DESIGN OF FLEXIBLE PAVEMENT USING PROVISIONS OF IRC: 37-2018 FOR A STRETCH BETWEEN SOLAN-PARWANOO ON NH 5

A

PROJECT REPORT

Submitted in partial fulfilment of the requirements for the Degree of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision of

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HIMACHAL PRADESH, INDIA

MAY-2020

STUDENT'S DECLARATION

I hereby declare that the work presented in the Project report entitled **"DESIGN OF FLEXIBLE PAVEMENT USING PROVISIONS OF IRC: 37-2018 FOR A STRETCH BEETWEEN SOLAN-PARWANOO NH 5"** submitted for partial fulfilment of the requirements for the degree of Bachelor of Technology in Civil Engineering at **Jaypee University of Information Technology, Waknaghat** is an authentic record of my work carried out under the supervision of **Dr. AAKASH GUPTA.** This work has not been submitted elsewhere for the reward of any other degree/diploma. I am fully responsible for the contents of my project report.

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CERTIFICATE

This is to certify that the work which is being presented in the project report titled "**DESIGN OF FLEXIBLE PAVEMENT USING PROVISIONS OF IRC: 37-2018 FOR A STRETCH BEETWEEN SOLAN-PARWANOO NATIONAL HIGHWAY 5"** in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology and in Civil Engineering submitted to the Department of civil engineering, **Jaypee University of Information Technology, Waknaghat** is an authentic record of work carried out by **Ritesh Kumar Chaurasia (161691)** & **Keshav Singh Thakur (161677)** during a period from Aug 2019 to May 2020 under the supervision and guidance of **Dr. AAKASH GUPTA,** Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

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ABSTRACT

The National Highways serves as a backbone of the road transport and connects all crucial roads in our country. Country's freight and passenger traffic are mostly dependent on road transportation. National highways (NH) are the most crucial category of roads and currently aggregating to a length of 1,42,126 km. It operates approximately 40 % of the total traffic load throughout the country. Flexible pavements possess poor or insignificant flexural strength and bends in their structural action under the influence of load. The lifespan of such type of pavements is generally designed for the range between 15 to 20 years. Required thicknesses of respective layers of a bituminous pavement differ vastly with respect to the extent and count of repetitions of traffic loads, materials to be used, diverse environmental and regional conditions and the desired lifespan of the pavement. For using non-conventional types of materials even in the sub-base and base, the latest design method guidelines published in IRC: 37-2018 may be used. It is based on mechanistic-empirical approach of design for analysis of flexible pavements. We are using same IRC guidelines for the design and check of the pavement. The stretch between Solan to Parwanoo (near Kumarhatti) on NH 5 is considered for the analysis and all the important data required are gathered through NHAI office, Shimla. Taking traffic data, the cumulative design traffic in standard axles is computed for the planned life-span. Using IRC method for design of flexible pavement and considering the cumulative standard axles and effective CBR value for effective design, the pavement is being designed for a time period of 15 years.

Keywords: Flexural strength; Flexible pavement; Design traffic; Cumulative standard axles; Pavement thickness; Effective CBR; mechanistic-empirical; VDF

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LIST OF ABBREVIATIONS

AASHO -	American Association of State Highway Officials
AASHTO -	American Association of State Highway and Transportation Officials
ASTM -	American Society of Testing and Materials
BM -	Bituminous Macadam
BC-	Binder Course
CBR -	California Bearing Ratio
csa -	Cumulative standard axles
DBM-	Dense Bituminous Macadam
GB -	Granular Base
GSB -	Granular Sub-base
IRC -	Indian Roads Congress
MoRTH -	Ministry of Road Transport & Highways
MPa -	Mega Pascal
NHAI -	National Highway Authority of India
OMC-	Optimum Moisture Content
VDF -	Vehicle Damage Factor
WBM -	Water Bound Macadam
WMM -	Wet Mix Macadam

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Flexible pavements are called flexible because of the total structure deflects, or flexes, under load. Each layer takes the burden from upper layer, spreads them throughout, and then passes these coming loads to the next supporting layer underneath. The main purpose of designing a Flexible pavement is to come up with a structure which is efficient in resisting the traffic loads which would be transferred to it during the designed life-span of the pavement. Their design procedure demands determining the thicknesses of respective layers based on the strength properties of the pavement materials. At present, National highways (NH) having a total length of about 1,42,126 km, and are the most essential category of roads. National Highway 5 runs from West to East and connects Punjab to the India-china border at Shipki La. The highway passes through Ludhiana, Chandigarh, Panchkula, Kalka, Solan, Shimla, Theog, Narkanda and continues with the Sutlej river till its final destination near the Tibet border.

Figure 1.1 Map Outline NH

1.2. Background of the Project

Faster movement and transportation of various goods in a Country like India, is a guiding force for economic development. Faster transportation of consumer goods requires complete and comfortable transportation systems and thus increased road traffic requires improved riding quality of roads with more comfort and uninterrupted movement. Hence, it becomes essential to develop new roads and repair all other connecting roads. In recent economic environment of India, development of Road transport is aimed to improve the international competitiveness of exports and attract foreign direct investments. Observing the benefits more and more help is being given now to road projects by national and other funding agencies and stakeholders. In the view of discussed facts, National Highways Authority of India (NHAI) has decided to construct and extend the 4 lane highway, including the section of NH-22 from Solan to Shimla. This section covers the districts of Solan and Shimla of Himachal Pradesh. The length of proposed project is 50.507 km. The proposed road stretch is a part of Tourist Avenue and connects the cities of Kalka, Shimla, Parwanoo, Ambala, Chandigarh, etc. Shimla is the capital city and Tourist hotspot of Himachal Pradesh. Solan is an important town of Himachal Pradesh as it surrounds by many industries, and bulk trading markets of apples. This road carries a heavy traffic (both way) from Shimla and other parts of the State. Thus, there is an immediate necessity for widening the existing road and enhancing the economic capability of the state.

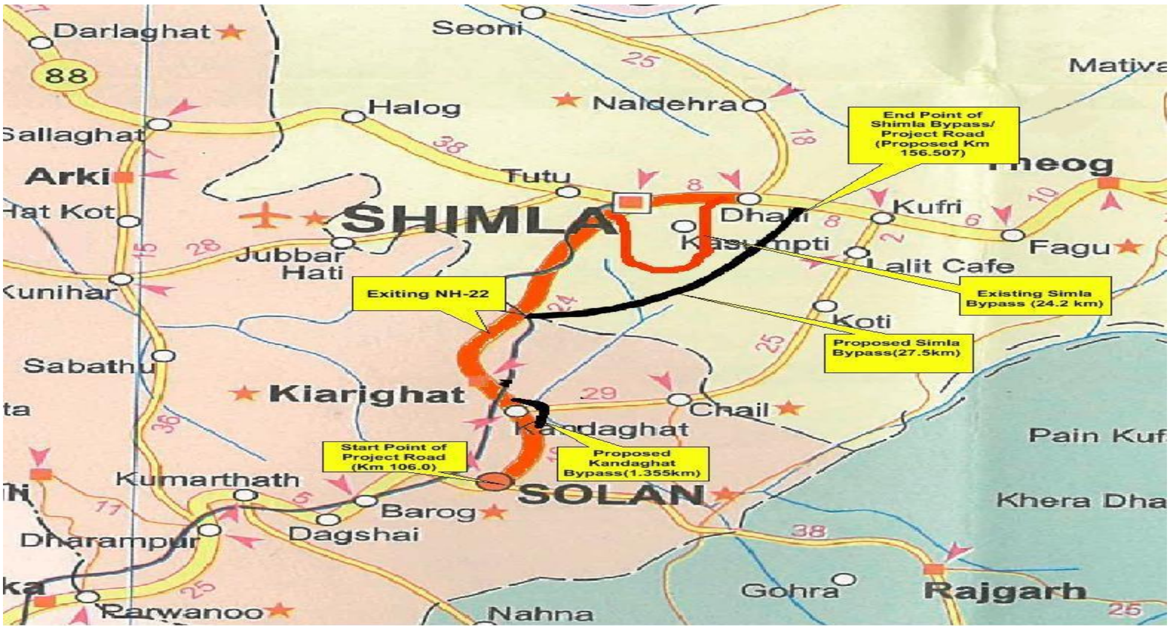


Figure 1.2 Location Map of Project Road

1.3 Site Introduction

We have chosen a stretch of 1 KM between Solan-Parwanoo on national highway 5. This site is actually present near kumarhatti(H.P). Currently NHAI (National Highway Authority Of India) in association with Airef Engineers Pvt. Ltd. is involved in 4 laning of existing road on NH 5. The project was started in 2016 and is expected to complete in ending of 2020. Since the site lies on hilly terrain, a proper management plan of sustainable development is required to carry out the construction. The pavement is selected as a flexible pavement with a design life of 15-20 years.

