International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 5, Issue 03, March-2019

EFFECT OF HIGHER AXLE LOAD FREQUENCY ON CEMENT CONCRETE PAVEMENT THICKNESS

Ezatullah Rahimi[a], S.N. Sachdeva[b]

[a]M.Tech student, Department of Civil Engineering, National Institute of Technology Kurukshetra,Haryana-136119, India,
[b]Professor, Department of Civil Engineering, National Institute of Technology, Kurukshetra, Haryana-136119, India,

Abstract**: Design of rigid pavements is done considering the flexural stress under the simultaneous action of load and temperature gradient for different categories of axles. Sum of cumulative fatigue damage caused by single, tandem and tridem axle load applications causing tensile flexural stress at the top and the bottom of the pavement slab should be less than one for the design to be safe. In this paper the thickness of a rigid pavement has been designed with variation in the frequency of rear (single, tandem and tridem) axles type. The variation considered in frequency for five types of highest load group for single axles (190 to 150 kN), for tandem axles (390 to 310 kN) and for tridem axles (545 to 425kN) is from 8.33% to 100% for the five highest load categories. Variation in frequency has also been taken in a random manner.

Keywords: axle load frequency, rigid pavement, thickness design, subgrade strength, tied concrete shoulder.

I. INTRODUCTION

A rigid pavement is constructed from cement concrete or reinforced concrete slabs. Grouted concrete roads are in the category of semi-rigid pavements. The design of rigid pavement is based on providing a structural cement concrete slab of sufficient strength to resist the loads from traffic.
The component of a typical rigid pavement or cement concrete (CC) pavement structure (form bottom towards the top) consist of:
a). compacted soil subgrade at the bottom or lowest layer
b). granular sub-base (GSB) course and drainage layer
c). base course
d). CC/PQC pavement slab
The main factors effecting on the design of a rigid pavement are axle load repetition, types of axle load spectrum, subgrade strength or subgrade reaction (k), temperature gradient and types of the shoulders.
Well-design tied concrete shoulders are an important part of rigid pavements. They not only provide lateral support to concrete pavements, but also reduce the flexural stress on the edge of rigid pavements. Moreover, the widened part can be used for parking in populated urban area specially it can bring more safety during night hours and it can be an economical way for future widening of the pavement.
The subgrade soil plays an important roles for the design of rigid pavements, by increasing the strength of subgrade soil, the flexural stress under action of load will decrease. the relationship between CBR and k value is given in IRC: 58. The design of cement concrete pavement follow guidelines given in IRC: 58-2015, which are based upon the fatigue damage analysis for bottom up cracking (BUC) and top down cracking (TDC). If the sum of cumulative fatigue damage with different axle load for BUC and TDC is less than one, the pavement thickness is safe.
In this paper the thickness of a rigid pavement has been designed with variation in the frequency (%) for rear (single, tandem and tridem) axles type. The variation considered in frequency for five types of highest load group for single axles (190 to 150 kN), for tandem axles (390 to 310 kN) and for tridem axles (545 to 425 kN) is from 8.33% to 100% for the five highest load categories. Variation in frequency has also been taken in a random manner. The effective CBR of compacted subgrade is 8% and the foundation of pavement consist 150 mm thick of granular subbase and provided a DLC subbase of thickness 150 mm. The traffic volume considered is 6000 (CVPD) commercial vehicle per day in both directions. The design has been carried out for tied concrete shoulder. The effect on the thickness of rigid pavement due to change in the frequency of the loads is worked out in this study.

II. DATA FOR ANALYSIS

A cement concrete pavement has been designed for a four-lane divided National Highway with two lanes in each direction (7.0 m x 2) in the state of Haryana, India. The pavement has been designed for a period of 30 years. Lane width = 3.5 m; transverse joint spacing = 4.5 m.
It is expected that the road will carry, in the year of completion of construction, about 3000 commercial vehicles per day in each direction. The traffic growth rate is taken 7.5 percent. Axle load survey of commercial vehicles indicated that the percentage of front single (steering) axle, rear single axle, rear tandem axle and rear tridem axle are 45%, 15%, 25% and 15%

respectively. The percentage of commercial vehicles with spacing between the front axle and the first rear axle less than 4.5 m is 55%. Traffic count indicates that 60% of the commercial vehicles travel during night hours (6 PM to 6 AM). Design flexural strength of concrete is taken as 4.95 MPa with a unit weight of concrete as 24 KN/m^3 and elastic modulus as 30000MPa.

