IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X.
PP 52-57
www.iosrjournals.org

Thickness Requirement of a Rigid Pavement with varying Conditions of Subgrade, Sub-Base and Shoulders

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Abstract: *From the past few years, the reliance is shifting more on rigid pavements because of its low maintenance cost, long service life and the smoother riding surface. The thickness of the concrete slab depends upon the strength of subgrade, axle load repetitions, type of sub-base and shoulders. Even a small decrease in the thickness of the concrete slab with proper design can result in appreciable economy to the project. Therefore, an attempt has been made to design a two lane two-way State Highway proposed to be laid in Haryana by considering all the available options of subgrade, sub-base and shoulders. The design has been carried out with Dry Lean Concrete, Granular and Cement treated subbase of different thickness with both tied and untied shoulder conditions. The pavement is provided with dowel and tie bars. It is observed from the design that an increase in the CBR value of subgrade and an increase in thickness of subbase layer has insignificant effect on the thickness of the pavement slab, but providing tied concrete shoulders reduce the slab thickness appreciably.*

Keywords - *California Bearing Ratio, Shoulders, Subbase, Subgrade, Thickness*

I. Introduction

The main factors affecting the thickness of the cement concrete pavement are subgrade strength axle load repetitions, type of sub-base and shoulders. Well-designed and maintained shoulders are an important part of cement concrete pavement. They do not only give lateral support to the pavement slab but also protect the edges of high volume highway pavements by reducing the edge flexural stress. Moreover, this widened part can be used by vehicles as an extra lane, thereby maintaining the Level of service and can be used for parking in populated urban areas and if rough texture is provided to it, will bring in additional safety to vehicles, particularly during night hours. This will also cut the economy of the future project as this widened part itself can be extended to make a new lane.

The subgrade soil plays an important role as the load is ultimately borne by the subgrade only. There is a general perception that stronger the subgrade lesser would be the thickness required for the pavement or conversely weaker the subgrade more is the thickness of cement concrete pavement required. The subgrade strength in case of cement concrete pavement is expressed in terms of modulus of subgrade reaction, which is determined by plate load test. As conducting the plate load test involves a number of complexities, it will be usual to indirectly check the modulus of subgrade reaction from the CBR value of soil using the relationships between CBR and k value given in IRC: 58.

The design of rigid pavement follow guidelines given in IRC: 58-2011[1], which are based upon the fatigue damage analysis for both bottom up and top down crackings. If the sum of cumulative fatigue damage caused by different axle loads is less than one for bottom up and top down cracking, the thickness of the pavement is safe.

The government of India is spending large amounts on the projects such as Pradhan Mantri Gram Sadak Yojna to connect the rural population and road pavements are an important part of this scheme which can cost a considerable amount. Therefore, a cost effective design which consists of all the possible alternatives is necessary to give benefits to both the investors and the nation.

In this paper a design of a typical two lane divided carriageway is done, which is proposed to be laid in Haryana. The design has been carried out for different subbase such as dry lean concrete of 100 mm thickness, granular subbase of 150 mm thickness and cement treated subbase of 100 mm thickness with tied and untied shoulders and CBR value of subgrade varying from 2% to 10% and then selecting the best possible subgrade soil, subbase material and shoulders that can support the pavement effectively and economically.

II. Data For Analysis

A cement concrete pavement has been designed for a two lane divided state highway in the state of Haryana. The details of the axle spectrum of rear single, tandem and tridem axles are given in table 1.

A design life of 30 years is considered in this study. The total traffic in the year of completion of construction is taken as 2000 commercial vehicles per day in each direction. The traffic growth rate is taken as 7.5 percent. The percentage of front single axle, rear single axle, rear tandem axle and the rear tridem axle are taken as 45%, 15%, 25% and 15% respectively. The percentage of commercial vehicles with spacing between the front axle and the first rear axle less than 4.5m is taken as 55% and it is assumed that 50% of the vehicles travel during the night hours. Design flexural strength of concrete is taken as 4.95 mPa with a unit weight of concrete as 24kN/m^3 and elastic modulus as 30000 MPa. Table 2 shows the category wise design axle load repetitions for both bottom up and top down crackings analysis.