Figure 1.3 Stretch site Photo

1.4 Detail Work plan/Methodology

- To evaluate and analyze soil characteristics and traffic patterns
- To analyze all the traffic data to find estimates of annually, monthly and daily variation in traffic load.
- To find optimum moisture content and relatively C.B.R value of sub-grade soil.
- With the help of empirical formula, resilient modulus of different pavement components needs to be evaluated using suggested provisions published under IRC: 37-2018.
- Calculation need to be done to know reliability equations value for checking our structural parameters.
- To calculate design traffic that will be used in analyzing the pavement and calculation of resilient modulus.
- To select trial pavement using CBR data and Traffic design.
- To install and use IIT-Pave software for analyzing our pavement structure
- To check all the values evaluated with empirically values found through mechanistic-empirical models.
- To study and analyze all outputs for providing a guidelines for design procedure and structural requirements of a pavement.
- To achieve these goals, we need to conduct traffic surveys and its study, proctor test of the 500 mm sample of top and bottom soil, CBR test of the soil sample is much required to know the soil profile and to adopt different pavement thickness for different layers using the provisions of IRC:37 2018 and using IIT PAVE software. We need to adopt such design procedures which results in economical and sustainable developments of new roads in hilly terrains. We should also study local topographic and climatic conditions to enhance design procedures and further increase serviceability of newly constructed roads.

CHAPTER 2
LITERATURE REVIEW

2.1 General Introduction

The traffic conditions and sub-grade soil characteristics are important in order to design a Flexible pavement. The thickness of the pavement varies with the change in the value of C.B.R. (With higher value of C.B.R. the pavement thickness is less and vice Versa). Here we will study and observe different esteemed journals and literature reports related to our project. This will help us to find and eliminate different errors which could arise in commencing our project. Moreover, this study will give a broader idea of practical situations where precautions need to be taken. Resemblance of some of these literature works will help me to complete my research on design of flexible pavement. We can learn many things from their outcomes and conclusions.

2.2 Literature Review

- **Kumar Ravinder (2014) [1]** through his investigation on traffic study and structural design of Flexible Pavement using Cemented Base and Sub-base. He used updated design guidelines of IRC: 37-2012 which is a mechanistic-empirical design method and discuss the use of non conventional kinds of materials also in the base and sub-base. Through his study, he observed that design of Flexible Pavement using non-conventional layer needs less amount of bitumen and thus reduces pavement thicknesse. The IRC design method can be adopted to know the required pavement thickness due to its easy and practical application. The traffic movement and sub-grade soil characteristics need to be studied and required to design a pavement.

- **Pranshul Sahu, Ritesh Kamble (2017) [2]** observed that the pavement thickness differ with the change in C.B.R value. (With higher C.B.R. value, the pavement thickness is less and vice versa). Decrease in the pavement thickness will lower the quantity of bitumen required thus making design more economical.

- **P. Sikdar, S. Jain, S.Bose, P. Kumar (1999) [3]** observed that if the potholes are numerous or frequent, it may stipulate primary problem such as inadequate pavement or deteriorating surfacing requiring restoration or rehabilitation. Water going into the pavement is the main cause, and could be caused by a split surface. High shoulders or pavement slump results in ponding water over pavement surface.

- **Sireesh Saride, Pranav R. T. Peddinti, Munwar B. Basha (2019) [4]** through their reliability-based design optimization (RBDO) model, they evaluated four-layered flexible pavement system and primary interest of their research was the ideal design of flexible pavements with respect to fatigue and rutting performance while considering the inconsistency related with design variables. Through their research they observed that the flexible pavements design can be enhanced by examine the variability related with the geometric and material properties of pavement layers. The variability related with geometric and material characteristics of the flexible pavement layers give rise to inconsistency in the fatigue and rutting strains and finally affects the pavement design thickness of the system.
- **Samuel B. Cooper III, Mostafa Elseifi, Louay N. Mohammad, Marwa Hassan (2012) [5]** through their Mechanistic-Empirical Pavement Design approach, they evaluated effects of selected sustainable technologies on the performance anticipated by the Mechanistic-Empirical Pavement Design Guide (MEPDG) programming to evaluate the life-cycle expenses of pavement constructed with these sustainable options and they presumed that the forecasts of the MEPDG for rutting and cracking performances were quite dissimilar from those evaluated from physical laboratory tests. Such deviations are expected to be caused by the rutting and cracking performance models in the MEPDG that use E* as the prime factor in describing the mix mechanistic properties.
- **Bhrugu Kotak, Parth Zala, Abhijit singh Parmar, Dhaval M Patel, Mittal Patel [2015] [6]** through their case study on a road stretch between two points in a rural area which aims at providing cost effective, safe and economical approach leading to less repair and maintenance cost. To achieve their objectives, they used IRC approach of design using traffic data and soil characteristics to provide a economical and long lasting pavement surface design.
- **K. V R D N Sai Bruhaspathi, DR. B. N D Narasinga Rao**, **(2012) [7]** through their case study on reducing pavement thickness using IRC 37: 2001 and considering Mechanistic-Empirical principles with non conventional materials in designing pavement. They concluded that with such pavement design analysis, it will be easy for

the construction of the pavement using non conventional pavement design methods as discussed by them. Moreover, this will be result in improved performance of the pavement thus adding the life and leading to effective cost savings.

- **Hofstra and Klomp (1972**) **[8]** found that the deformation in flexible pavements was significant in loading imposition surface and gradually decreased depending on the depth. This is because the wheel tracking gives a permanent deformation and thus increasing the depth increases the resistance and resulting in reduced shear stresses. Asphalt having low shear strength, required for resistance to repetitive loads of traffic, have severe display wheel tracking problem. The problem is more extreme especially during the summer, as high temperatures are observed on the pavement surface.
- **Sousa et al. (1991) [9]** in their research stated that wheel tracking gradually increases under the influence of continuous loadings and typically represented in the form of deformations across the wheel tracks, accompanied by small rearrangements at the both ends. Mainly two causes that contribute to wheel tracking is compression and shear deformation and this appearance may occur at many times during the life of a pavement.
- **Woods and Adcox (2004) [10]** said failure of pavement may be viewed as structural, functional, or materials failure, or a mixture of all these. Structural failure is the loss of load bearing capacity, leading to failure of pavement surface to retain and transfer the wheel loading throughout the structure of the pavement without causing further more deterioration. Functional failure is a comprehensive term, which means the reduction in efficiency of certain functions of the road such as skid resistance, structural capacity, and serviceability or traveller comfort. Failure of materials generally results due to the breaking or reduction in material properties of any of the respective component materials.
- **A. Ahmed (2008) [11]** concluded the cracking up of the pavement surface results into various problems such as discomfort to the passengers, loss of user safety, etc. In addition to these, Entering of water into pavement causes decrease in the overall strength in bottom layers and also lowers the ultimate bearing capacity of sub grade soil by exposing of earth surface via cracks is also a considerable problem related to the pavement surface.
- **Indian Road Congress (2018) [12]** recommends usage of better performing bituminous mixtures and binders for surface and base courses. Further, it suggests

minimum required thickness of granular and cement treated sub-bases, bases and bituminous layers from structural and economical requirements. IRC suggested Simplification in the process for the calculation of the effective resilient modulus and C.B.R. of sub grade and provides mechanistic-empirical approach.

2.3 Summary of Literature Review

- All the above design procedures have been done according to IRC: 37-2012 or previous IRC guidelines.
- Some of the salient features of IRC: 37-2018 are-
  1. Mechanistic empirical design approach
  2. Reduction in extra moisture from interior of the pavement thus providing drainage support.
  3. Sub-grade rutting is an important performance criteria and vertical compressive strain is considered to be an important parameter for checking sub-grade rutting.
- Going through one of paper, we found that in the design of Flexible Pavement surface, non-conventional layers require less thickness of pavement and relatively smaller amount of bitumen which can save material specially aggregates and is considered good from environmental view.
- Estimation of traffic and sub-grade soil characteristics is important for designing a pavement using provisions of IRC: 37-2018. The IRC: 37-2018 guidelines for design may be referred to evaluate the different pavement thicknesses due to its easy and relative design procedures.
- Previous pavement designs were complex to provide economical approach for designing pavements. A latest provision of IRC provides with suitable solution for economically and time saving design methods.
- Pavement thickness plays important role in sustainable design of pavements.
- In latest design guide, empirical approach to performance criteria such as rutting sub-grade criteria and fatigue cracking criteria is introduced with up to 90% reliability. This mechanistic-empirical approach provides a clear picture of accuracy in predicting rutting and fatigue characteristics of sub-grade performance.

