: Increase of temperature (2008 to 2017)

2.4 Asphalt Surface Temperature Determination (24-h model Development)

Continuous 24-h data from 2008-2017 were used to develop 24-h model. A nonlinear least square algorithm was scripted to fit the curve with the measured data and the obtained best fit regression equation is given below

$$Ts = 26.081 - 0.844 \times w + 0.479 \times Ta - 0.187 \times RH - 0.0173 \times S + 0.0042254w \times Ta + 0.00565w \times RH + 0.0016 \times w \times S + 0.00342 \times Ta \times RH + 0.000117 \times Ta \times S + 5.7029 \times RH \times S \times 10^{-5} + 0.00425 \times Ta^2 + 1.9125 \times S^2 \times 10^{-5} \quad (1)$$

2.5 Symbols and Meanings of 24 h Model Empirical Equation

Ts=Surface Temperature (°F), W=Wind Speed (m/s), Ta=Air Temperature (°F), RH=Relative Humidity, S=Solar Radiation (W/m2). R2 value of the regression is 0.973 which is very close to the unity reliability. (Zafrul, 2018)

2.6 Solar radiation determination

Solar radiation at any location (latitude) and day of the year can be calculated using the equations proposed by Iqbal

$$H_\circ = \frac{24 I_{sc}\, E_\circ}{\pi} \sin\phi \sin\delta \left(\frac{\omega_s \pi}{\pi} - \tan\omega_s\right) \quad (2)$$

2.6.1 Symbols and Meanings of Solar Radiation Determination and Calculation

Ho=Daily Solar radiation on a horizontal surface (kJ/m2), I_{sc}=Solar constant 4871 kj/m2, Ø=Latitude (degree), E^o=Eccentricity factor, I^-1=Day angle (rad), D_n=Day number of the year from 1 to 365, Δ=Solar declination (degree), ωs =Sunrise hour angle (degree).
Now,

$$E^\circ = 1.00011 + 0.034221\cos^{-1} + 0.001280\ \sin I^{-1} + 0.000719\cos 2I^{-1} + 0.000077\ \sin 2I^{-1} \quad (3)$$

$$I^{-1} = (2 * \pi * dn - 1/365) \quad (4)$$

$$\delta = (0.006918\sin 2I^{-1} - 0.399912\ \cos I^{-1} + 0.070257\ \sin I^{-1} + 0.006758\cos 2I^{-1} + 0.000907\ \sin 2I^{-1} - 0.002697\cos 3I^{-1} + 0.00148\ \sin 3I^{-1})180/\pi \quad (5)$$

$$\omega_s = \cos^{-1}(-\tan\text{ø}\tan\delta) \quad (6)$$

Now calculation, Isc =solar constant 4871 kj/m^2, ø =latitude 23.822° (Mirpur Area), Day angle = 4.18 [considering August Month], Eo = 1.03505, δ = -22.67°, ωs = 79.37 ,Finally, from equation 2,
Ho =838339.2 kj/m2 =39.4 W/m2 . (Shobha Rani Arangi,2015)

2.7 Pavement Surface Temperature Determination

For our particular zone Ts is calculated from eqn 1 using necessary inputs.

Table 1: Determination of Pavement Temperatures of Last 10 Years (2008-2017)

Year	Wind speed (m/s)	Relative humidity (%)	Air temperature (F)	Pavement Temperature (F)
2008	2.53	89.35	89.96	117.06
2009	2.23	88.38	92.3	120.74
2010	2.17	87.07	92.462	121.03
2011	2.35	90.07	92.174	119.8
2012	2.48	88.08	91.22	119.04
2013	2.67	89.38	92.408	120.95
2014	2.76	89.17	93.56	122.73
2015	2.57	89.84	92.48	121.03
2016	2.47	89.23	93.416	122.16
2017	2.14	90.08	93.38	122.45

Converting air & pavement temperature into Celsius below graph is plotted.

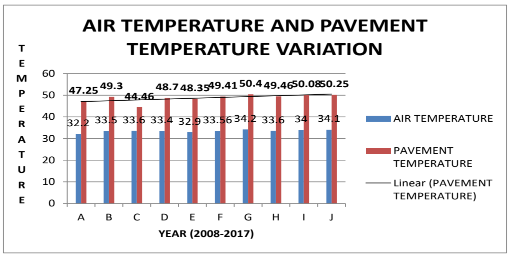

Figure 2: Variation of pavement and air temperature

3. Determining ESAL From CBR, MR and Soil Properties Relationship

3.1 Relationship between CBR with different Soil Properties

CBR values can be measured directly in the laboratory test in accordance to AASHTO. However, an attempt has been made in this study to correlate CBR value statistically with the liquid limit (LL), Plastic limit (PL), Plasticity index (PI), maximum dry density (MDD) (Naveen B Shirur,2017)

3.2 Regression Analysis

The various regression analyses between soaked CBR values with respect to different soil properties are presented according to Multiple Linear Regression Analysis (MLRA). It shows the linear trend line, which shows the effect of various soil properties with CBR value.