Table 1: Axle load distribution

Single axle load (kN)	Frequency (%)	Tandem axle load (kN)	Frequency (%)	Tandem axle load (kN)	Frequency (%)
190	18.15	390	14.5	545	5.23
180	17.43	370	10.5	515	4.85
170	18.27	350	3.63	485	3.44
160	12.98	330	2.5	455	7.12
150	2.98	310	2.69	425	10.11
140	1.62	290	1.26	395	12.01
130	2.62	270	3.9	365	15.57
120	2.65	250	5.19	335	13.28
110	2.65	230	6.3	305	4.55
100	3.25	210	6.4	275	3.16
90	3.25	190	8.9	245	3.1
80	14.15	170	34.23	215	17.58
	100		100		100

Table 2. Category wise design Axle load repetitions

Axle category	Proportion of the axle category	For bottom-up cracking analysis	For top-down Cracking analysis
Front single axle	0.45	5986632	4938972
Rear single axle	0.15	1995544	1646324
Tandem axle	0.25	3325907	2743873
Tridem axle	0.15	1995544	1646324

III. Methodology And Results

For a given slab thickness and other design parameters, the pavement is checked for cumulative bottom-up and top-down fatigue. For bottom-up cracking, the flexural stress at the edge due to the combined action of single and tandem rear axle load and the positive temperature differential cycle is considered. Similarly for top-down cracking, the stresses due to the combined action of negative temperature differential cycle; and rear single, tandem and tridem axles are considered (100% of rear single, 50% of tandem and 33.33% of tridem axle). If the sum of the cumulative fatigue damage for bottom up and top down cracking is less than one, then the assumed thickness is safe.

3.1 Granular Subbase (GSB) of 150 mm

Providing granular subbase of 150 mm thickness with earthen shoulders and dowel bars across the transverse joints, cumulative fatigue damage at different trail thickness for varying subgrade strength are expressed in tabular form in Fig. 1. It is observed that with an increase in the thickness of concrete slab, the sum of cumulative fatigue damage for bottom-up and top-down cracking decreases. When CBR is 3% and the thickness of the pavement is 30 cm, the cumulative fatigue damage comes out to be 14.694. With further increase in the thickness of slab to 31cm and 32 cm, CFD decreases to 4.706 and 1.208 respectively, and at 33 cm CFD falls to 0.205 and this slab thickness is considered safe against bottom up and top down cracking. When the strength of the subgrade is increased to 4%, CFD decreases from 14.831 to 0.21 with an increase in the thickness of slab from 30 cm to 33 cm and here also 33 cm thick slab is found out to be safe against both cracking.

With further increase in the strength of subgrade, the same trend in the values of CFD is observed with an increase in the slab thicknesses, but the required safe thickness remains 33 cm.

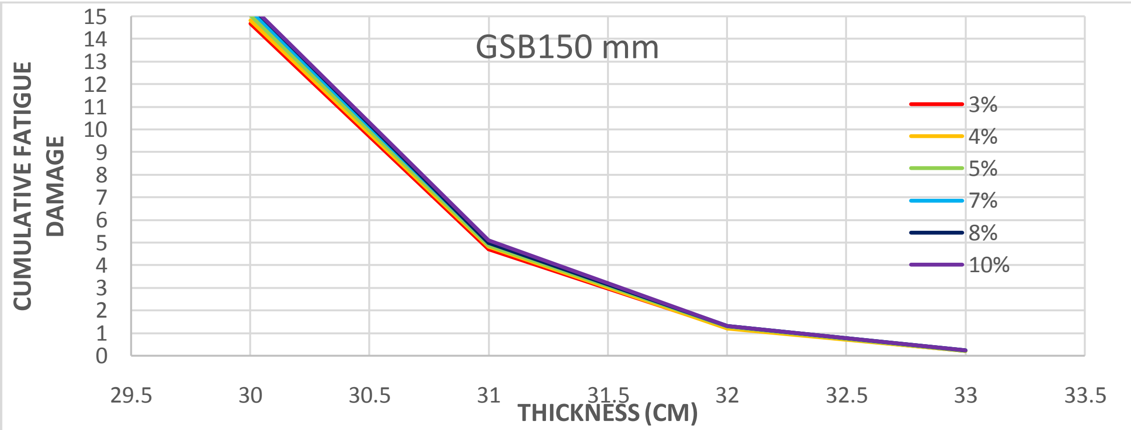

Fig. 1. Cumulative fatigue damage curve for Granular Subbase (GSB) at different Subgrade strengths