- With advancement in technologies, the primary focus is to develop a pavement design which will be useful from user point of view. Comfort and safety of the passenger is one of the main factors to be considered before designing pavements.
- Repairing and rehabilitations is not quite easy on busy roads (state highways, national highways and other important roads), thus a pavement design should sustain heavy traffic load for the designed life span. Thus achievement of such accuracy is quite difficult and repairing is often taken into account due to diverse climatic conditions.

CHAPTER 3
PAVEMENT PERFORMANCE CRITERIA

3.1 General Introduction

The study of pavement design emphasizes on designing such pavements that can serve all functional and structural requirements of the pavement throughout its planned service period. Some of the functional and structural performance indicators of pavements are roughness due to variation in surface profile, fissure in layers bounded by bitumen mixes or cement material, rutting of unaltered or partly altered sub grade, granular layers and bituminous surfaces. Efficiency of the pavement is evaluated by mainly two performance criteria (a) empirical (taken from past experiences) or (b) mechanistic-empirical, where the performance efficiency is measured in terms of functional parameters such as stresses, strains and deflections evaluated through specified theory models and using the stated guidelines of IRC. Approximately, all the recent design methods consider the empirical-mechanistic relationship for the effective design of flexible pavements. This method is very reliable as for every specific structural risks, individual mechanistic parameters is defined and stated to an allowable (minimum) value in the design procedure. The check values of any of these important mechanistic functions are evaluated from the performance criteria empirical models.

Mechanistic-Empirical design performance criteria models are very reliable and even used in the previous versions of IRC: 37. Seeing its accuracy and easy approach, model is again retained in this revision for the design of flexible pavement surface. 'Linear elastic layered theory' is adopted here for the evaluation and design of pavement components. In this theory, pavement is considered as a multi-layer system. Sub-grade is the lowest of all the layers and assumed to be semi-infinite. And other upper layers are considered infinite in the horizontal stretch and finite in depth.

For calculation of functional parameters (due to load applied at the top of the pavement) such as stresses, strains and deflection at a specified point, inputs are required in terms of resilient modulus, Poisson's ratio and thicknesses of respective layers. We will be using IIT-PAVE software to analyse our flexible pavement design. IIT-PAVE software is an updated version of FPAVE which was previously used for the analysis.

3.2 Performance Criteria

The following performance criteria are recommended by IRC: 37-2018 guidelines for flexible pavement design.

3.2.1 Sub-grade Rutting Performance Criteria

Critical rutting condition is considered when mean rut depth of 20 mm or more is determined across the wheel paths. To find sub-grade rutting life, empirical equations are discussed and given in IRC guidelines. These equations gives the equivalent number of cumulative standard axle load (80kN) repetitions that may be withstand by the pavement, until the average rut depth of 20 mm or more persists for 80 and 90 percent reliability conditions

$$N_R = 4.1656 \text{ x } 10^{-08} [1/\varepsilon_v]^{4.5337} \text{ (for 80 percent)} \quad (3.1)$$

$$N_R = 1.41 \text{ x } 10^{-08} [1/\varepsilon_v]^{4.5337} \text{ (for 90 percent)} \quad (3.2)$$

where, N_R = sub-grade rutting life

ε_v = vertical compressive strain at the top of the sub grade

IITPAVE software is primarily used to calculate vertical compressive strain value at the top of the pavement. We input values such as different layer thicknesses, Poisson's ratio and resilient modulus and calculate stresses, strains and deflections at selected points. Using above empirical relations, we can compute sub-grade rutting life as per IRC: 37-2018 guidelines. All other values needed in calculation are also present in guidelines.

3.2.2 **Fatigue Cracking Criteria for Bituminous Cracking**

The development of fatigue cracking, comprises of complete area in the segment of the pavement under consideration is 20 % or more than the paved surface area of the segment, is considered to be in critical or failure condition. The equivalent numbers of standard axle (80 kN) load repetitions that can be withstand by the road, before the extreme condition of the cracked surface area of 20 percent or more persists, is calculated by equations 3.3 and 3.4 respectively for 80 percent and 90 percent reliability levels.

$$N_f = 1.6064*C*10^{-04} [1/\varepsilon_t] 3.89* [1/M_{Rm}]^{0.854} \text{ (for 80 percent reliability)} \quad (3.3)$$

$$N_f = 0.5161*C*10^{-04} [1/\varepsilon_t]\ 3.89* [1/M_{Rm}]^{0.854} \quad \text{(for 90 percent reliability)} \qquad (3.4)$$

Where, C= adjustment Factor

N_f = fatigue life of bituminous layer

ε_t = max horizontal tensile strain at the bottom of the bituminous layer

M_{Rm} = resilient modulus (MPa) of the bituminous mix used in the bottom Bituminous layer

3.2.3 Reliability

As per IRC recommendation, 90 percent reliability equations to be used for sub-grade rutting and fatigue cracking of bituminous layer (discussed above) for all major category roads such as expressways, national highways, state highways and other important rural and urban roads. For other sections of road, 90 percent reliability equations to be used for design traffic of 20 msa or more and for less than 20 msa design traffic, 80% reliability equations will be used.

3.2.4 Analysing Flexible Pavements models

Assuming pavement as linear elastic layered system, different functions parameters such as stresses, strains and deflections are computed. For analysing linear elastic layered system, IIT-PAVE software can be used. This software is effective in designing and analyzing flexible pavements. As stated previously, for checking adequate performance of flexible pavements the vertical compressive strain and horizontal tensile strain are considered to be the essential mechanistic factors needed to be checked for sub-grade rutting and bottom-up cracking of bituminous layers. These strains and stress parameter are calculated using the software.

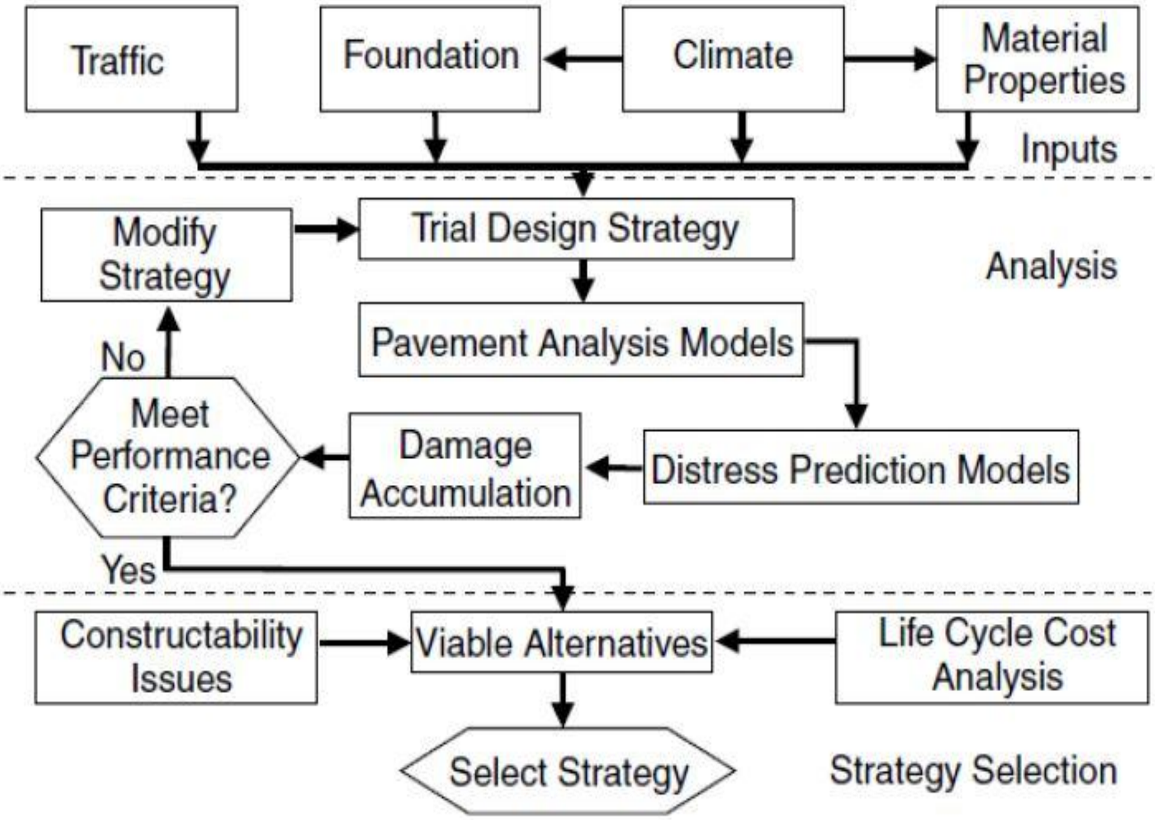


Figure 3.1 Pavement Design cycle/ Procedure

CHAPTER 4
PAVEMENT

4.1 General Introduction

Pavement is made up of some long-lasting surface material laid on a stretch to bear motor or pedestrian activity. Previously, cobblestones and stone mixes combinations were widely applied, but now these surfaces are being replaced by bitumen or cement concrete. Pavements are mainly divided into two categories

- Flexible pavement
- Rigid pavement

4.2 Flexible Pavement

Flexible pavements possess low flexural quality and remain flexible in its structural capability under the influence of effective burdens. Reflection of deformation of the below layers can be observed on the pavement surface.