3.3 Simple Linear Regression Analysis (SLRA)

Simple Linear Regression Analysis (SLRA) was carried out by considering soaked CBR value as dependent variable and liquid limit, plastic limit, plasticity index, maximum dry density and optimum moisture content are considered as independent variables. It has been carried out to develop the correlation between individual soil property and soaked CBR value. Values are given below.

Table 2: Values of CBR and Soil Properties

Sample	Labratory CBR	Plasticity index	Optimum Moisture content	Max dry density	Liquid limit
1	5.13	8.34	10.68	1.84	25.34
2	6.17	6.32	9.28	2.12	23.54
3	5.65	7.51	10.37	1.91	24.67
4	5.29	8.24	10.51	1.87	25.08
5	5.73	7.309	9.79	1.97	24.39

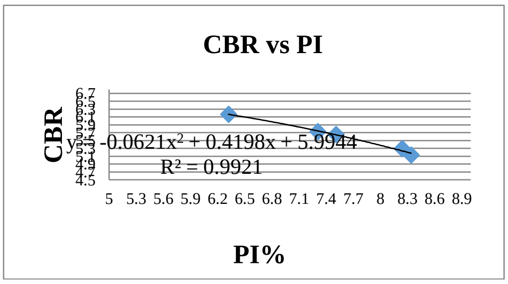

Figure 3: CBR VS PI

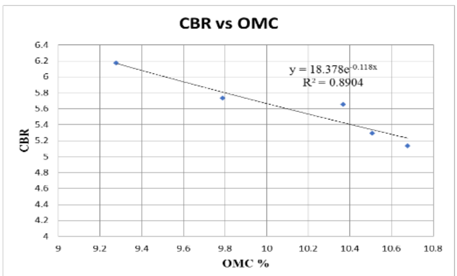

Figure 4: CBR VS OMC

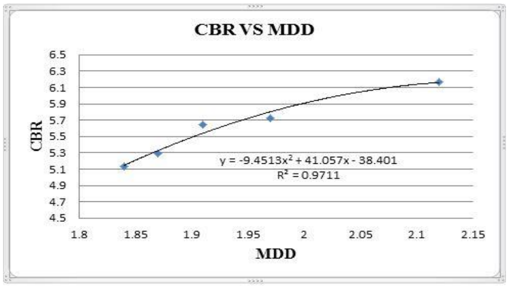

Figure 5: CBR VS MDD

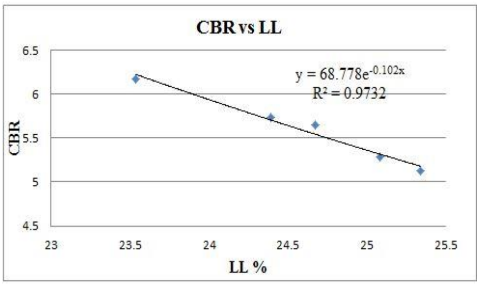

Figure 6: CBR VS LL

(CBR VS PI)- The suitable trend line is third degree polynomial equation

$$CBR = -0.0621PI^2 + 0.4198PI + 5.9944 \quad (7)$$

(CBR VS OMC) -The suitable trend line is exponential equation:

$$CBR = 18.37e^{-0.118OMC} \quad (8)$$

(CBR VS MDD)- The suitable trend line is second degree polynomial.

$$CBR = 9.4513MDD^2 + 41.05MDD - 38.401$$
(9)

CBR VS LL- The best fit trend line is an exponential equation

$$CBR = 68.778e^{-0.102LL} \quad (10)$$

The coefficient of correlation of different curves plotted in fig 3-6 is given in table:

Table 3: Values of CBR and Soil Properties

Serial No	Correlation of CBR with	Coefficient of correlation (R^2)
1	Plasticity index	.9921
2	Optimum Moisture Content	.8904
3	Max Dry Density	.9711
4	Liquid Limit	.9732

3.4 Multiple Linear Regression Analysis (MLRA)

It has been carried out by considering soaked CBR value as the dependent variable and remaining soil properties as independent variable. It can be expressed as, Soaked CBR =f (LL, PL, PI, MDD, OMC) Equations are given below:

$$CBR = 12.5255 – 0.52053\,(LL) + 0.344402\,(PL) \quad (11)$$

$$CBR = -0.83252 – 0\,.02233\,(OMC) + 3.425685(MDD) \quad (12)$$

$$CBR = 11.34707 – 0.58526(PI) - .68896\,(MDD) \quad (13)$$

$$CBR = 9.188265 – 0.026201(OMC) - 0.51162\,(PI) \quad (14)$$

Equation 11,12,13,14 shows the multiple variable regression analysis. These equations include the correlation of all the parameters with CBR value.