3.2 Dry Lean concrete Subbase (DLC) of 100mm

Providing dry lean concrete of 100 mm thickness with earthen shoulders and dowel bars across the transverse joints, cumulative fatigue damage at different trail thickness are expressed in Fig. 2.

Similar analysis is carried out with dry lean concrete subbase of 100 mm thickness and all the parameters remain same as in the above analysis. It can be seen that at 2% CBR and 30 cm slab thickness, sum of CFD for bottom up and top down cracking comes out to be 15.286, which goes on decreasing with an increase in the thickness of the slab and falls below one at 33 cm thickness. Similar trend can be seen at 3% CBR and required thickness increased to 33 cm. With further increase in the subgrade strength required thickness remains 33 cm.

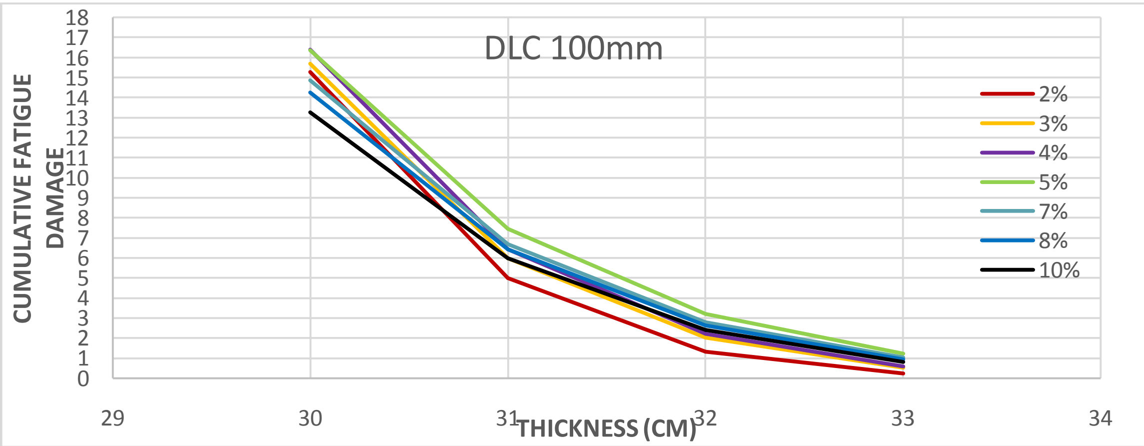

Fig. 2. Cumulative fatigue damage curve for Dry Lean Concrete (DLC) at different Subgrade strengths

3.3 Cement treated subbase (CTS) of 100mm

Providing cement treated subbase of 100 mm thickness with earthen shoulders and dowel bars across the transverse joints, cumulative fatigue damage at different trail thickness are expressed in tabular form in Fig. 3.

Designing the rigid pavement with cement treated subbase of 100 mm thickness and all the parameters same as in above analysis shows that at 3% CBR of subgrade soil the required safe thickness is 33 cm which remains same with the increase in the subgrade strength. From 4% CBR to 10% CBR required thickness remains same, i.e. 33 cm only.