A basic flexible pavement structure composed of mainly four layers:

Surface course Sub-base course

Soil sub-grade Base course

Fig 4.1 Laying of Flexible Pavement on Site

4.3 Rigid Pavement

Rigid pavements are named so because of its note-worthy flexural rigidity. The loads aren't transferred through surface to the below layers as compared to flexible pavement layers. The concrete pavement is efficient in transferring the traffic load stresses into a large area beneath with little depth and does not require more layers to help reduce the wheel load. Rigid pavements are mainly cement made concrete slabs with high flexural strength. Plain, Reinforced, prestressed any of these can be used to lay rigid pavements.

Fig 4.2 Rigid Pavement

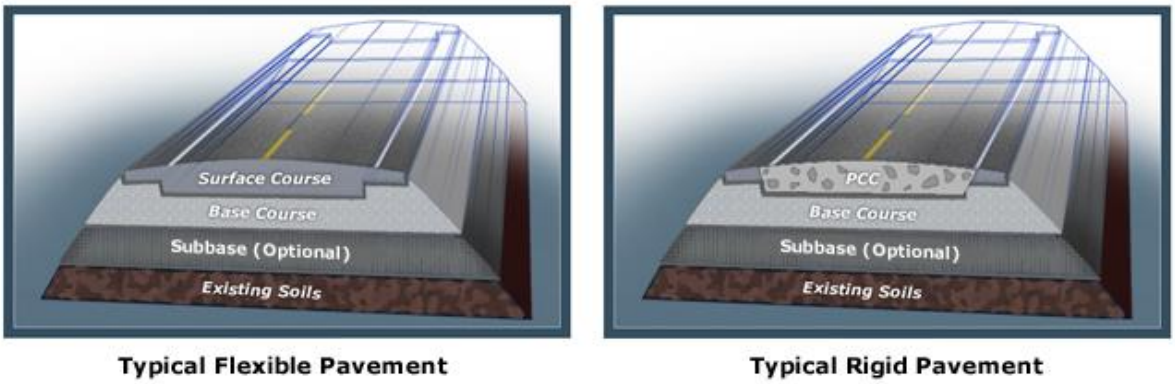


Fig 4.3 Pictorial Difference between Both Pavement Layers

CHAPTER 5

FLEXIBLE PAVEMENT COMPONENTS

5.1 Pavement Components and Its Functions

- SOIL SUBGRADE
- SUB-BASE
- BASE
- BITUMINOUS LAYERS

5.2 Soil Sub-grade

The soil sub grade is composed of a natural soil embankment to receive the different pavement materials layer placed on it. The load introduced on the pavement is likely to be transferred to the soil sub grade for its distribution to the soil mass. It is important to note that at no point, the soil sub-grade is overstressed. It suggests that the load experienced on the top of the subgrade is within the permissible range, restrain to cause too much stress condition or to deform sub-grade beyond the elastic limit. It is important to check the strength characteristics and other different properties of a soil sub-grade. It helps to consider the respective values of the strength variables for design method. In case, supporting layer fails to meet expectations then treatment and stabilization is required.

5.2.1 General

Stabilized soil made up of in-situ materials present immediately below the pavement making the foundation of the pavement known as sub-grade. The 500 mm in depth of prepared foundation from top is referred as sub grade. To attain overall strength and resist the rutting caused due to extra densification, soil compaction is required with minimum 97 percent of laboratory maximum dry density for all major category of roads such as expressways, national highways, major district Roads and other heavily traffic roadways.

Mainly, sub-grade is prepared from upper 500 mm of embankment soil but sometimes stronger materials are used to prepare sub grade. In that case, sub grade is set up in two distinct layers with extensive different strengths and properties and their effective mutual participation is considered for design. The effective share of both sub-grade and the prepared layers should be taken together for design plan.

In previous section, we have already discussed that the resilient modulus of respective distinct pavement layers are the primary required values for the evaluation and design purpose of pavements. We generally use California Bearing Ratio (CBR) value of the sample to derive resilient modulus because of its easy approach. Estimation of resilient modulus by laboratory method requires specific equipments and more time as compared to CBR method

5.2.2 Dry density and Optimum Moisture Content for Testing of Sub-grade

The laboratory testing conditions should be closely representing the actual conditions as much as attainable. Compaction on the ground is carried out when at least 97 % of the maximum dry density accomplished at optimum moisture content. The sub grade experiences variation in moisture relative to distinct field conditions, for example, water table depth variations, precipitation variations, soil permeability and seepage conditions are some such important factors.

For construction of new pavements and reconstruction works, we need to find California Bearing Ratio (CBR) of the sub-grade soil at the most ideal moisture condition probable to stay at field. For proper guidance and step-wise procedures, refer to IS: 2720 Part-16.

As per information guide, the test should be carried out on remolded specimens of sub-grade soils in the lab. The thickness of pavement evaluated should be derived from 4-day soaked CBR test value of the sub grade, remolded at placement density and optimum moisture content ensured from the plotted compaction curve.

90th percentile sub grade CBR is generally considered for designing and planning of excessive movement roadways such as expressways, national Highways, state Highways and major sub-urban roads and rural roads.

5.2.3 Resilient modulus of The Sub-grade

For the analysis of flexible pavement, resilient modulus is an important parameter and is computed by considering only the elastic part of deformation of the sample in a frequent load test. It is an important input value for linear elastic theory recommended by IRC. Laboratory method of calculating resilient modulus involves performing of the repeated tri-axial test according to the steps explained in AASHTO T307-99. Performing laboratory tests are quite costly due to expensive equipments; the following relations may also be used to find the resilient modulus of sub-grade (M_{RS}) using its CBR value.

$$M_{RS} = 10.0 * CBR \text{ for } CBR \leq 5\ \% \qquad (5.1)$$

$$M_{RS} = 17.6 * (CBR)^{0.64} \text{ for } CBR > 5\ \% \qquad (5.2)$$

Where,

M_{RS} = Resilient modulus (MPa).

CBR = California bearing ratio of sub-grade (percentage)

Poisson's ratio value for sub-grade may be taken as 0.35.

5.2.4 Effective CBR for Design

Situation arises when there is considerable dissimilarity between CBR values of soils present in the both the sub-grade and in the embankment layer 500 mm beneath the sub-grade. Otherwise, the 500 mm thick sub-grade may be deposited in 2 layers, each layer materials with different C.B.R. values. In such situations, the plan should be to use the composite C.B.R. value of a equivalent layer sub-grade which is corresponding to the composition of the both sub-grade layer and prepared layer. Using the following method, the overall resilient modulus value may be calculated

- We may use IIT-PAVE software to calculate the maximum deflection resulting due to single wheel load of 40,000 N and use contact pressure of 0.56 MPa for a three-layered elastic system incorporating of a composite (two sub-layers) of the 500 mm dense sub-grade layer on the semi-infinite earth layer. Using equations 5.1 and 5.2, the resilient modulus of sub-grade and embankment layers may be calculated with the help of their respective CBR values. Poisson's ratio for all the three layers may be taken as 0.35
- Now with the surface deflection value computed in above step, the resilient modulus (M_{RS}) of the composite single layer may be estimated by equation 5.3.

$$M_{RS} = 2(1-\mu 2)/\ \delta \qquad (5.3)$$

Where,

p = contact pressure of tyre (taken as 0.56 MPa)

a = radius of circular contact area

μ = Poisson's ratio

$\delta =$ surface maximum deflection

Note: the maximum resilient modulus value should be restricted to 100 MPa

5.3 Sub-base

The sub-base layer provides three main functions:

- To serve as a solid base for the compacting granular base layer
- To assist as drainage-cum-filter layers.
- To preserve the sub grade from over-stressing

5.3.1 General

The sub-base layer may be composed of granular materials which may be unbound or settled due to added substances, for example, crushed concrete, lime, fly ash and different cement stabilizers. The thickness of the sub-base, regardless of either bound or unbound, should fulfil these particular useful prerequisites.