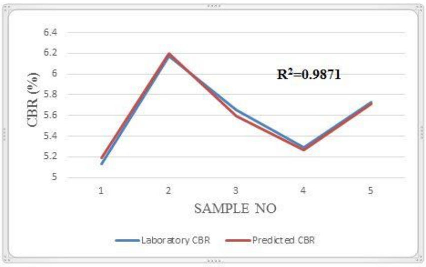

Figure 7 : Laboratory CBR vs Predicted CBR (Equation 11)

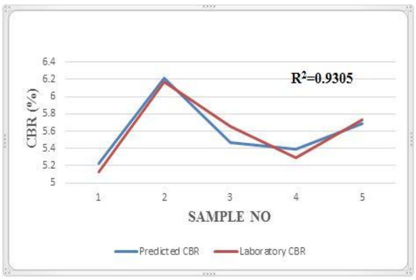

Figure 8 : Laboratory CBR vs Predicted CBR (Equation 12)

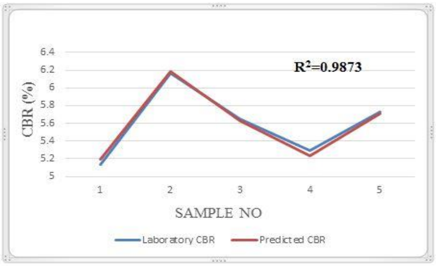

Figure 9 : Laboratory CBR vs Predicted CBR (Equation 13)

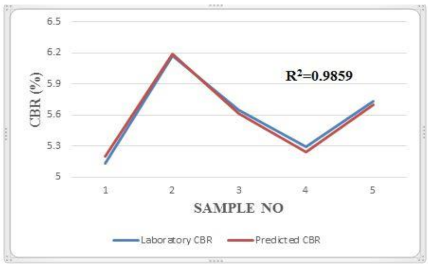

Figure 10 : Laboratory CBR vs Predicted CBR (Equation 14)

3.5 Resilient Modulus Based Design Procedure

The AASHTO Guide for Design of Pavement Structures is considered as the standard for pavement design using the resilient modulus.

$$MR\ (psi)\ = 1500\ *\ CBR \tag{15}$$

Taking equation (15) and establishing relationship between the CBR and MR, the following table shows the conversion. (Adama Dione,2014)

Table 4: Determination of Resilient Modulus (MR) from CBR

Serial No	CBR (%)	MR=1550*CBR (psi)
1	5.13	7695
2	6.17	9255
3	5.65	8475
4	5.29	7935
5	5.73	8595

3.6 Determination of ESAL

Observed or measured phenomena (pavement features) can be linked to outcomes using empirical equations (pavement performance). The basic design equation for flexible pavements is presented in the 1993 AASHTO Guide. In practice, this empirical equation is commonly utilized in the following form:

$$log\,10(W_{18}) = Z_{R\times}\,S_{\circ} + 9.36 \times log\,10(SN+1) - 0.20 + \frac{log\,10(\frac{\Delta PSI}{4.2-1.5}}{0.40+\frac{1094}{(SN+1)^{\wedge}5.19}} + 2.32 \times log10(M_R) - 8.07 \qquad (16)$$

(AASHTO, 1993)
Here,
Z_R= -1.645(for 95% Reliability), S_o= 0.35, SN=4.565, ΔPSI=4.2-2.5=1.7, M_R=7695 (Taking the lowest M_R)
Putting the values in equation 16, W_{18}= 6.04 Million. Design ESAL= 23 Million**.** So the design ESAL is much higher than the calculated ESAL. This might be one of the reasons of pavement distress occurred in KALSHI-ECB CHOTTOR Road.

