

## TO STUDY THE ECONOMY OF FLEXIBLE AND RIGID PAVEMENTS WITH VARIATION IN SUBGRADE STRENGTH AND TRAFFIC

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### ABSTRACT

Transportation contributes to the economic, industrial, social and cultural development of any country. Transportation is vital for the economic development of any region since every commodity produced whether it is food, clothing, industrial products or medicine needs transport at all stages from production to distribution. It provides movement of passengers and goods from one place to another place. Main modes of transportation in our country are Roadways, Railways, Waterways, and Airways. Out of these, roadways allow movement of about 85% of passengers and 70% of goods because it is nearest to the people and also provides flexibility for movement of vehicles.

Pavements are generally classified into two categories based on the structural behaviour :

Flexible Pavement and Rigid Pavement.

Keyword: Flexible pavement, Rigid pavement, deformation, Bituminous concrete, reinforced concrete pavement.

### 1. INTRODUCTION

Flexible Pavement: Flexible pavement are those, which on the whole have low or negligible flexural strength and are rather flexible in their structural actions under the loads. The flexible pavement layers reflect the deformation of the lower layers on-to the surface of the layer. Thus if the lower layer of the pavement or soil subgrade is undulated, the flexible pavement surface also gets undulated. Bituminous concrete is one of the best flexible pavement layer materials. A typical section of flexible pavement consists of four components:

Surfacing (Wearing Course + Binder Course)

→ Base Course

Sub-base Course

→ Soil Subgrade

The flexible pavement layers transmit the vertical or compressive stresses to the lower layers by grain to grain transfer through the points of contact in the granular structure. The vertical compressive stress is maximum on the pavement surface directly under the wheel load and is equal to the contact pressure under the wheel. Due to the ability to distribute the stresses to a larger area in the shape of truncated cone, the stresses get decreased at the lower layers. Therefore by taking the advantage of the stress distribution characteristics of the flexible pavement, the layer system concept was developed. According to this, the flexible pavement may be constructed in a number of layers and the top layer has to be the strongest as the highest compressive stress are to be sustained by this layer, in addition to the wear and tear due to the traffic. The lower layers have to take up only lesser magnitudes of stresses and there is no direct wearing action due to the traffic loads, therefore inferior materials with lower cost can be used in the lower layers. The service life of a flexible pavement is typically designed in the range of 15 to 20 years components. Rigid Pavement: Rigid pavements, as the name implies, are associated with rigidity preventing them to bend under loads like their flexible counterparts. The rigid pavements are made of Portland Cement Concrete (PCC)- plain, reinforced or pre-stressed concrete. The plain cement concrete slabs are expected to take up about 45 kg/cm<sup>2</sup> flexural stress. In case of rigid pavements, stresses are not transferred from grain to grain to the lower layers as in the case of flexible pavements. The rigid pavement has the slab action and is capable of transmitting the wheel load stresses through a wider area below. H.M Westergaard is considered the pioneer in providing the rational treatment of the rigid pavement analysis and his theory is used as the base for design of rigid pavements by IRC. The typical designed service life of a rigid pavement is between 30 and 40 years, lasting about twice as long as a flexible pavement. One major design consideration of rigid pavements is reducing fatigue failure due to the repeated stresses of traffic. Fatigue failure is common among major roads because a typical highway will experience millions of wheel passes throughout its service life. The Components of rigid pavement or cement concrete pavement structure (From to bottom) consists of:

Pavement Quality concrete (PQC)

Sub-base course (DLC)

Granular Sub-base (GSB)

Compacted Soil Sub-grade

A thin separation membrane is placed on the top of the base course before laying the PQC slab. The CC pavement is provided with the traverse and longitudinal joints. Three main types of concrete pavements commonly used are jointed plain concrete pavement (JPCP), jointed reinforced concrete pavement (JRCP) and continuously reinforced concrete pavements (CRCP).

## 2. LITERATURE REVIEW

Khan (1998) describes the Group Index Method and California Bearing Ratio Method for design of flexible pavements. In Group Index Method the thickness is obtained by first determining the Group Index value of the soil. The curves are plotted between Group Index of subgrade and thickness of the pavement for various traffic conditions. In California Bearing Ratio Method, the curves are plotted between California Bearing Ratio percent and depth of construction. Hadi and Arfiadi (2001) state that the design of rigid pavements involves assuming a pavement structure then using a number of tables and figures to calculate the two governing design criteria, the flexural fatigue of the concrete base and the erosion of the sub-grade/sub- base. Each of these two criteria needs to be less than 100%. The designer needs to ensure that both criteria are near 100% so that safe and economical designs are achieved. This paper presents a formulation for the problem of optimum rigid road pavement design by defining the objective function, which is the total cost of pavement materials, and all the constraints that influence the design. A genetic algorithm is used to find the optimum design. The results obtained from the genetic algorithm are compared with results obtained from a Newton-Raphson based optimization solver. Arora (2003) has reported that the Westergaard's analysis is used for design of rigid pavements. The stresses in the concrete slab are determined using Westergaard's theory. Westergaard considered the rigid pavement as a thin elastic plate resting on soil subgrade. The upward reaction at any point is assumed to be proportional to the deflection at that point. The slab deflection depends upon the stiffness of the subgrade and the flexural strength of the slab. Thus the pressure-deformation characteristics of a rigid pavement depend upon the relative stiffness of the slab and the subgrade. Darestani [et.al](#) (2006) state that the 2004 edition of Austroads rigid pavement design guide has been based on the work of Packard and Tayabji which is known as the PCA method. In this method, a number of input parameters are needed to calculate the required concrete base thickness based on the cumulative damage process due to fatigue of concrete and erosion of sub base or subgrade materials. This paper reviews the 2004 design guide, introduces design software specially developed to study the guide and highlights some important points. Results of the current study show the complex interdependence of the many parameters.