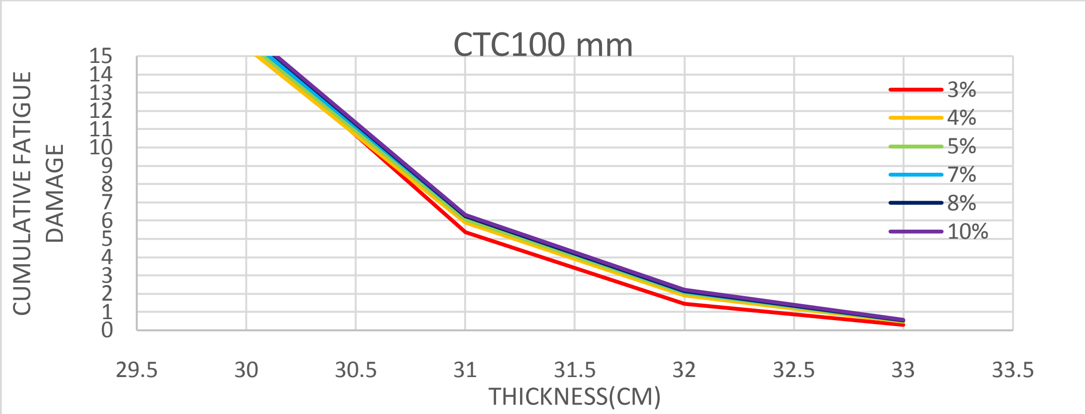

Fig. 3. Cumulative fatigue damage curve for Cement Treated Subbase (CTC) at different Subgrade strengths

IV. Analysis With Tied Concrete Shoulders

Providing Dry Lean Concrete of 100 mm thickness with tied concrete shoulders and dowel bars across the transverse joints, cumulative fatigue damage at different trail thickness are expressed in Fig. 4. It can be seen that for 2%, 3%, 4% and 5% CBR of subgrade soil, the safe thickness comes out to be 29 cm which decreases to 28 cm for 7, 8 and 10% CBR. Similarly with Granular Subbase of thickness 150 mm, the safe thickness of the slab is 30 cm for 3 and 4% and reduces to 29 cm for the rest of the subgrade strength (Fig. 5). For Cement Treated Subbase of 100 mm thickness, required thickness remains constant for all the subgrade strength, i.e. 29 cm (Fig. 6).

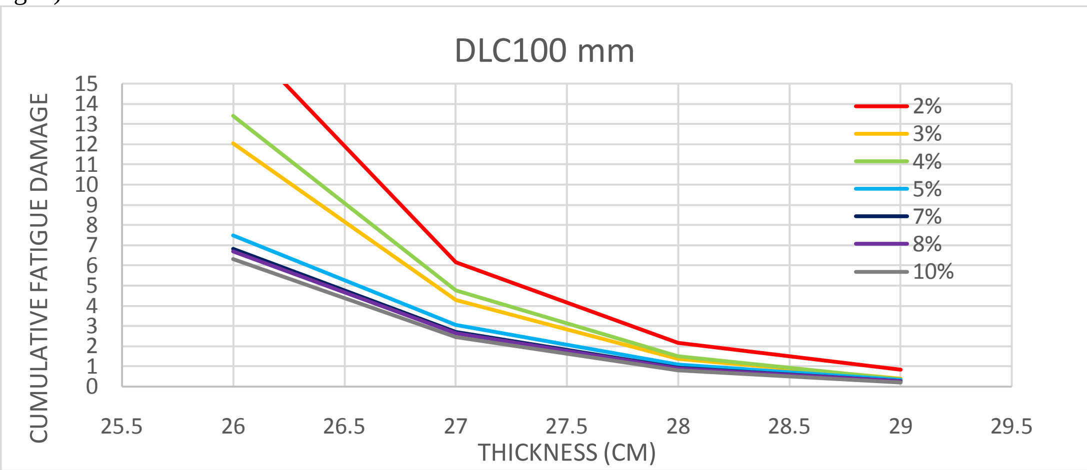

Fig. 4. Cumulative fatigue damage curve for Dry Lean Concrete (DLC) at different Subgrade strengths