Effective CBR of compacted subgrade = 8%. Modulus of subgrade reaction = 50.3 MPa/m (from table 2, IRC: 58-2015) and Effective modulus of subgrade reaction of combined foundation of subgrade + granular subbase (from table 4, IRC: 58-2015 by interpolation) = 285 MPa/m. Max.day-time Temperature Differential in slab (for bottom-up cracking) = 15.8^oC (for Haryana) and

Night-time temperature differential in slab (for top-down cracking) = day-time differential/2 +5 = 12.9^oC. Poisson's ratio of concrete, $\mu = 0.15$.

Detail of axle load spectrum of rear single, tandem and tridem axles are given in table. 1. Front (steering) axles are not included. The average number of axles per commercial vehicles is 2.35 (due to the presence of multi-axles vehicles).

TABLE 1. Axle load spectrum

Rear Single Axle			Rear Tandem Axle			Rear Tridem Axle		
Load Group (kN)	**Mid-Point of Load Group (kN)**	**Frequency (%)**	**Load Group (kN)**	**Mid-Point of Load Group (kN)**	**Frequency (%)**	**Load Group (kN)**	**Mid-Point of Load Group (kN)**	**Frequency (%)**
185-195	190	8.33333	380 - 400	390	8.33333	530-560	545	8.33333
175-185	180	8.33333	360 - 380	370	8.33333	500-530	515	8.33333
165-175	170	8.33333	340 - 360	350	8.33333	470-500	485	8.33333
155-165	160	8.33333	320 - 340	330	8.33333	440-470	455	8.33333
145-155	150	8.33333	300 - 320	310	8.33333	410-440	425	8.33333
135-145	140	8.33333	280 - 300	290	8.33333	380-410	395	8.33333
125-135	130	8.33333	260 - 280	270	8.33333	350-380	365	8.33333
115-125	120	8.33333	240 - 260	250	8.33333	320-350	335	8.33333
105-115	110	8.33333	220 - 240	230	8.33333	290-320	305	8.33333
95-105	100	8.33333	200 - 220	210	8.33333	260-290	275	8.33333
85-95	90	8.33333	180 - 200	190	8.33333	230-260	245	8.33333
< 85	80	8.33333	< 180	170	8.33333	< 230	215	8.33333
		100			100			100

The axle load category-wise design axle load repetitions for bottom-up and top-down fatigue cracking analysis are given in the table 2.

TABLE 2. Category-wise axle load Repetition

Axle Category	Proportion of the Axle-Category	Design number of axle load repetition in day-time	Design number of axle load repetition in night-time	Category-Wise Axle Repetition for Bottom-Up Cracking analysis	Category-Wise Axle Repetition for Top-Down Cracking analysis
Front (steering) single	0.45	13303626	10975491	5986632	4938971
Rear single	0.15	13303626	10975491	1995544	1646324
Tandem	0.25	13303626	10975491	3325906	2743873
Tridem	0.15	13303626	10975491	1995544	1646324

III. CONCRETE PAVEMENT WITH TIED CONCRETE SHOULDER

3.1. Variation of the frequency (%) for single axle load

The variation is done by increasing the frequency (%) of 190 kN rear single axle load from 8.33% to 100% with matching uniformly distributed decrease in the frequency of other load groups of rear single axle as shown in Table 3. The frequency of rear tandem and tridem axles is maintained the same while effecting this variation in single axle loads. Fig 1 shows the slab thickness variation with this variation in the frequency of single axle loads.

TABLE 3. Slab thickness variation with increase in frequency of 190 kN load with matching decrease in frequency of other single axle loads

Rear Single Axle													Rear Tandem Axle		Rear Tridem Axle	
Mid-Point of Load Group (kN)	Variation of Frequency (%) for 190 kN												Mid-Point of Load Group (kN)	Frequency (%)	Mid-Point of Load Group (kN)	Frequency (%)
190	8.33	16.7	25	33.3	41.7	50	58.3	66.7	75	83.3	91.7	100	390	8.33	545	8.33
180	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	0	370	8.33	515	8.33
170	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	0	0	350	8.33	485	8.33
160	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	0	0	0	330	8.33	455	8.33
150	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	0	0	0	0	310	8.33	425	8.33
140	8.33	8.33	8.33	8.33	8.33	8.33	8.33	0	0	0	0	0	290	8.33	395	8.33
130	8.33	8.33	8.33	8.33	8.33	8.33	0	0	0	0	0	0	270	8.33	365	8.33
120	8.33	8.33	8.33	8.33	8.33	0	0	0	0	0	0	0	250	8.33	335	8.33
110	8.33	8.33	8.33	8.33	0	0	0	0	0	0	0	0	230	8.33	305	8.33
100	8.33	8.33	8.33	0	0	0	0	0	0	0	0	0	210	8.33	275	8.33
90	8.33	8.33	0	0	0	0	0	0	0	0	0	0	190	8.33	245	8.33
80	8.33	0	0	0	0	0	0	0	0	0	0	0	170	8.33	215	8.33
	100	100	100	100	100	100	100	100	100	100	100	100		100		100
Safe thickness (m)	0.28	0.28	0.28	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29				
Sum of CFD for BUC & TDC	0.46	0.66	0.87	0.26	0.32	0.37	0.43	0.48	0.54	0.59	0.64	0.69				