3.7 Fatigue and rutting failure analysis using GAMES software

Data used
Resilient Modulus for asphalt concrete at 700 F, E = 425000psi, CBR value of base material = 90%, CBR value of subbase material = 50%, CBR value of subgrade = 5.594%, MR value, HMA = 2931.03 MPa, Base = 206.9 MPa, Subbase = 110.34 MPa, Subgrade = 57.87 MPa
Fatigue Criteria:

No of repetitions to failure $N_f = 0.0796 \times (\in_t)^{\wedge} - 3.291 \times (E)^{\wedge} - 0.854$ (17)
$=0.0796 \times (4.2967\times10^{-4})^{-3.291} \times (425000)^{-0.854}$
$=0.15\times10^6$

Rutting Criteria:
No of repetitions to failure $N_r = 1.365 \times 10^{\wedge} - 9 \times\ (\epsilon_c)^{\wedge} - 4.477$ (18)
= 1.365×10-9 × (2.7055×10-4)-4.477
= 12.82×106
The result of the pavement response indicates that the pavement will not fail due to rutting, however the pavement will fail due to fatigue cracking. (Emmanuel O. Ekwulo1,2009)

4. RESULT AND DISCUSSION

4.1 Result Analysis of Air Temperature and Pavement Temperature

From the graph analysis of temperature clearly shows air temperature is increasing day by. In 2008 average air temperature was 32.2°C and in 2017 it was 34.1°C. Air temperature has increased almost 2°C. In 2008 pavement surface temperature was 47.25°C while in 2017 it is found 50.25°C. Increase of pavement temperature is almost 3°C.Pavement surface temperature is much higher than air temperature and it causes distresses in pavement. An increase of 2°c air temperature increases the pavement temperature by almost 3°C. An increase of 1°C air temperature increases the pavement temperature by approximately 1.5°C.

4.2 Distresses Occurred in Test Site Due to Temperature Increase

Fatigue Cracking: Occurred in areas due to gradual increase of temperature & repeated traffic loadings (wheel paths). Rutting: Ruts are most visible after a rain, when they have been filled with water. Excessive rains have also contributed to the deterioration of the current situation. Potholes: On the pavement surface, bowl-shaped holes of various sizes were detected.

Figure 11 : Fatigue Cracking

Figure 12 : Rutting

Figure 13: Potholes

4.3 Comparison between Design ESAL & Estimated ESAL

KALSHI- ECB-CHOTTOR road was constructed by 16 Engineer Construction Battalion back in 2008. During that time the design ESAL was calculated 23 million. Basing on the ESAL and 4 days soaked CBR of subgrade, the thickness of the pavement was determined as follows:

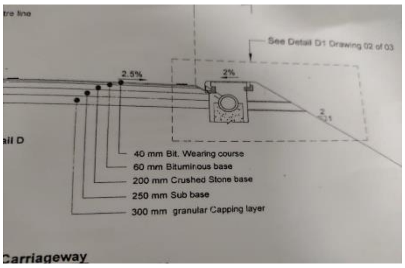

Figure 14 : Design pavement thicknesses

Later after 11 years using the same thickness and 7 days soaked CBR of subgrade the estimated ESAL calculated is 6.04 million. From the result it is clear that, 74.4% ESAL is reduced due to climate change effect on subgrade. It shows serious deterioration of pavement strength from 23 million to 6.04 million i.e. only 26.26% of estimated ESAL can be carried by the roadway due to prolonged inundation.

4.4 GAMES Software Analysis

From GAMES software analysis number of repetitions to fatigue failure is 0.15 million traffic and for rutting failure is 12.82 million traffic. So, the result of the pavement response indicates that the pavement will fail due to fatigue cracking.

5. CONCLUSION

Research findings have led to the following conclusions, which are based on the study's goals document.

a) Excel graphs of air temperature from the year of 2008 to 2017 of Kalshi area represent the gradual increase of air temperature. Almost 2°C temperature increase has been occurred

b) 24 h model: used in this research determines the pavement surface temperature of particular road and represents that from 2008 to 2017 almost 3°C temperature has been increased.

c) In every year pavement temperature is much higher than air temperature.

d) Due to temperature and natural effect the distresses occurred in particular road are identified.

e) Multiple Linear Regression Analysis (MLRA) is used to represent the numerous regression analyses between soaked CBR values and other soil parameters. The linear trend line highlights the effect of different soil parameters on the CBR value of a soil sample.

f) Multiple Linear Regression Analysis developed some equations assuming soaked CBR value as the dependent variable and remaining soil properties as independent variable.

g) Using MR (psi) =1500 * CBR equation relationship of MR and CBR is developed. Finally, ESAL is determined 6.04 million and the design ESAL was 23 million which is much higher than the calculated ESAL.

h) 74.4% ESAL is reduced due to climate change effect on subgrade. It shows serious deterioration of pavement strength from 23 to 6.04 million i.e., only 26.26% of estimated ESAL can be carried by the roadway due to prolonged inundation.

i) An analysis in GAMES software indicates that the pavement will not fail due to rutting, however, the pavement will eventually fail as a result of fatigue cracking.

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