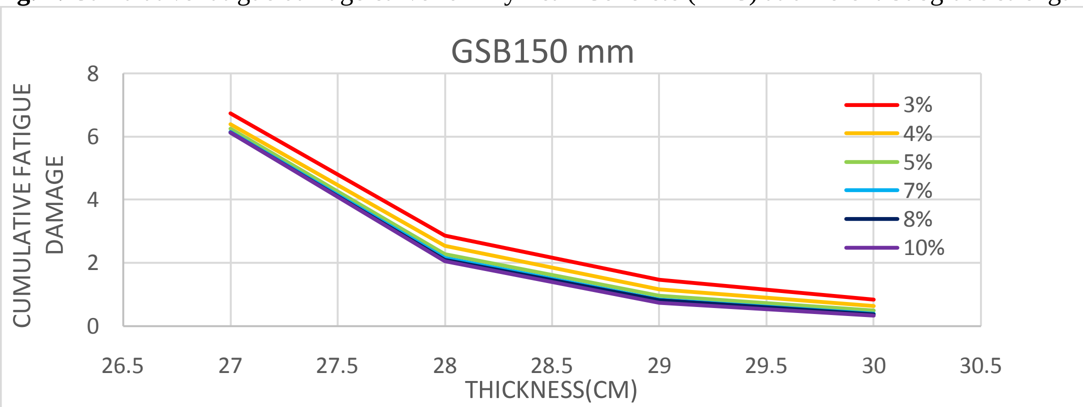

Fig.5. Cumulative fatigue damage curve for Granular Subbase (GSB) at different Subgrade strengths

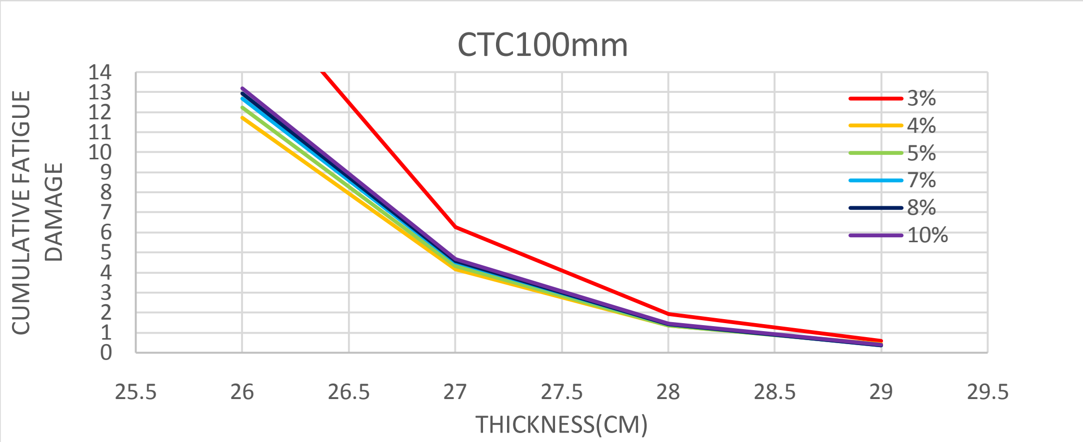

Fig.6. Cumulative fatigue damage curve for Cement Treated Subbase (CTC) at different Subgrade strengths