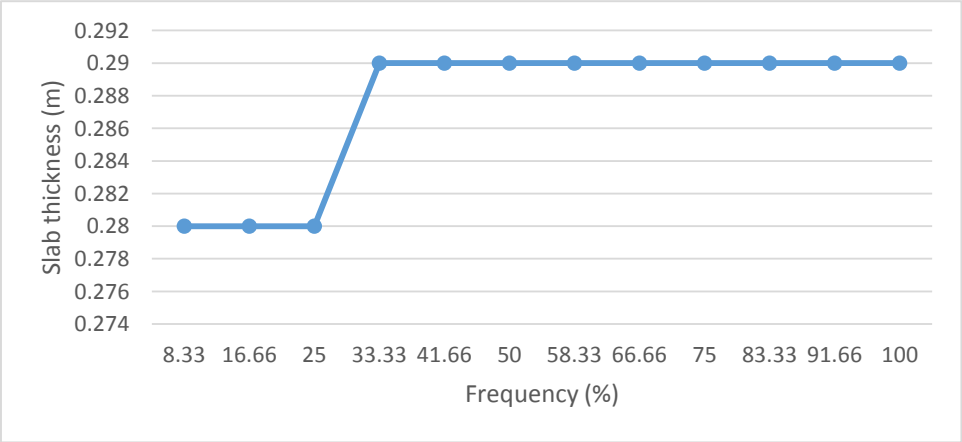

Figure 1. Slab thickness variation with increase in frequency of 190 kN load with matching decrease in frequency of other single axle loads

Figure 2. shows safe thickness with tied concrete shoulders for five highest class of loading for single axle type by variation of the frequency (%).

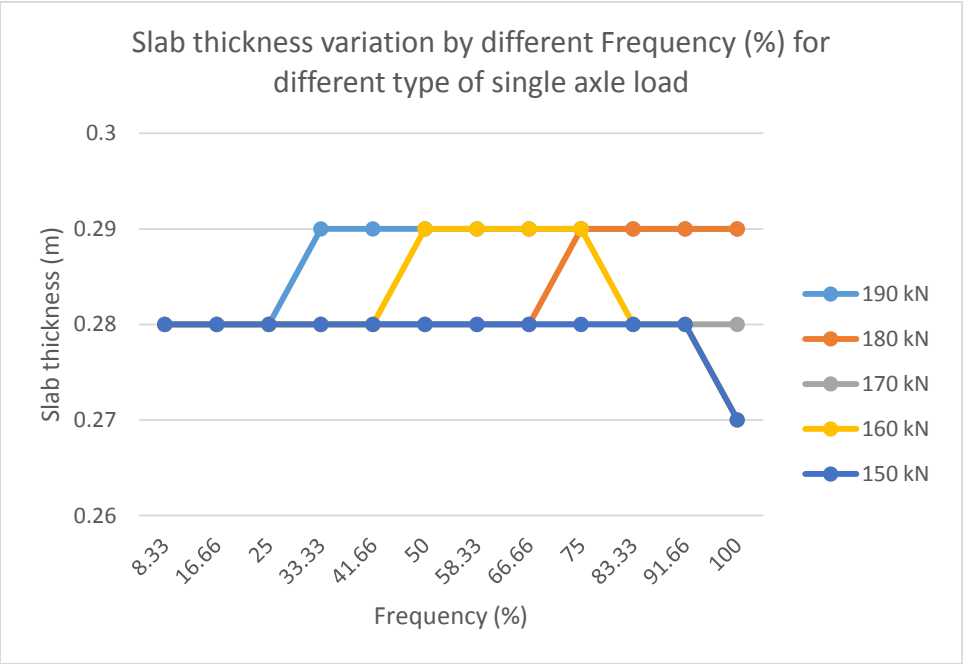

Figure 2. Slab thickness variation by different frequency (%) for different types of single axle load with tied concrete shoulders

3.2. Variation of the frequency (%) for tandem axle load

Fig 3. shows the slab thickness variation with tied concrete shoulders in Different frequency (%) for 390, 370, 350, 330 and 310 kN of Tandem axle load by keeping the frequency of Single and Tridem axles.