5.3.2 Granular (unbound) Sub-base Layer

Regular sand, moorum, rock gravel, laterite, kankar, crushed brick, squashed stone, squashed slag, reclaimed crushed concrete, reclaimed asphalt pavement, river bed material or different blends may be used according to meeting the prescribed evaluating and physical principles.

For using combination of different materials in granular sub-base, blending needs to be done properly by either with an appropriate mixer or incorporating the mix in place method.

Granular sub-base layer should be provided as per MORTH guidelines for Road and Bridge construction.

In the event that the thickness of the sub-base layer proposed in the plan allows, the sub-base layer will have two layers; drainage layer and the channel layer. The top surface of the sub-base acts as a drainage layer to remove the water that comes inside through surface splits. The bottom surface of the sub-base should act as the partition covering to stop interruption of sub-grade soils into the paved surface. In case, designed depth of the granular sub-base is lower or equivalent to 200 mm, together drainage and channel layer can't be laid separately. In that case, one drainage-cum-filter layer with Granular sub-base gradation properties may be considered.

5.3.3 Thickness of Granular Sub-base Layers

The following minimum thickness of granular sub-base layers may be adopted.

- 100 mm should be considered as the minimum thickness of drainage as well as channel layer.
- 150 mm should be the minimum thickness of the single filter-cum-drainage layer as per functional necessity.

5.3.4 Resilient Modulus of GSB Layer

The resilient modulus estimation of the GSB layer is subject to the elastic modulus value of the sub-grade surface on which it is laid and the thickness of the granular layer. A poor base doesn't allow higher modulus of the top GSB layer on account of the excessive deformation recorded due to higher loads results in de-compaction in bottom of the granular layer. For the estimation of the resilient modulus of the granular layer, equation 5.4 may be used and inputs needed for calculation are resilient modulus value and the thickness of the supporting layer.

$$M_{RGRAN} = 0.2(H)^{0.45} * M_{RSUPPORT} \qquad (5.4)$$

Where,

H = Granular layer thickness (mm)

M_{RGRAN} = Resilient modulus of the granular layer (MPa)

$M_{RSUPPORT}$ = Effective resilient modulus of the support layer (MPa)

For the analysis of the granular base and granular sub-base, both are taken together as a single layer and a single resilient modulus value is allocated to the composite layer. Now, the resilient modulus of the combined layer might be determined using equation 5.4 and referring the M_{RGRAN} as the resilient modulus of the combined GSB layer and $M_{RSUPPORT}$ as the resilient modulus of the support layer/sub-grade.

Input value of Poisson's ratio for the GSB layer may be considered as 0.35.

5.4 Base

Base course are provided in flexible pavement mainly to enhance the weight carrying limit by transferring the load burden throughout a finite thick layer. Base course may also be provided in the rigid pavement for following reasons:

- To prevent pumping
- To Protect the sub-grade against frost action

5.4.1 Unbound Base Layer

According to MoRTH guidelines, the base layer comprises of wet mix macadam (WMM), water bound macadam (WBM), crusher run macadam, reclaimed concrete, etc. combinations such as blast furnace slag mixed with crushed stone (as per the MoRTH specifications) may be used to prepare wet mix macadam. As per guidelines, the thickness of the unbound base layer will not be less than 150 mm with exception for the crack-protected surface laid on cement-treated base for which the thickness will be taken as 100 mm.

In case where both base layer and sub-base layer are composed of unbound granular layer, the effective resilient modulus of the combined granular base will be calculated by applying equation 5.4 and considering M_{RGRAN} as the resilient modulus of the composite unbound granular layer (MPa), 'H' as the composite equivalent thickness of the GSB + base and $M_{RSUPPORT}$ as the effective resilient modulus in "MPa" of the supporting layer.

Input value of Poisson's ratio for granular bases and sub-bases may be considered as 0.35.

5.5 Bituminous Layers

The primary role of surface course is to provide a smooth riding finish that is thick as well as comfortable. It withstands pressure applied by tyres and bears damage and deformations due to the traffic. Wearing course additionally acts as a water-tight protection against the surface water intrusion.

A bituminous pavement mainly comprises of bitumen surface course and a bitumen base or binder course. Stone matrix asphalt (SMA), Gap Graded mix with rubberized bitumen (GGRB) and Bituminous Concrete (BC) with modified binders is suggested for higher traffic experiencing pavements with design traffic of 50 msa or greater as they serves as a wearing course for durable, aging-resistant and crack-resistant surface pavements. Stone Matrix Asphalt mix is mainly adopted for higher traffic experiencing roads. It is more preferred to use with modified binders as we know that adding some modified-binders in mixes will extend service life-span and in addition extra preventive against aging. Roads having design traffic in the scale of 20-50 msa, binder course with VG40 bitumen may be provided in the wearing course. IRC recommends usage of mastic asphalt mix in wearing course as an alternative for densely stressed roads or in highly rainfall regions and junction points.

S.No	Traffic Level	Surface course		Base/Binder Course	
		Mix type	Bitumen type	Mix type	Bitumen type
1	>50 msa	SMA	Modified bitumen or VG40	DBM	VG40
		GGRB	Crumb rubber modified bitumen		
		BC	With modified bitumen		
2	20-50 msa	SMA	Modified bitumen or VG40	DBM	VG40
		GGRB	Crumb rubber modified bitumen		
		BC	With modified bitumen or VG40		
3	<20 msa[1]	BC/SDBC/PMC/MSS/ Surface Dressing	VG40 or VG30	DBM/ BM	VG40 or VG30

[1]For expressways and national highways, even if the design traffic is 20 msa or less, VG40 bitumen shall be used for DBM layers.

Figure 5.1 Summary of Bituminous layer options recommended

Mix type	Average Annual Pavement Temperature °C				
	20	25	30	35	40
BC and DBM for VG10 bitumen	2300	2000	1450	1000	800
BC and DBM for VG30 bitumen	3500	3000	2500	2000	1250
BC and DBM for VG40 bitumen	6000	5000	4000	3000	2000
BC with Modified Bitumen (IRC: SP: 53)	5700	3800	2400	1600	1300
BM with VG10 bitumen	500 MPa at 35°C				
BM with VG30 bitumen	700 MPa at 35°C				
RAP treated with 4 per cent bitumen emulsion/ foamed bitumen with 2-2.5 per cent residual bitumen and 1.0 per cent cementitious material.	800 MPa at 35°C				

Note: For the purpose of the design

Figure 5.2 Recommended values of resilient modulus (MPa) for surface couse

CHAPTER 6
TRAFFIC

6.1 Traffic Surveys

A precise estimation of the design traffic that is probably going to utilise the planned pavement is necessary as it shapes the essential contribution in planning, designing, activity and cost-estimating. Some information on the movement properties of the traffic possibly to ride the planned pavement just as another significant road in the impact region of the research is, therefore, important for upcoming traffic predictions. So, comprehensive traffic-movement survey needs to be done to evaluate the current day traffic and its characteristics. In the estimation of design traffic, the overall structural deformation to the road surface by various types of axles conveying distinct axle loads is analysed with the help of vehicle damage factors (VDF). These various respective inputs are needed for estimation of the design traffic (cumulative standard axle load repetitions in msa) for the specified road (for a predefined design life).

- Average traffic growth rate throughout the given design life
- Initial traffic (two-way) after construction recorded in number of commercial vehicles per day (cvpd)
- Design life
- Vehicle Damage Factors (VDF)
- Estimation of the lateral distribution of commercial traffic across the Carriageway.

Commercial vehicles weighing 3 tonnes or above are taken into consideration for the structural analysis of pavement design.

6.2 Traffic growth rate

For estimation of the future traffic going to use that road till its design-life, it is important to know the increasing rate at which the commercial traffic will rise throughout its design-life. Required data for predicting the increase in traffic over design period are:

- Past data trends of traffic inflation.
- Flexibility in traffic with respect to macroeconomic parameters.

Due to lack of information for determination of the yearly increase rate in vehicular traffic or when the predicted development rate is under 5 percent, a least yearly increase rate of 5 percent should be considered for commercial vehicles for calculating the required design traffic.

6.3 Design period

For National Highways, State Highways and Urban Roads, IRC recommends a design life of 20 years may be considered for the flexible pavements design. This condition may vary according to distinct regional and climatic diversity of proposed project site in diverse regions.

6.4 Vehicle damage factor

Vehicle Damage Factor (V.D.F.) is a factor to change over the No. of commercial vehicles with different axle combinations and loads into an equal count of standard axle load repetitions.

Initial (two-way) traffic volume in terms of commercial vehicles per day	Terrain	
	Rolling/Plain	Hilly
0-150	1.7	0.6
150-1500	3.9	1.7
More than 1500	5.0	2.8

Figure 6.1 Indicative VDF values

6.5 Lateral distribution vehicular traffic over the carriageway

6.5.1 Dual carriageway roads

The design of dual two-lane carriageway roads should be based on 75 percent of the count of commercial vehicles in each direction. For dual three-lane carriageway and dual four-lane carriageway, the distribution factors shall be 60 percent and 45 percent respectively.

