Design of Asphalt Pavements: Methods followed in India and Australia

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Abstract-India and Australia are very large countries in terms of total land area. The combined total road length of these two countries goes more than a million kilometres. A large portion of these roads are asphalt pavements. The methods adopted for design and construction of these roads in these countries are: California Bearing Ratio (CBR) method and mechanistic empirical methods. The methods have been discussed in this paper. The advantages and limitations of the methods are identified. From the discussion, it seems that using mechanistic empirical method is more advantageous than the CBR method.

I. INTRODUCTION

India is the 7th largest country in the world and 2nd largest in Asia in terms of land area. In terms of population, it is just behind China, which is the most populated country in the world. However as per latest UN report by 2024, India is due to overtake China and would become the most populated country in the world (1). India has now one of the largest labour force and India is rapidly progressing economically. As per International Monetary Fund (IMF), it is one of the fastest growing economy of the world with yearly GDP growth rate is approximately 7% (2). India is now industrializing in a constant rate for last two decades. The cities, town, villages and ports of India are now being connected by high speed roads to give better mobility and access. As of year 2015, the total road length of India was 5,603,293 km (3). Australia is one of the wealthiest countries of the world with high living standards (4). It is the 6th largest country in the world in terms of total land area. Population of Australia is approximately 24 million (5). Majority of Australian population is residing in urbanized areas. The total road length of Australia is 873,561 km (6).

The majority of the roads of these countries are made either from asphalt material or concrete. The Fig. 1 below shows the total road length (considering both asphalt and concrete pavement) per person in India and Australia. From the figure, it can be seen that the total road length available per person in Australia is 50 m/person and whereas in India, it is only 3.81 m/person.

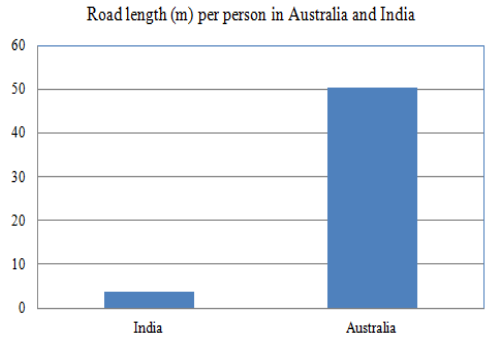

Fig 1: Comparison of road length per person in India and Australia

The focus of this paper is on asphalt pavements and hence methods followed for design of asphalt pavements have been discussed here. For structural design of asphalt pavement, several factors are considered and thus make the pavement design process a complex task. For example, traffic loading considered for the design depends on vehicle types, axle configurations, and axle loading. Also, the material used for pavement construction, respond to traffic loading in various ways due to stress-strain, temperature variation, moisture content, loading rate, and various other factors etc. Thus, methods such as California Bearing Ratio (CBR) method, empirical and mechanistic empirical methods have been developed to take account of these factors for the design of reliable asphalt pavements.

CBR method was suggested by O.J. Porter of the California State Highway Department (7). But later, it was developed and modified by several authorities in USA specially U.S. Corp Engineers. In this method, load penetration test is performed on the soil either in the laboratory or in-situ to find the soil CBR value. Later, empirical design charts are used to find the design thickness of pavement (9). The method has been discussed broadly later in this paper.

In empirical methods, usually laboratory data, such as test track data are used (pavement behaviour under repeated loading). The data is then used to develop model curves to represent the trend of pavement life under traffic loading. Such curves/models are used for the design of pavement. The methods may have good accuracy; but such methods are applicable to conditions such as same material selection and climatic condition in which they were developed.

Mechanistic empirical pavement design procedure has been developed based on the work of Dorman (8). The procedure is based on two models; first, empirical models, which co-relates the theory of mechanics and the performance of pavement structure and second, mechanistic based approach to model the responses-behaviour of pavement under loading (9,10,11,12,13). The pavement response is studied through multilayer elastic analysis. These two models are co-related for design and hence known as mechanistic-empirical method.

In India, both CBR and mechanistic empirical methods are used. In Australia, the design method followed is primarily mechanistic empirical. For construction of asphalt pavements in India, the design manual “IRC 37: 2012” titled “Guideline for Design of Flexible Pavement” from Indian Road Congress has been followed (9). The guideline is applicable to design of asphalt pavements for different road types in India, which are: expressway, national highways, state highways, major district roads, and other categories of roads etc. The guideline discusses both the CBR and mechanistic empirical design method.

These two methods are discussed in the subsequent sections below. The limitations and advantages of the methods are also discussed in the same sections. Before these discussions, an overview is presented on asphalt pavement structure.

II. ASPHALT PAVEMENTS

Asphalt pavements are essentially made by laying subbase layer(s) of stone aggregates (granular material) on top of the soil subgrade. The soil subgrade is compacted to carry the expected traffic load repetitions before being overlaid by

subbase layer(s). On top of the subbase layer(s), single or multiple layers of asphalt concrete are laid, as per design requirement. Fig. 2 shows a typical asphalt pavement. Generally, the design period of asphalt pavement is 12-15 years. However, the design period can be changed by changing the layer thicknesses of the pavement.