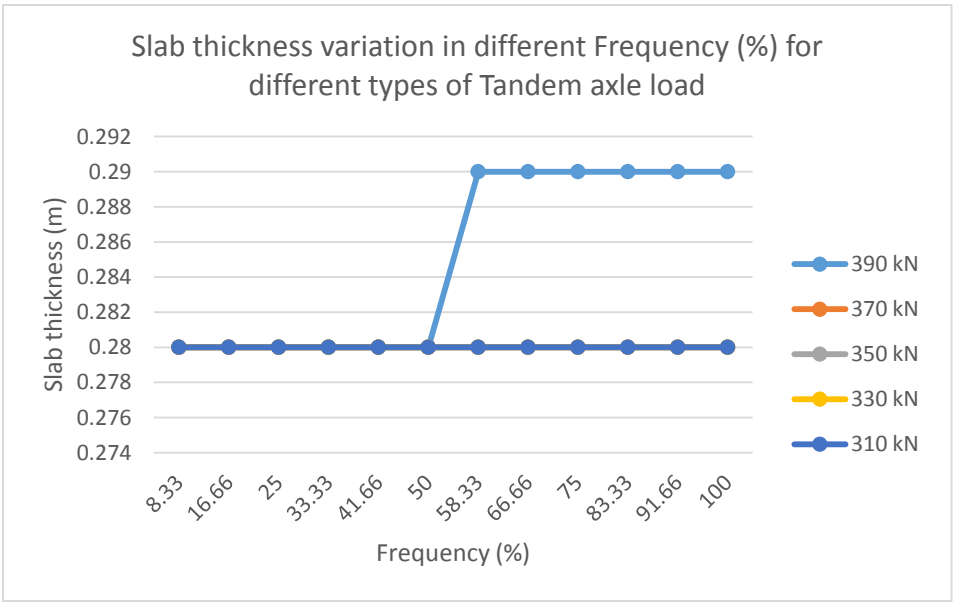

Figure 3. Slab thickness variation by different frequency (%) for different types of Tandem axle load with tied concrete shoulders

3.3. Variation of the frequency (%) for tridem axle load

Fig 4. shows the slab thickness variation with tied concrete shoulders in Different frequency (%) for 545, 515, 485, 455 and 425 kN of tridem axle load by keeping the frequency of Single and Tandem axles.

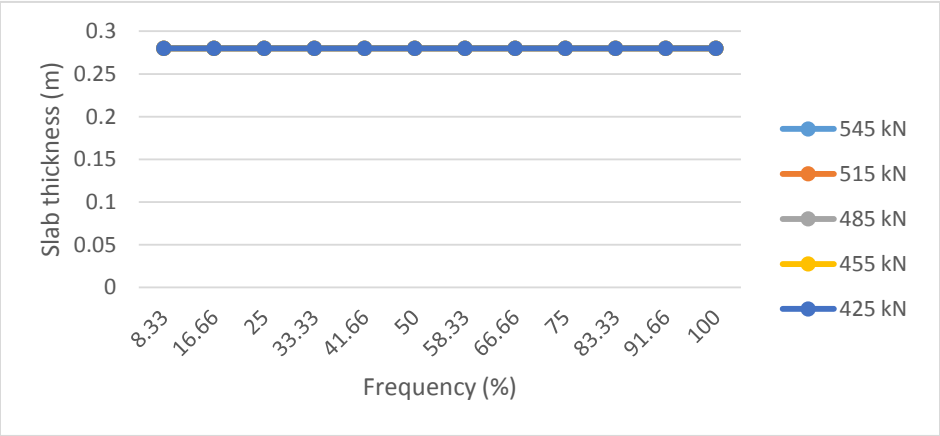

Figure 4. Slab thickness variation by different frequency (%) for different types of Tridem axle load with tied concrete shoulders

IV. Variation of the frequency (%) for single, tandem and tridem axle load at same time for tied concrete shoulders

Variation of the frequency (%) is done for (190 to 150 kN) of single axles, (390 to 310 kN) of Tandem axles and (545 to 425 kN) of tridem axles load respectively at same time for tied concrete shoulders. The variation is done by increasing the frequency (%) of 190 kN of rear single axle, 390 kN of tandem axle and 545 kN of tridem axle load from 8.33% to 100% with matching uniformly distributed decrease in the frequency of other load groups of rear single, tandem and tridem axles. Table 4. and Fig 5. Are a sample of the frequency (%) variation for 190 kN of single axle, 390 kN of tandem axle and 545 kN of tridem axle.

