DEVELOPMENT OF PERFORMANCE GRADING MAP OF NEPAL BASED ON SUPERPAVE SYSTEM

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Abstract

The Performance of the bituminous binder plays important role in the overall performance of the pavement system. One of the major cause of pavement failure is the bitumen grade, i.e selection of suitable grade of bitumen. Therefore, performance grading of bituminous binder is inevitable for the specific temperature and climatic zones. This study is focused on the determination of performance grading of bituminous binder for various temperature zones in Nepal. In this study, twenty one years' daily maximum and minimum secondary temperature data of 70 meteorological stations were collected and were analyzed for temperature zoning. Performance grading of bituminous binder was conducted with the help of Strategic Highway Research Program (SHRP) and Long-Term Pavement Performance Program (LTPP) prediction models. The concept of Superpave has been adopted for the analysis, which stands for superior performing asphalt pavement. The Superpave mix design includes a new analysis system based on performance characteristics of the pavement layer. The bituminous binder grades for Nepal have been determined on the basis of air temperature thereafter predicting the pavement temperatures. The study has determined seven different performance grade zones based on SHRP and four different performance grade zones based on LTPP model. The study synthesized the Performance Grade (PG) map of the country.

Keyword: Superpave, Performance grade, Performance grade zone, Pavement temperature, Performance grading map

1. Introduction

Nepal is a landlocked country that has an area of 147,181 square kilometer. Out of the total area of the country, about 80% is comprised of hilly and mountainous regions, with the remaining 14% as flatland and is divided into five major physiographic regions (Marahatta et al., 2009).Due to the vast change of altitude from 60m to 8848m within about 200km horizontal distance (south - north) and being landlocked country, road transportation is being one of the primary mode of transportation in Nepal. Most of the highways and motorways of Nepal get damaged (rutting, fatigue, thermal crack) within a few months/years after construction without completing their design life. The reason may be high temperature, low temperatures, precipitation, overloading and practicing old methods, etc. Superpave mix design method addresses all of these problems. Especially the binder characterization is given tremendous importance in this system (Khan et al., 2013).According to the Superpave mix design "A Performance Grade (PG) is a new asphalt binder specification for selecting the appropriate binder for pavement performance in terms of rutting, fatigue and low temperature cracking." This PG belongs to the Superpave mix design, which is an acronym for Superior Performing Asphalt Pavement and is the product of the Strategic Highway Research Program (SHRP)(Kennedy et al., 1994). The binders are selected using the performance based binder specification and based on the climate of the

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(Received: November 22, 2019 Accepted: August 11, 2020)

pavement where it will be used (Kobbail et al., 2016, Mampearachchi et al., 2012). Cominsky (1994) concludes that bituminous binder softens as the temperature increases and stiffens as temperature decreases. The measurements have shown that the deflection and rebound of the bituminous pavements are more affected by temperature than load. Temperatures cause pavements to expand and contract, creating pressures that can cause pavements to buckle or crack.

2. Temperature Historical Data

It is very important to know the climate of the project area to select the required and suitable asphalt binder, which should be used to achieve all the physical properties under the traffic condition during different seasons. The temperature data shall be collected from the available weather stations for many years backward as much as possible depending on their locations and recorded information. There are no specified years for the historical temperature data collection (Kobbail et al., 2016).

2.1 Collection of Air Temperature Data of Nepal

The required daily maximum and minimum air temperature for 21 years (1989-2009) from 70 weather stations were collected from Department of Hydrology and Meteorology (DHM). The location of each station has been shown in Fig 1.

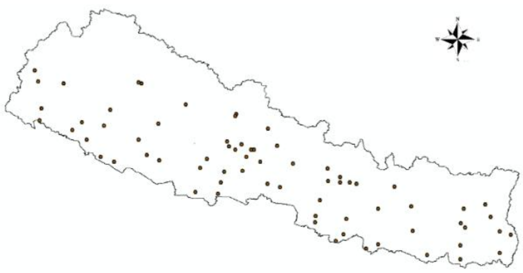

Fig. 1 Study area with meteorological stations (Nepal)

2.2 Analysis of Air Temperature Data

Using the daily maximum and minimum temperature data, the average of the 7-day maximum air temperature and the 1-day minimum air temperature for each year is calculated. For all years of operation the mean and standard deviation of the 7-day average maximum air temperature and 1-day minimum air temperature are calculated. The 7-day average maximum temperature is defined as the average highest air temperature for a period of 7 days within a given year. The 1-day minimum temperature is defined as the lowest air temperature recorded in a given year.

3. Pavement Design Temperature

The pavement temperature is always warmer than air temperature. So that the air temperature from the weather station can't be used directly to determine the PG. Thus, air temperature is converted into the pavement temperature, which can be also known as design temperature using the SHRP and LTPP equations/model, and assumptions set by SHRP researchers. According to the Superpave specification, the location of high pavement design temperature will be at a depth of 20 mm below the pavement surface, and the low pavement design temperature will be at the pavement surface (Mirza et al., 2011).

3.1 High Pavement Temperature Model

Following are the high temperature model developed under SHRP and LTPP.