Objective:

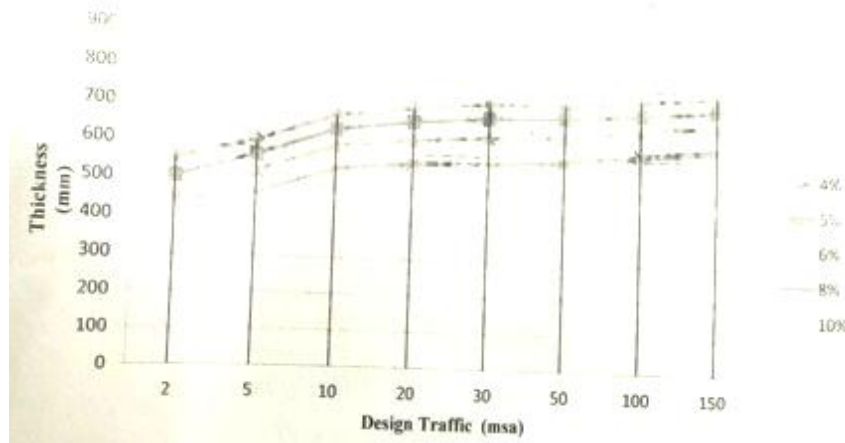
1. To evolve the design of a Flexible and Rigid Pavement for varying values of subgrade strength and design traffic.
2. To determine the effect of variation in subgrade strength on thickness of the pavement.
3. To determine the effect of variation in design traffic on thickness of the pavement.
4. To do the cost estimation of the designed sections of the Flexible and Rigid Pavements.

## 3. EXPERIMENTAL INVESTIGATION

Variation in pavement thickness with subgrade strength and design traffic The traffic design for 7.5m carriageway road has been done for given values of traffic such as 2msa, 5msa, 10msa, 20msa, 30msa, 50msa, 100msa and 150msa with given subgrade CBR values such as 4%, 5%, 6%, 8% and 10% as per guidelines of IRC 37:2012 and IRC 58:2015 respectively. Details of axle spectrum of rear single, tandem and tridem axle are taken from IRC 58:2015. The design thickness obtained in the study are given in table 1 and table 2 respectively. Variation in Flexible Pavement thickness with CBR and Design Traffic Table: Thickness of flexible pavement in mm for Different combinations of Soil and Traffic

Soil CBR(%)	Design Traffic (msa)							
	2	5	10	20	30	50	100	150
4	560	620	700	730	750	750	770	785
5	510	580	660	690	710	715	730	745
6	470	535	655	640	655	660	685	700
8	445	475	550	575	590	590	615	635
10	445	475	550	570	585	585	610	625

Graphical representation of variation in thickness for Flexible Pavement with Different Combinations of Subgrade Strength and design traffic has been shown below



**Fig 1.** Thickness Variation of Flexible Pavement with Soil CBR and Design Traffic

As seen in fig.1, it is observed that total thickness of flexible pavement decreases upto 8% CBR of subgrade soil then there is no significant variation in the thickness of flexible pavement from 8% to 10% CBR for all values of design traffic such as 2msa, 5msa, 10msa, 20msa, 30msa, 50msa, 100msa and 150msa.

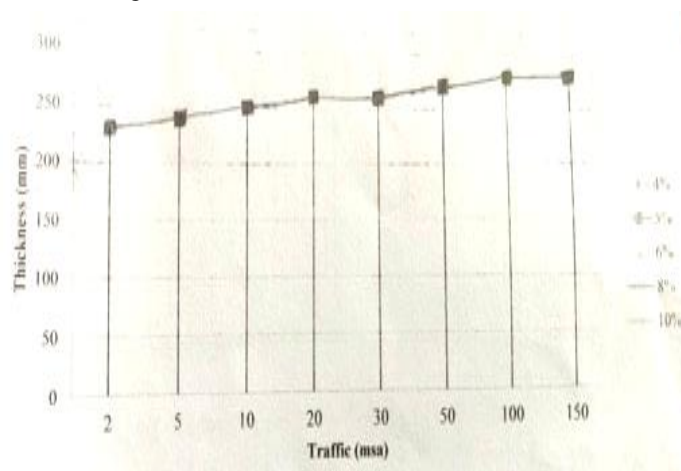
**Variation of rigid pavement thickness with CBR and equivalent traffic value**