Table 4. Slab thickness variation with increase in frequency of 190, 390 and 545 kN load with matching decrease in frequency of other single, tandem and tridem axle loads

Rear Single axle	**Rear Tandem Axle**	**Rear Tridem Axle**	**Variation of Frequency (%) for 190, 390 and 545 kN**											
Mid-Point of Load Group (kN)	**Mid-Point of Load Group (kN)**	**Mid-Point of Load Group (kN)**												
190	390	545	8.33	16.66	25	33.33	41.66	50	58.33	66.66	75	83.33	91.66	100
180	370	515	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	0
170	350	485	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	0	0
160	330	455	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	0	0	0
150	310	425	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	0	0	0	0
140	290	395	8.33	8.33	8.33	8.33	8.33	8.33	8.33	0	0	0	0	0
130	270	365	8.33	8.33	8.33	8.33	8.33	8.33	0	0	0	0	0	0
120	250	335	8.33	8.33	8.33	8.33	8.33	0	0	0	0	0	0	0
110	230	305	8.33	8.33	8.33	8.33	0	0	0	0	0	0	0	0
100	210	275	8.33	8.33	8.33	0	0	0	0	0	0	0	0	0
90	190	245	8.33	8.33	0	0	0	0	0	0	0	0	0	0
80	170	215	8.33	0	0	0	0	0	0	0	0	0	0	0
			100	100	100	100	100	100	100	100	100	100	100	100
Safe thickness (m)			0.28	0.28	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.3
Sum of CFD for BUC & TDC			0.457	0.768	0.269	0.353	0.437	0.521	0.605	0.689	0.773	0.857	0.94	0.137

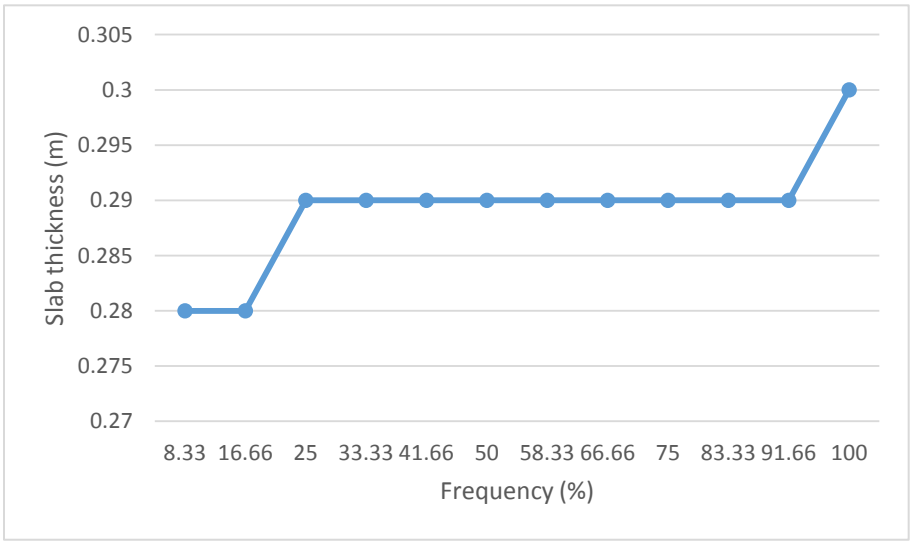

Figure 5. Slab thickness variation with increase in frequency of 190, 390 and 545 kN load with matching decrease in frequency of other single, tandem and tridem axle loads

Figure 6. shows safe thickness with tied concrete shoulders. Variation of the frequency (%) is done for (190 to 150 kN) of single axles, (390 to 310 kN) of Tandem axles and (545 to 425 kN) of tridem axles load respectively at same time for tied concrete shoulders.

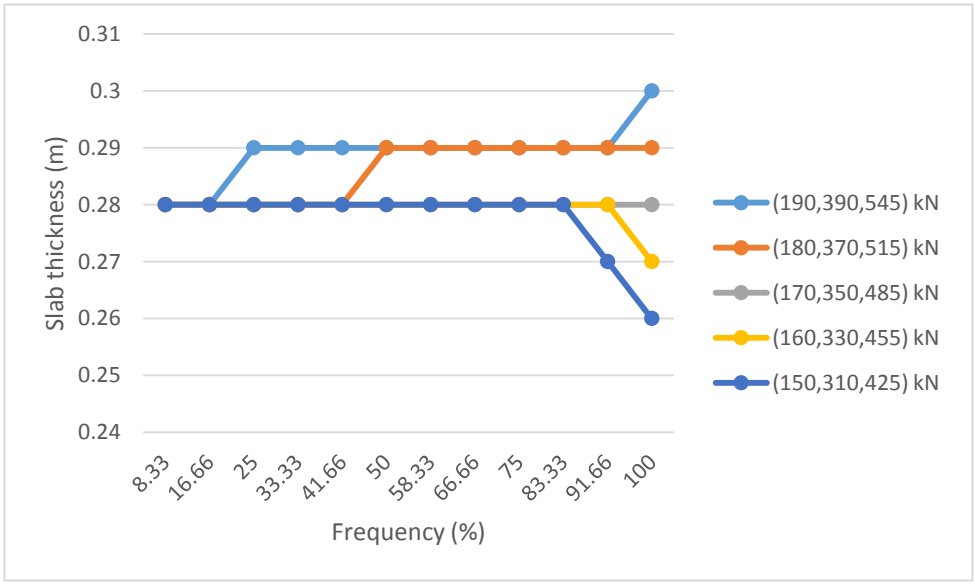

Fig 6. Slab thickness variation in different frequency (%) for different load group of single, tandem and tridem axle with tied concrete shoulders