6.6 Computation of design traffic

The design traffic should be calculated using equation 6.1. It is estimated in terms of increasing count of standard axles to be catered during the design life period of the pavement

$$N_{Des} = 365*[(1+r)^{n}-1]/r*A*D*F \qquad (6.1)$$

Where,

N_{Des} = cumulative number of standard axles to be carried during the design period of 'n' years

A = Initial traffic (CPVD) in the year of completion of construction

D = Lateral distribution factor

F = Vehicle damage factor (VDF)

n = design period (years)

r = annual inflation rate of commercial vehicles in decimal

The expected traffic in the completion year of construction project may be calculated by equation 6.2.

$$A = P\,(1+r)^{X} \qquad (6.2)$$

Where,

P = Count of commercial vehicles per day as per previous record.

x = Difference in No. of years during the last record and the year of termination of construction.

CHAPTER 7

LABORATORY TESTING METHODOLOGY

7.1 Standard Proctor test

Materials Required:

1. Weighing machine
2. Rammer (2.5kg weight)
3. Standard proctor mould (998cc capacity)
4. Sieves of 20 mm and 4.5 mm
5. container
6. Oven dried soil sample
7. Graduated cylinders
8. Edge tool

Procedure:

- A 5kg oven-dried soil was taken for the experiment. It was mixed with a required amount of water using graduated cylinder
- Then without base and collar proctor mould was weighed and recorded. Afterwards with the base and collar, soil specimen was filled in three layers and 25 uniformly distributed blows were given to respective layer.
- By using straight edge, sample was trimmed and the surface was levelled.
- To determine the bulk density, the weight of compacted soil was divided by the volume of the proctor mould.
- Sample was taken thoroughly and small amount of sample was put in oven to determine water content and methods employed to determine was water content.
- Plot the graph between water content and dry density to find OMC.

Fig 7.1 Proctor test procedure

7.2 California Bearing Ratio Test (CBR Test)

APPARATUS:

Mould

Dial gauges

Spacer Disc

Loading Machine

Filter Paper

IS Sieves

Steel Cutting collar

Surcharge weight

Weighing balance

PROCEDURE:

- Taking 3 oven dried specimens each of about 7 kg must be compacted so that their compacted density must be close to 97 percent respectively with 10, 30 and 65 blows.
- Weight of empty mould should be done and recorded in observation sheet
- Add water in the first specimen compact it in five layer by giving total of 65 blows
- After compaction, remove the collar and level the surface. Take specimen for determination of moisture content. Recorded all observation precisely
- Place the mould in the soaking tank for four days
- Take rest specimens and compact them similarly repeating the whole process.
- After four days, measure the swell reading and find %age swell.
- Remove the mould from the tank and allow water to drain from the specimen
- Then place the specimen under the penetration piston and place surcharge load.
- Apply the load and note the penetration load values relatively.
- Draw the graphs between the penetration and respective load and find the value of CBR.

Fig 7.2 CBR Test Apparatus-1

Fig 7.3 CBR Test Apparatus 2

Fig 7.4 Testing of sample in CBR Test apparatus

CHAPTER 8

RESULT & CONCLUSION

8.1 Proctor Test Result

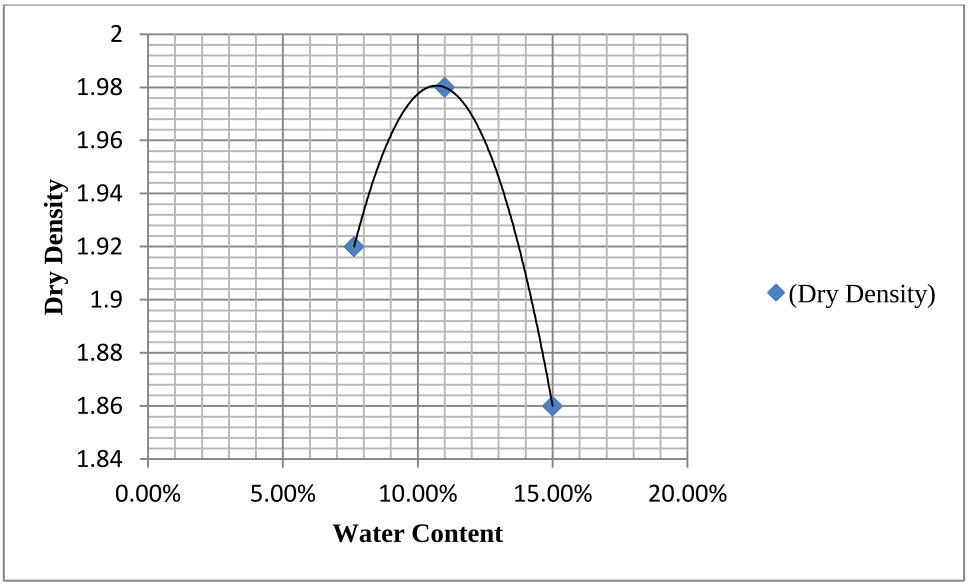
We performed proctor tests on two samples of soils collected from the actual sites.

a. Top 500 mm
b. Bottom 500 mm

8.1.1 Top 500 mm

Table 8.1 Proctor test result for top 500mm

(Water Content)	(Dry Density)
7.64%	1.92
11%	1.98
15%	1.86



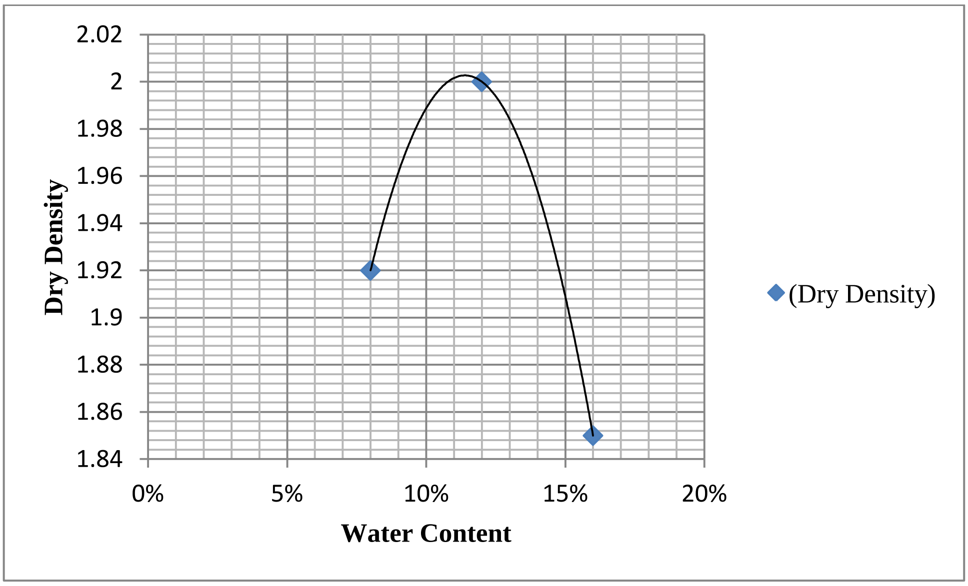
Graph 1 Graph between Dry Density &Water Content