Model developed under the SHRP (Mirza et al., 2011)

$$T_{pav,h} = (T_{air} - 0.00618Lat^2 + 0.2289Lat + 42.4)(0.9545) - 17.78 + z\sigma_{air} \quad (1)$$

Model developed under LTPP

$$T_{pav,h,d} = 54.32 + 0.78T_{air} - 0.0025Lat^2 - 15.14\, log_{10}(d + 25) + z\,(9 + 0.61\sigma^2_{air})^{1/2} \quad (2)$$

where,

$T_{pav,h}$ = High AC pavement temperature at 20 mm from surface,°C

$T_{pav,h,d}$ =High AC pavement temperature at depth d from surface, °C

T_{air} = High 7-day mean air temperature, °C

Lat = Latitude of the section, degrees

d= Pavement depth, mm

σ_{air} = Standard deviation of the 7-day maximum air temperature, °C

z = 2.055 for 98% reliability, and z = 0.0 for 50% reliability

3.2 Low Pavement Temperature Model

Model developed by SHRP

$$T_{pav,l} = T_{air} + 0.051\,d - 0.000063\,d^2 - z\sigma_{air} \quad (3)$$

Model developed by LTPP

$$T_{pav,l} = -1.56 + 0.72T_{air} - 0.004Lat^2 + 6.26\,log_{10}(d + 25) - z\,(4.4 + 0.52\sigma^2_{air})^{1/2} \quad (4)$$

where,

$T_{pav,l}$ = Low AC pavement temperature, °C

T_{air} =1-day minimum mean air temperature, °C

σ_{air} = Standard deviation of the 1-day minimum air temperature, °C

4. Reliability

The Superpave system defines reliability, as the percent probability in a single year that the actual temperature (one-day low or seven-day high) will not exceed the design temperature (Khan et al., 2013). The common reliability used is 50% and 98% where 98% means when the PG 70-10 binder is selected, the bituminous binder in the bituminous pavement should perform satisfactorily under normal traffic condition at the location where the extreme pavement temperature is within the range of −10°C and 70°C throughout its service life with a minimum 98% confidence level (Performance Grade, 2017).

5. Performance Grading System

By using performance grade binder specification chart provided by superpave system (Cominsky, 1994), performance grade of binder was determined. The PG system is based on climate, so the grade notation consists of two portions: high and low pavement temperatures (Khalil et al., 2009). A binder identified as PG 70-10 must meet performance criteria on the maximum pavement temperature of 70°C and at a minimum pavement temperature of −10°C where PG is stand for performance grade. For both high and low-temperature grades, PG are graded in 6°C increment. The average 7-day maximum pavement temperature typically ranges from 46°C to 82°C, and minimum pavement temperature typically ranges from −46°C to −10°C (Kennedy et.al., 1994).The study has determined seven different PG zones based on SHRP and four different PG zones based on LTPP model and are represented in Table 1.

Table1: PG of binder using SHRP and LTPP model

PG Based on SHRP	PG Based on LTPP
PG 76-10	PG 70-10
PG 70-10	PG 64-10
PG 64-10	PG 58-10
PG 58-16	PG 52-10
PG 58-10	
PG 52-16	
PG 52-10	

6. Development of Performance Grading Map of Nepal

While making performance grading map, maximum and minimum pavement temperature (design pavement temperature) determined by SHRP and LTPP model based on 98% level of reliability were used.

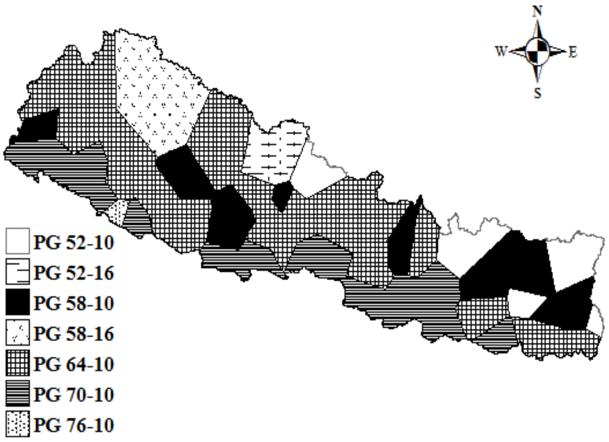

Fig. 2 Performance grading map of Nepal using SHRP model

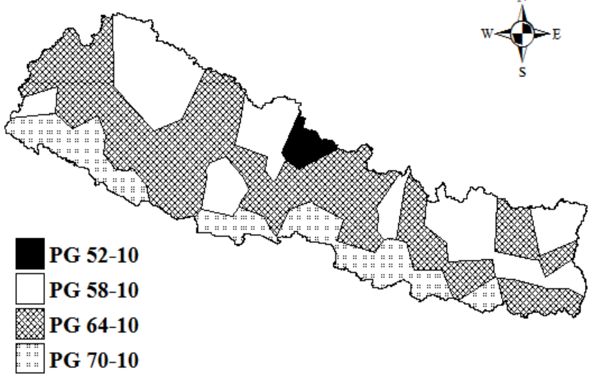

Fig. 3 Performance grading map of Nepal using LTPP model

The use of 98% level of reliability provides additional safety margin against high traffic level and uncontrolled axle loadings (Mirza et al., 2011). Fig 2 and Fig 3 present PG grading map of Nepal using SHRP and LTPP model respectively.

7. Conclusion

1. It is observed that the temperatures in Nepal vary significantly from one end of the country to another, with northern part much cooler compared to the southern part. The average lowest air temperature observed is -9.7°C in Rara and the high 7-day average air temperature is of 42.5°C in Dhangadhi.

2. The two models, SHRP and LTPP were used for the prediction of pavement temperatures with 50% and 98% level of reliability. By using performance grade binder specification chart provided by superpave system, performance grade of binder was determined.

3. This study has determined seven and four different performance grade zones based on SHRP and LTPP model respectively.

4. Relatively, difference was observed for high and low pavement temperature prediction using the SHRP and LTPP model approach at 98% level of reliability in terms of the average and standard deviations values. The predicted low pavement temperature from the LTPP model are about 3 to 4 degree higher than the SHRP model. This means a model developed under SHRP provide additional protection against low temperature cracking for those areas, which have significantly low temperature as compared to the LTPP model while LTPP provides additional protection against high temperature.

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