V.RANDOMLY VARIATION OF THE FREQUENCY (%) FOR SINGLE, TANDEM AND TRIDEM AXLE LOAD AT SAME TIME FOR TIED CONCRETE SHOULDERS

Randomly variation of the frequency (%) is done for (140, 110, 100 and 80 kN) of single axles, (290, 230, 210 and 170 kN) of Tandem axles and (395, 305, 275 and 215 kN) of tridem axles load respectively at same time.

Table 5. shows the safe thickness with tied concrete shoulders by randomly variation of the frequency (%) for 80, 170 and 215 kN of single, tandem and tridem axles respectively.

Table 5. Slab thickness variation in different frequency (%) for 80, 170 and 215 kN of single, tandem and tridem axle load with tied concrete shoulders

Rear Single axle	Rear Tandem Axle	Rear Tridem Axle	Variation of Frequency (%) for 80, 170 and 215 KN			
Mid-Point of Load Group (kN)	Mid-Point of Load Group (kN)	Mid-Point of Load Group (kN)				
190	390	545	0	0	0	0
180	370	515	0	0	0	0
170	350	485	0	0	0	0
160	330	455	0	0	0	0
150	310	425	0	0	0	0
140	290	395	0	0	0	0
130	270	365	0	0	0	0
120	250	335	0	0	0	0
110	230	305	8.33	8.33	8.33	0
100	210	275	8.33	8.33	0	0
90	190	245	8.33	0	0	0
80	170	215	75	83.33	91.66	100
			100	100	100	100
Safe thickNess (m)			0.21	0.21	0.21	0.195
Sum of CFD for BUC & TDC			0.539	0.539	0.455	0.86

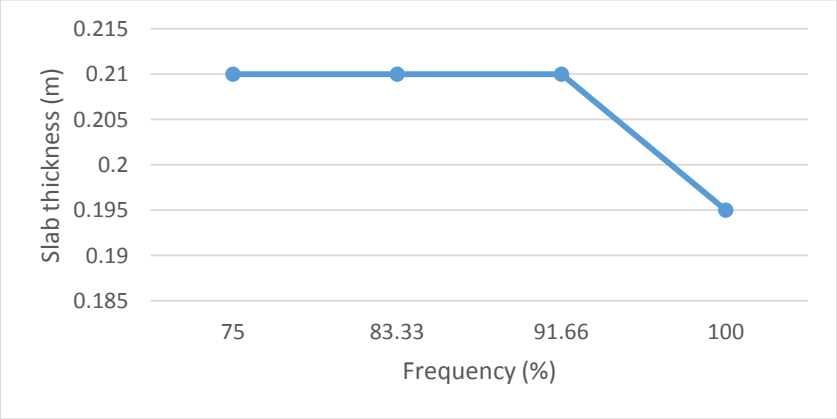

Figure 7. Slab thickness variation by different frequency (%) for 80, 170 and 215 KN of single, tandem and Tridem axle load with tied concrete shoulders

Table 6. and Figure 8. shows safe thickness with tied concrete shoulders for different class of loading for single, Tandem and Tridem axles type by randomly variation of the frequencies (%) at same time.

Table 6. Safe thickness with tied concrete shoulders for different class of single, tandem and Tridem axle load

Safe thickness for different class of loading for single, Tandem and Tridem axles' type by randomly variation of the frequencies (%)					
Numbers	Frequency (%)	Safe thickness (m)			
		(140,290,395) kN	(110,230,305) kN	(100,210,275) kN	(80,170,215) kN
1	75	0.25	0.22	0.22	0.21
2	83.33	0.25	0.22	0.22	0.21
3	91.66	0.25	0.22	0.22	0.21
4	100	0.25	0.23	0.215	0.195