The optimum moisture content for above soil sample is **11.05%**

8.1.2 Bottom 500 mm

Table 8.1 Proctor test result for bottom 500mm

(Water Content)	(Dry Density)
8%	1.92
12%	2
16%	1.85



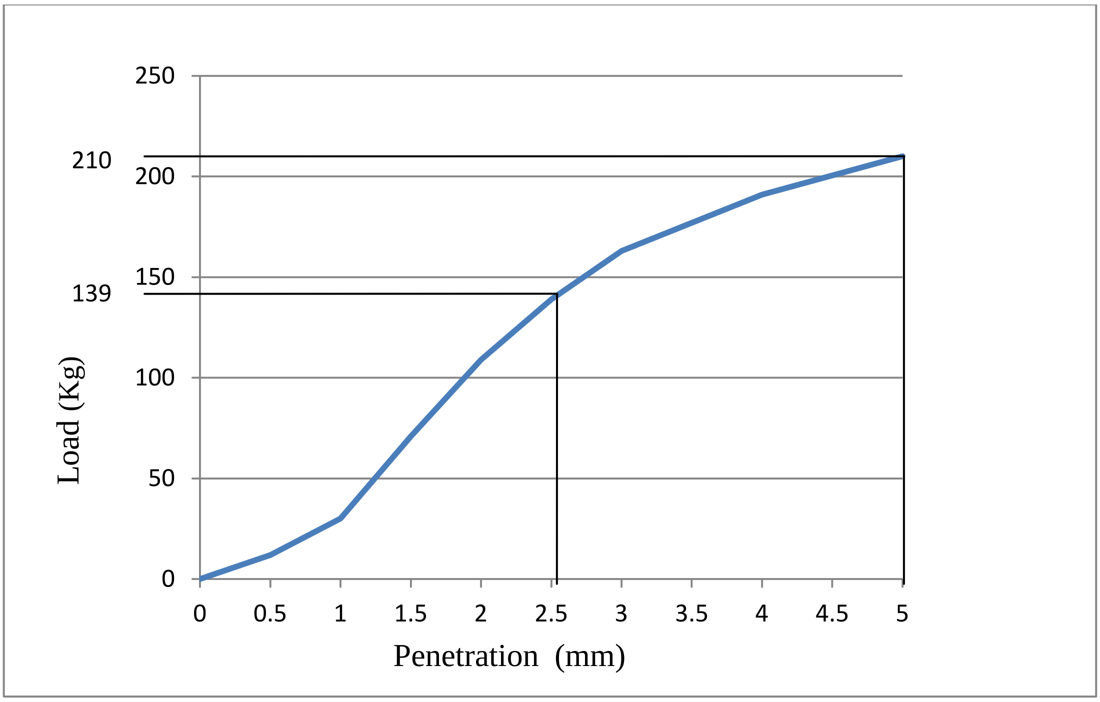
Graph 2. Graph between Dry Density &Water Content

The optimum moisture content for above soil sample is **11.85%**

8.2 C.B.R Test Results

Table 8.3 Penetration with respective load for sample 1

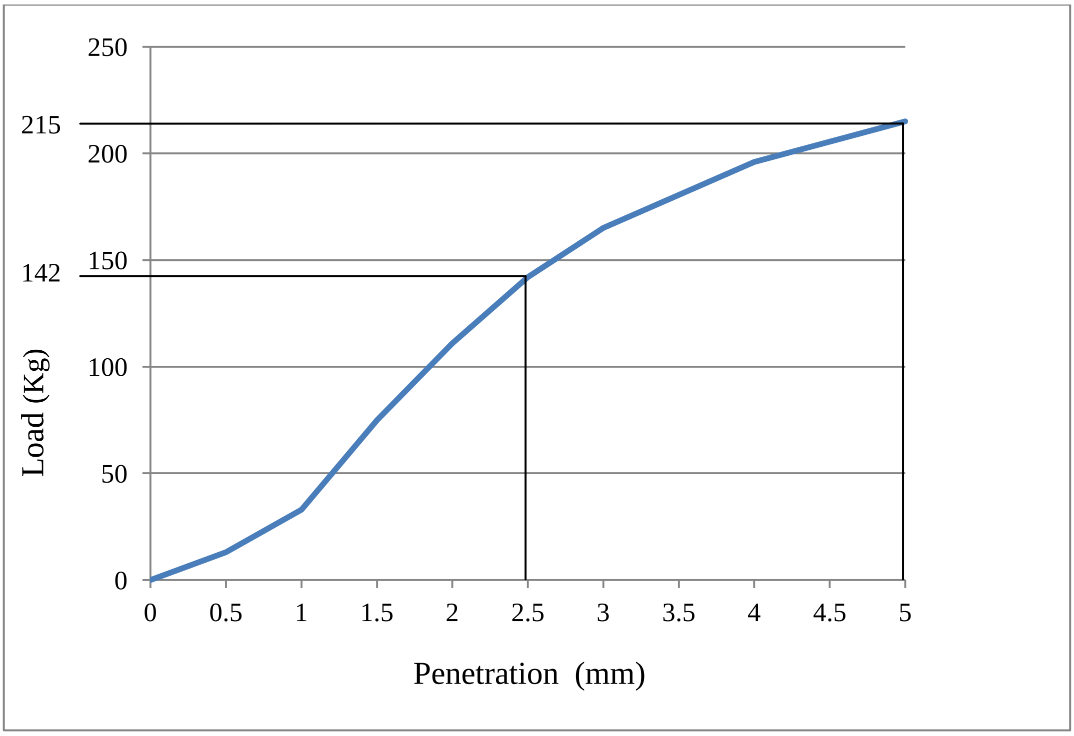
Penetration (mm)	Applied Load (kg)
0	0
0.5	12
1	30
1.5	71
2	109
2.5	139
3	163
4	191
5	210
CBR %	10.21%



Graph 3 Penetration vs. load

Table 8.4 Penetration with respective load for sample 2

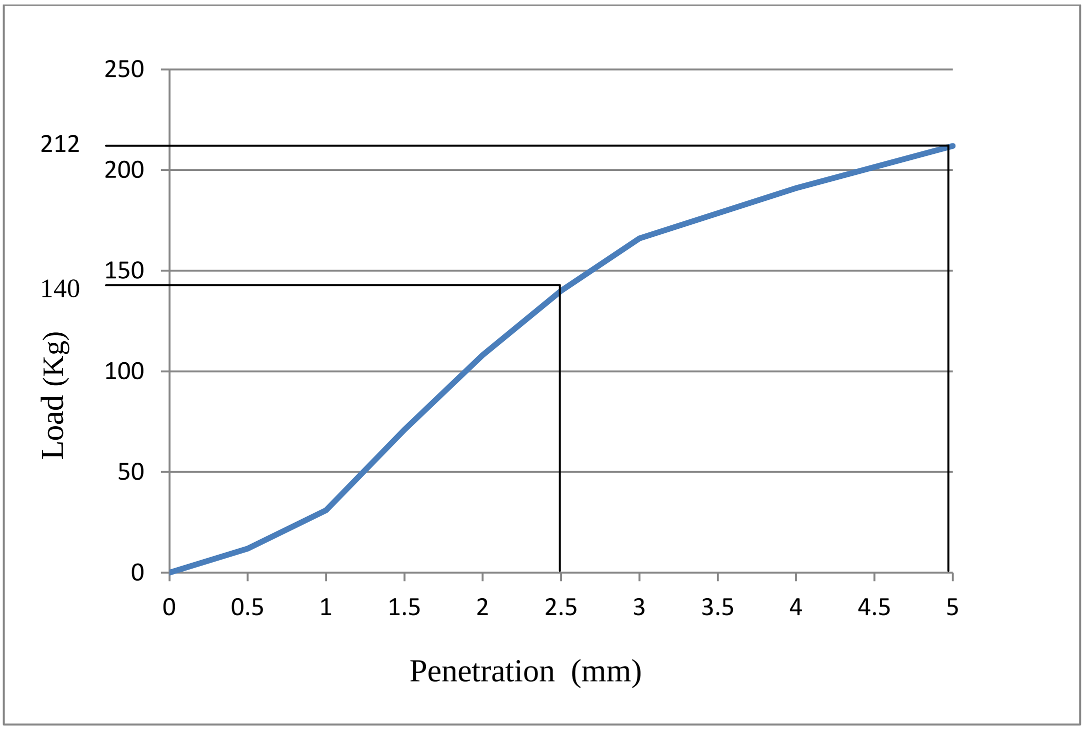
Penetration (mm)	Applied Load (kg)
0	0
0.5	13
1	33
1.5	75
2	111
2.5	142
3	165
4	196
5	215
CBR %	10.46%



Graph 4 Penetration vs. load

Table 8.5 Penetration with respective load for sample 3

Penetration (mm)	Applied Load (kg)
0	0
0.5	12
1	31
1.5	71
2	108
2.5	140
3	166
4	191
5	212
CBR %	10.31%



Graph 5 Penetration vs. load

So adopted CBR value for calculation and design purpose is **10.5 %**

8.3 Design of Pavement

We have already discussed all parameters and dependent values which will be used to design the pavement. We will be using IIT-PAVE software to compute different Structural values and will be comparing that with values we will get through empirical-mechanistic equations discussed above. So we will be going step by step and also be explaining every single process which will be used to work out our economical and effective design approach.

8.3.1 Calculation of Design Traffic

Here, we have added the commercial traffic recorded in both the directions. The recorded data of traffic is attached in annexure. Now, we will be using equation 6.2 to compute expected traffic in year of completion of the project. Here our total commercial count is 2215 and we are taking annual growth at 5 percent. Our difference between last count recorded and expected year of completion of construction is 4 years.

So putting values in equation 6.2, we get

$$A=2215(1+0.05)^4$$

$$=2692 \text{ Veh/day}$$

We are taking our design period of 15 years (as recommended by IRC for National Highways).