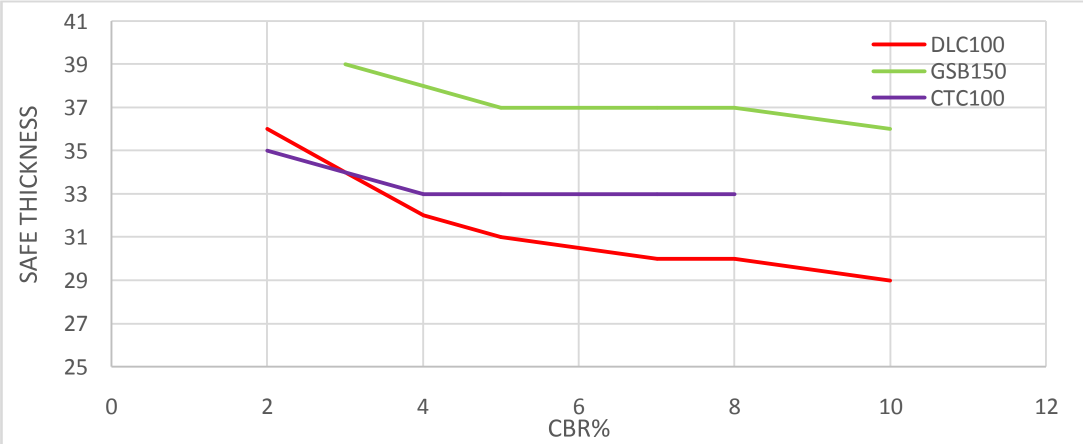

Fig.7. Safe thickness VS CBR% by IRC: 58-2002

4.1 Comparison with IRC: 58-2002

The analysis done with the help of IRC: 58- 2011 is verified with the previous guidelines (IRC: 58-2002 [2]) according to which, "if the cumulative fatigue damage caused by the single and tandem axle loads is less than one and if the sum of temperature and flexural stresses due to the higher wheel load is less than the modulus of rupture, then the thickness is said to be safe". The results of the analysis are totally different from the analysis done using IRC: 58-2011 and these are represented in graphical form. Fig. 7 shows the safe thickness with different values of CBR for dry lean concrete (DLC) of 100 mm thickness, granular subbase (GSB) of 150 mm thickness and for cement treated subbase (CTS) of 100 mm thickness. It can be clearly seen that with the increase in the subgrade strength, design thickness is decreasing.

V. Discussion

It is observed from Fig. 1, 2, and 3 that the required safe thickness remains same for all changes in subgrade strength. Moreover, change in the type of subbase material also has no effect on the slab thickness i.e required thickness remains 33 cm. Analysis with tied concrete shoulders show somewhat different results. For DLC 100 mm, the slab thickness remains constant below 7% CBR, afterwards decreases, but remains constant up to 10%. Similar happens with GSB of 150 mm thickness, i.e. for 3% and 5% CBR, safe thickness comes out to be 30 cm and after that it decrease, but remains 29 cm from 5% to 10% CBR. In case of CTC 100 mm, this remains constant for all changes in the subgrade strength. Contrary to the above, if the same is designed by IRC: 58-2002, the results are obtained as given in fig. 7. It can be seen from the figure that stronger subgrade leads to lesser pavement thickness.

There is a general perception that stronger the subgrade lesser would be the thickness required for the pavement or conversely weaker the subgrade more is the thickness of cement concrete pavement required. Many a time, the existing soil is either replaced with soil having a higher California bearing ratio or stabilized to enhance the CBR value of using it in the subgrade. There is a general trend that with an increase in the slab thickness, stresses tended to decrease, but according to IRC: 58-2011, "if there is zero temperature differential, the flexural stresses decrease with increase in effective modulus of subgrade reaction (k-value) for all the thicknesses. But for almost all the positive temperature differential, the warping stresses are high for thicker slabs and it results in higher flexural stresses in slabs while flexural stresses are lower for higher 'k' values for thinner slabs. For a thickness in the region of 270 mm there is practically no effect of 'k' value on the flexural stresses and if we increase the 'k' value then there will be no effect on the design thickness because of high curling stresses offered by stiff support".

If we consider this theory, then the individual analysis done for DLC, GSB and CTS may be all right, but change in the type of subbase from dry lean concrete to cement treated subbase and granular subbase and required thickness remains unchanged seems to be contradictory.

VI. Conclusion

1. In the analysis of the pavement with earthen shoulders, subgrade strength has insignificant effect on the slab thickness for all types of subbase materials.
2. Analysis with tied concrete shoulders show somewhat different results, but still after a subgrade strength, thickness remains constant.
3. At 8% CBR for both tied and untied concrete shoulder condition, required thickness is the same for dry lean concrete (100 mm), granular subbase (150 mm) and cement treated subbase (100mm).
4. Validation of the results by previous IRC guidelines shows completely different results with increases in subgrade strength, design thickness decreases.
5. Therefore, it is recommended to verify the results by IRC: 58-2002, before placing the design into the actual field.
6. It is mentioned in the IRC: 58-2011 that a minimum of 8% CBR is recommended for the 500 mm of the select soil used as subgrade. But results show that at 8% CBR, required thickness is the same for all types of subbase materials. Therefore, a detailed investigation should be done to discuss this problem.

References

[1] Indian Road Congress, IRC: 58-2011, Guidelines for the Design of Plain Jointed Rigid Pavement for Highways.
[2] Indian Road Congress, IRC: 58-2002, Guidelines for the Design of Plain Jointed Rigid Pavement for Highways.