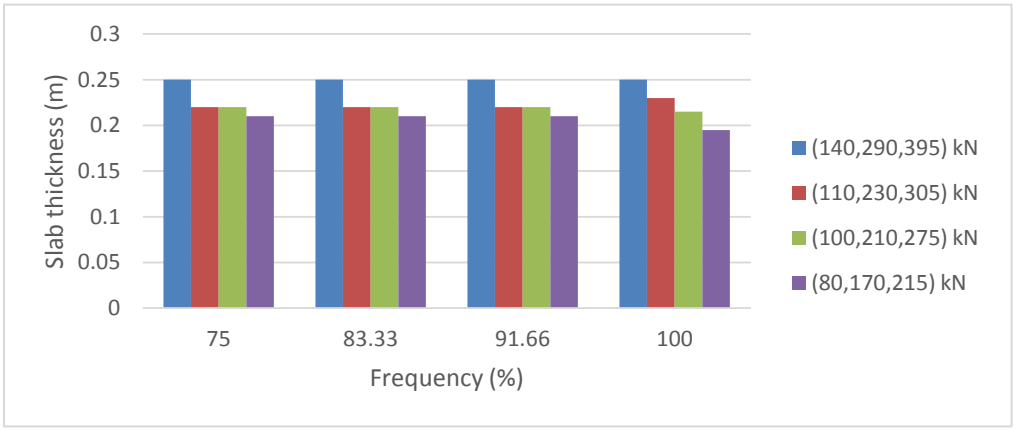

Figure 8. Slab thickness for tied concrete shoulders with randomly variation of the frequency (%) for different types of loading for single, tandem and Tridem axle loads

Fig 9. shows lab thickness variations for tied concrete shoulders with different conditions by regular and randomly variation of the frequency (%) for different types of loading for single, tandem and Tridem axle loads in Haryana state.

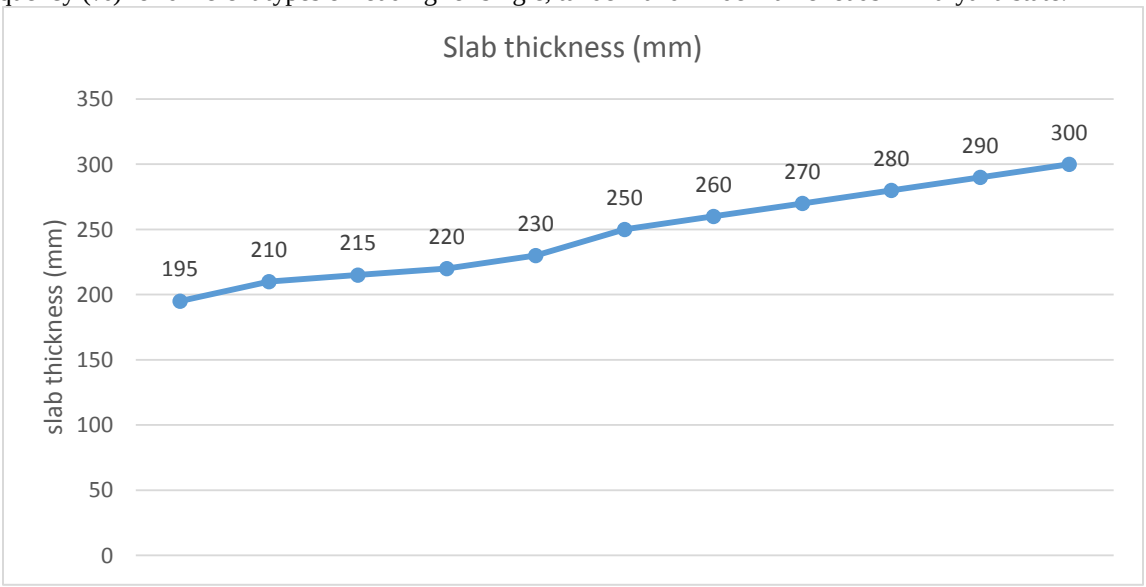

Fig 9. Slab thickness variations for tied concrete shoulders with different conditions by regular and randomly variation of the frequency (%) for different types of loading for single, tandem and Tridem axle loads

VI. DISCUSSION

It is observed from Fig 1. That the required safe thickness remains for all change in the frequency for single axle type by keeping the frequency for tandem and tridem axles.
In this study the CBR value is constant 8%, so by changing the subgrade strength the thickness of pavement would have variation. By increasing the California bearing ratio (CBR) the k-value or modulus of subgrade reaction will increase and it required less thickness and by decreasing the subgrade strength, the thickness of pavement will increase. Also by variation of the (GSB and DLC) materials and thickness, it will effect on the thickness of pavement.
In this study the single axle load has more effect on the thickness of pavement. Highest load groups has more effect on the thickness requirement and lowest load group axle types required less thickness.
On fig. 7 I have considered the empty vehicles for single, tandem and tridem axles type. The thickness variation is from 195 mm to 210 mm for different frequency and fig. 9 shows slab thickness variation with different condition, the variation is from 195 mm to 300 mm.