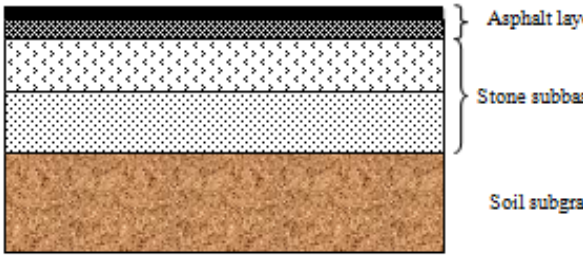

Figure 2: Cross section of a typical asphalt pavement

III. CBR METHOD

In this method, empirical design charts have been developed and provided by IRC design guidelines (9). These design charts, with information of (i) soil CBR values and (ii) design traffic in million standard axle load repetitions; the asphalt pavement can be designed. As per the IRC design guideline, an asphalt pavement could be designed for a CBR range between 2% to 10% and the design traffic ranging from 1 msa (million standard axles) and 150 msa. To estimate the design thickness of the granular subbase layer with its CBR value known, the same design charts could be used. The design traffic would be same as above for the design of subbase layer. Total thickness of the pavement as well as individual pavement layer thicknesses could be estimated using the charts as per IRC guidelines. It is thus understood that there are advantages of using CBR method such as: (i) it is easier to conduct CBR tests of soil subgrade in the laboratory and (ii) the design method is simple as it uses design charts for pavement design.

However, there are some limitations to CBR methods, such as: (i) CBR value of soil is measured by penetration test, which is empirical. Thus, the CBR value does not show the basic strength of soil, (ii) the punching shear test under the CBR tests, can not represent the stresses caused by traffic wheel load of soil subgrade, (iii) soaking of soil subgrade sample to measure the CBR value requires proper engineering judgement to replicate the true condition of the field (iv) the total thickness of the pavement entirely depends on the CBR value of soil subgrade. The total thickness of the pavement does not change with change of materials in the pavement layers and (v) The design charts for the design of asphalt pavement may not be suitable every time, as if conditions are different.

IV. MECHANISTIC-EMPIRICAL METHOD

In this method, the load initiated critical stress and strain values in the asphalt pavement are determined (horizontal tensile strain below the top asphalt layer and the vertical compressive strain on the soil subgrade). The method is based on analysing the performance indicators of asphalt pavement which are dependent on the critical stress-strain parameters. The

performance indicators reflect the performance of the pavement over time. Fatigue cracking (bottom up cracking) and rutting (permanent deformation) are the two performance indicators (refer to Fig. 4 and 5). Fatigue cracking and rutting distress are considered to be the primary causes of failure of asphalt pavements (9,10,11,12,13). In mechanistic-empirical method, a pavement is considered to be made up of multiple layers which behave elastically. Thus, Burmister approach (14) of multilayer elastic analysis is used to find the critical stress-strain values of the pavement. Later, mechanistic empirical models were used to predict the pavement life using the critical stress-strain parameter. The method is discussed below.

Fig 4: Fatigue cracking on an asphalt pavement

Fig 5: Rutting on an asphalt pavement

Fig. 6 shows the step wise approach of the mechanistic empirical method. The input parameters are: climatic conditions, load characteristics, material properties and thickness of pavement layers. The method of pavement design is iterative. At first, trial thickness is given as input. The critical stress-strain values are estimated using multilayer elastic analysis. The estimated stress-strain parameters are then used to find the allowable traffic load repetitions against fatigue and rutting failure by empirical equations. The projected year wise traffic is estimated and with the allowable traffic load repetitions known, the damage ratio (D) is calculated. Calculation of damage ratio is based on Miner's law (15). If the damage ratio is less than 1, the assumed pavement thickness is taken as the final design thickness. However, if the damage ratio is greater than 1, the process is repeated by varying the inputs such as: new pavement thickness.

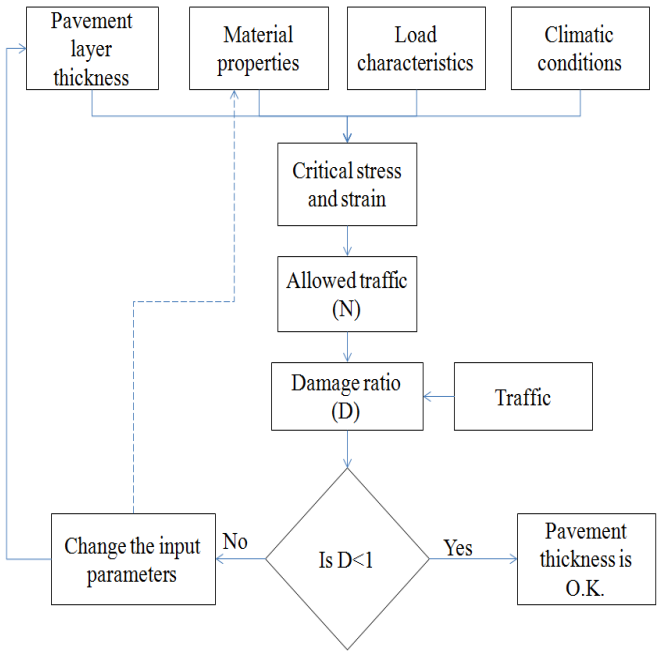

Fig 6: Flowchart showing the mechanistic empirical method of asphalt pavement design

V. CONCLUSION

Design of asphalt pavement is a complex task as it involves incorporating various factors such as: traffic loading repetitions, traffic loading pattern, material properties and its response under loading etc. CBR method, empirical methods and mechanistic empirical methods are developed for design of asphalt pavements by incorporating these factors. The present paper highlights only the methods used for design of asphalt pavement in India and Australia. In India, asphalt pavements are designed using both CBR and mechanistic empirical methods. The design guideline has been documented in IRC 37:2012. In Australia, asphalt pavements are designed as per mechanistic empirical method. The limitations and advantages of both the methods have been discussed. It seems that the mechanistic empirical method is better compared to CBR method for design of asphalt pavement. The major portion of the mechanistic–empirical method is based on theory which is empirical.

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