**Table 2.** Thickness variation of rigid pavement in mm for different combinations of soil and traffic

Soil CBR (%)	*Equivalent Traffic (msa) at the end of design life							
	2	5	10	20	30	50	100	150
4	230	240	250	260	260	270	280	280
5	230	240	250	260	260	270	280	280
6	230	240	250	260	260	270	280	280
8	230	240	250	260	260	270	280	280
10	230	240	250	260	260	270	280	280

Equivalent traffic is traffic in msa of CVs in both directions at the end of design life with same initial number of CVs as that for flexible pavement design. This traffic is further multiplied with LDF of 0.25 to get total design traffic which is further split into 6-hr day time and 6-hr night time design msa for fatigue analysis of BUC and TDC respectively.

Graphical representation of variation in thickness for rigid pavement with different combinations of subgrade strength and design traffic has been shown in Fig. 2.



**Fig.2** Thickness variation of rigid pavements with soil CBR and Equivalent Traffic Value

As seen from Fig. 2 it is observed that there is no sufficient variation in the thickness of rigid pavement for improvement in subgrade strength from 4% to 10% CBR.

**VARIATION IN COST OF PAVEMENTS WITH SOIL CBR AND TRAFFIC**

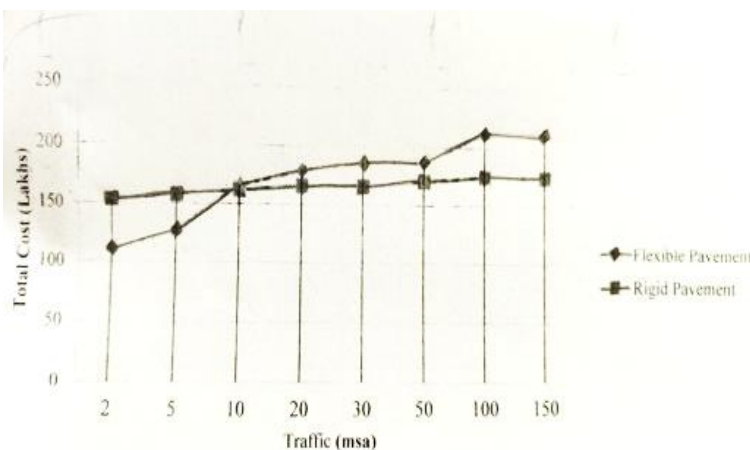
Variation in cost of flexible and rigid pavements for Soil CBR 4% with design traffic

**Table 3** Variation in total cost for 1km length of pavement for subgrade CBR 4%

Design Traffic (msa)	Cost of pavements per Km in Lakhs					
	Flexible Pavement			Rigid Pavement		
	Construction cost	Maintenance cost	Total cost	Construction cost	Maintenance cost	Total cost
2	83	28	111	150(81)	3	153(38)
5	94	33	127	155(65)		158(24)
10	116	50	165	159(34)		162(-2)
20	129	50	178	163(23)		166(-7)
30	137	50	187	163(19)		166(-11)
50	137	50	187	168(19)		171(-9)
100	147	60	213	172(14)		175(-18)
150	153	60	213	172(10)		175(-18)

( ) indicates percentage increase in construction cost of rigid pavement over flexible pavement construction cost.

Graphical representation of variation in cost of flexible and rigid pavements for subgrade CBR 4% with various design traffic values has been shown in Fig 3.



**Fig.3** Cost variation for Soil CBR 4%

It is observed from table 3 that the cost of construction of rigid pavements is more by 10 to 81% for various values of design traffic from 150 msa to 2 msa. However, as seen from fig 3, the total cost of rigid pavement is more than the total cost of flexible pavement upto 5msa traffic and then for remaining values of design traffic upto 150msa, the cost of flexible pavement becomes higher than the cost of rigid pavement by 2% to 18%.

#### 4. CONCLUSION

The dissertation entitled "Economy of Flexible and Rigid Pavements with variation in Subgrade strength and Traffic" has been taken up with the view to study the effect of CBR and design traffic on the cost of flexible and rigid pavements. The pavements have been designed for a two lane carriageway of width 7.5m assumed to be located in Kurukshetra, Haryana. The CBR of existing ground has been varied from 4% to 10% and design traffic on the road has been varied from 2msa to 150msa to determine its effects on the thickness of the pavement and ultimately on the cost of the pavement.

##### The main conclusions drawn from the study are:

Maintenance Cost for Flexible Pavements for entire design life is very high and may be 9 to 20 times costlier with design traffic varying from 2 msa to 150 msa as compared to the Rigid Pavements. Maintenance Cost for Flexible Pavements increases with increase in the design traffic but for Rigid Pavements there is little change in the Maintenance Cost. As far as total cost including maintenance is concerned, for low design traffic the flexible pavements are more economical than the rigid pavements for any value of CBR. However, as design traffic becomes more, the Rigid Pavements are more economical than the Flexible Pavements due to their low maintenance cost.

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