VII. CONCLUSIONS

On the basis of above mentioned studies it can be concludes that:

1. Design of rigid pavements is done considering the flexural stress under the simultaneous action of load and temperature gradient for different categories of axles.
2. Sum of cumulative fatigue damage caused by single, tandem and tridem axle load applications causing tensile flexural stress at the top and the bottom of the pavement slab should be less than one for the design to be safe. Thus if CFD (BUC) + CFD (TDC) ≤ 1, the pavement is save from large scale cracking.
3. by variation of the frequency for five highest load groups of single axle types from (190 to 150) kN by keeping the frequency for tandem and tridem axles, the thickness is varied from 270 mm to 290 mm.
4. by changing the frequency for five highest load groups of tandem axle types (390 to 310) kN and by keeping the frequency for single and tridem axles, the slab thickness is varied from 280 mm to 290 mm.
5. by variation of the frequency for five highest load group of tridem axles type (545 to 425) kN and by keeping the frequency for single and tandem axles load, the slab thickness is constant (280 mm).
6. With considering the variation for five highest load groups of single, tandem and tridem axles at same time, the slab thickness variation is 260 mm to 300 mm.
7. by randomly variation of the frequency for different load groups of three types of the axles (single, tandem and tridem) axle is 195 mm to 210 mm, it is mentioned on table 6.
8. The main factors governing design of concrete pavements are design period, design commercial traffic volume, composition of commercial traffic in terms of single, tandem, tridem and multi-axles, axle load spectrum, tyre pressure, lateral replacement characteristic, directional distribution, strength of foundation and climatic consideration.
9. Axle load spectrum affects the thickness of concrete pavement. More severe the axle load frequency in the higher categories of load spectrum like 150 kN and higher, more is the flexural stress and fatigue damage which requires more thickness of the pavements. However, more frequency of axles loads in the lower categories of axle load spectrum of value less than 150 kN does not lead to a higher thickness of the pavement.

REFERENCES

[1] Surender Singh[1], Dr.S.N.Sachdeva[2], "Thickness Requirement of a Rigid Pavement with varying Conditions of Subgrade, Sub-Base and Shoulders", *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), (2015),PP 52-57*
[2] S.K. KHANA[1], C.E.G JUSTO[2], A.VEERARAGAVAN[3], "Highway Engineering", 10th Edition.
[3] Ezatullah Rahimi[1], S.N. Sachdeva[2], "Effect of Axle Load Spectrum on Design of Rigid Pavement", Advanced Structures, Materials and Methodology in Civil Engineering (ASMMCE 2018), Proceedings of the National Conference, Jalandhar, Punjab, India, November 3-4, 2018
[4] AASHO (American Association of State Officials) road test (1962).
[5] A. C. Bordelon1; J. E. Hiller2; J. R. Roesler3; and V. G Cervantes4 (2015) "Investigation of ESALs versus Load Spectra for Rigid Pavement Design" Airfield and Highway Pavements 2015 © ASCE 2015.
[6] B.S Morton1, E. Luttig1, E. Horak2 and A.T. Visser2 (2004), "The Effect of Axle Load Spectra and Tyre Inflation Pressures on Standard Pavement Design Methods", Proceedings of the 8th Conference on Asphalt Pavements for Southern Africa (CAPSA'04)
[7] Chen-Ming kue and Shen-Hsian Lin (2001) "An analytical study of axle load equivalency factors of concrete pavements" Journal of the Chinese Institute of Engineers.
[8] Danny x. Xiao, Zhong Wu (2016) "Using systematic indices to relate traffic load spectra to pavement performance" International Journal of Pavement Research and Technology 9 (2016) 302–312.

[9] Indian Roads Congress (IRC: 58-2015) "Guidelines for the Design of Plain Jointed Rigid Pavements for Highways" (Fourth Revision).
[10] Jorge A. Prozzi & Feng Hong (2009) "Optimum statistical characterization of axle load spectra based on load associated pavement damage" International Journal of Pavement Engineering.
[11] Sara I.R. Amorim, Jorge C. Pais, Aline C. Vale & Manuel J.C. Minhoto (2015) "A model for equivalent axle load factors" International Journal of Pavement Engineering.
[12] Surya Teja Swarna, Braj Bhushan Pandey (2017) "Analysis and design of concrete pavements: A new approach" Invitation International seminar on Repair, Rehabilitation and Retrofitting of Bridge & Structures.
[13] Yanqing Zhao, Yiqiu Tan & Changhong Zhou (2012) "Determination of axle load spectra based on percentage of overloaded trucks for mechanistic empirical pavement design" Road Materials and Pavement Design.