TABLE 8.6 Recommended V.D.F Values

Types of vehicles	Km 82.000	
	Parwanoo to Solan	Solan to parwanoo
LCV	1.3	1.3
Bus	0.8	0.8
2T	5.28	5.28
3T	4.8	4.8
MAV	4.85	4.85

According to this table, we will select our V.D.F value for calculation of design traffic. Since we can see 5.28 is the maximum value. So as recommended by IRC, we will be using maximum value for our design traffic. V.D.F value is taken as 5.28.

Since we are designing our pavement for 2-lane dual carriageway and taking lateral distribution factor as 0.75.

Now we can put all these values in equation 6.1 and calculate our design traffic in terms of increasing No. of standard axles to be carried for the design period of ‘15’ years.

$$N_{Des} = [365 * \{(1 + 0.05)^{15} – 1\} * 0.75 * 1346 * 5.28] / 0.05 * 10^6$$

$$\mathbf{= 41.98 \text{ or } 42 \text{ msa}}$$

Now we have our design traffic and with different catalogues given in IRC: 37-2018, we will select one matching our CBR data and design traffic.

8.3.2 Selection of Pavement Thickness

Now we have both our initial parameters for designing pavement. Since selection of accurate pavement thickness is very important and with the new version of IRC guidelines, selection of pavement thickness trial is relative easy. There are multiple catalogues present to select required thickness trial.

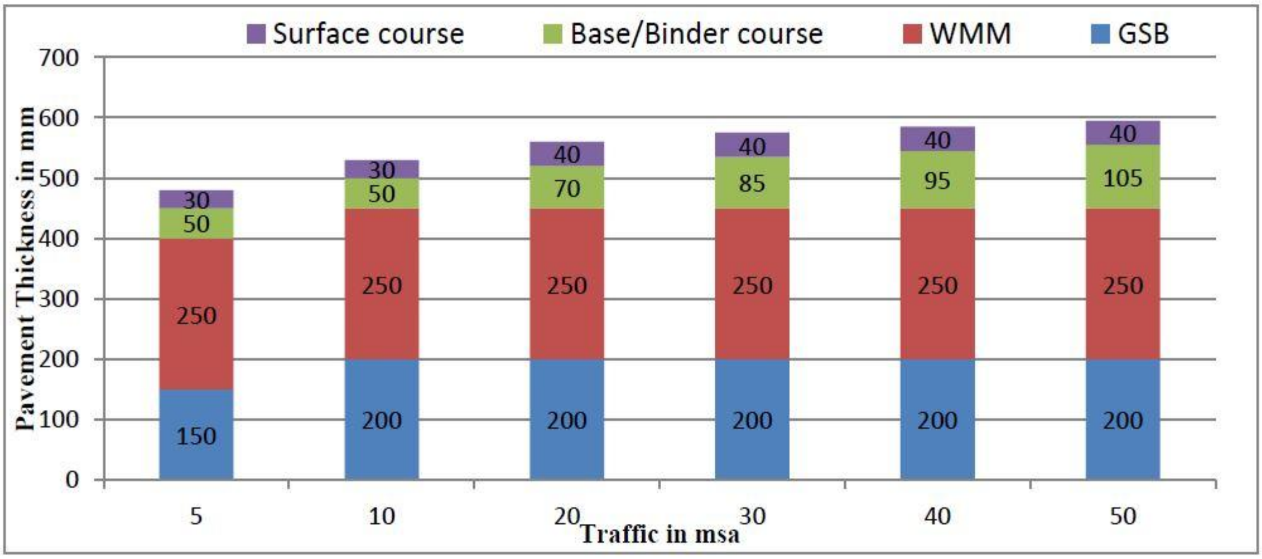


FIGURE 8.1 Trial Pavement Thicknesses For 10% CBR

Since, Design traffic is 42 msa so as recommended by IRC; we will be taking thicknesses for 50 msa design traffic.

Surface course = 40 mm

Binder course = 105 mm

Water mix macadam = 250 mm

Granular sub base = 200 mm

8.3.3 Estimation of Resilient Modulus of Each Layer

Effective CBR of sub-grade is 10.5%

Using equation 5.2, we can calculate resilient modulus of subgrade as our CBR > 5%

$$M_{RS} = 17.6 * (10.5)^{0.64}$$

$$= 79 \text{ MPa (less than 100 MPa)}$$

Since the calculated design traffic exceeds 50 msa, we will provide either stone mastic asphalt or BC with modified bitumen in wearing course and dense bituminous macadam binder with VG40.

Since seeing the native place of pavement, annual average temperature resembles equivalent to 35°C, so taking resilient modulus of surface and base course as 3000 MPa.

Selected a trial thickness with 145 mm total bituminous layer, providing 40 mm thick surface course, 55 mm thick dense bituminous macadam-II, 50 mm thick bottom rich dense bituminous macadam-I; 250 mm thick granular base (WMM) and 200 mm thick GSB.

Combined thickness of granular layer = 450 mm

The Poisson's ratio for all layers can be taken as 0.35

Tyre contact pressure can be taken as 0.56 and radial distance 310 mm for dual wheel set

Resilient modulus for the granular layer = $0.2 \times (450)^{0.45} \times 79 = 247$ MPa

Numbers of layer is taken as 3

8.3.4 Estimation of Reliability Performance Models

To apply 90 percent reliability performance models for sub-grade rutting and bituminous layer cracking, we need to analyze our trial pavement thickness using IIT-PAVE Software and computing all the parameter values discussed above as a input in IIT-PAVE software.

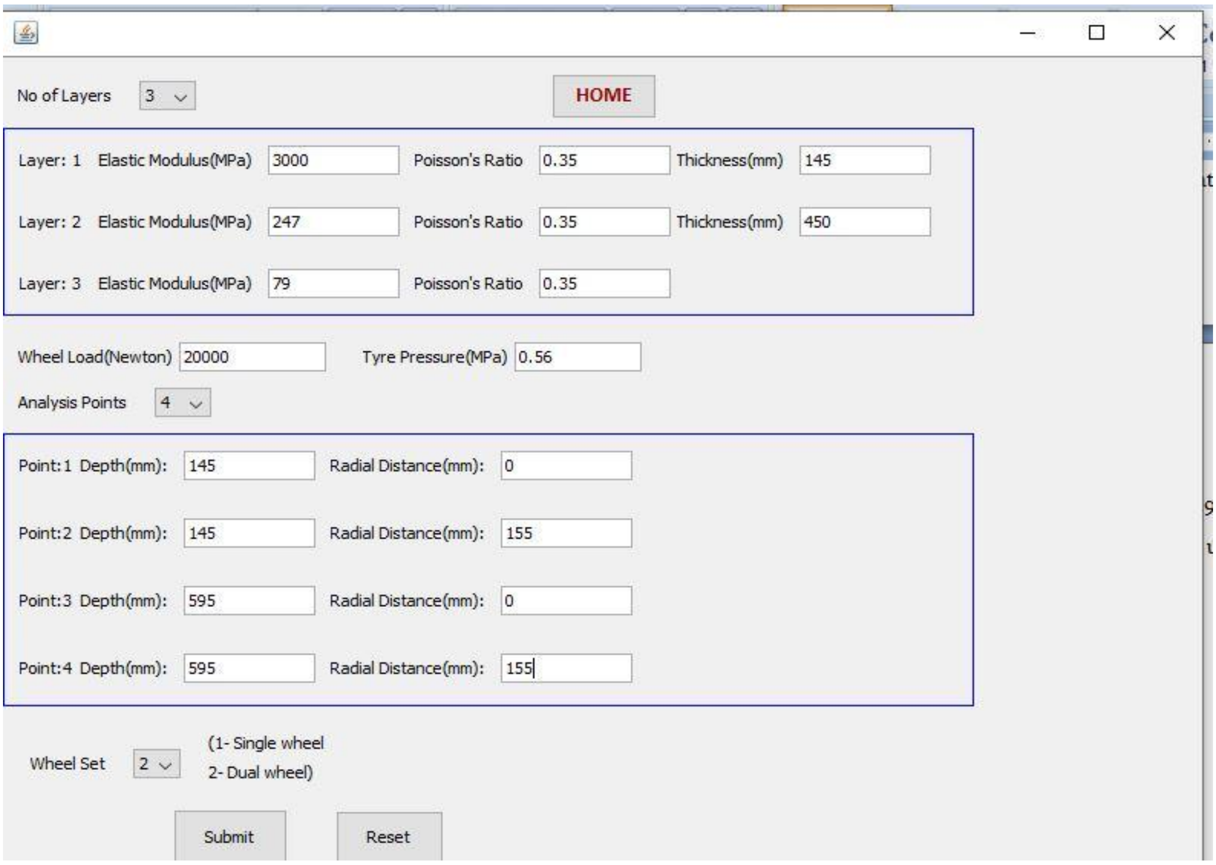


Figure 8.2 Input values for IIT-PAVE software

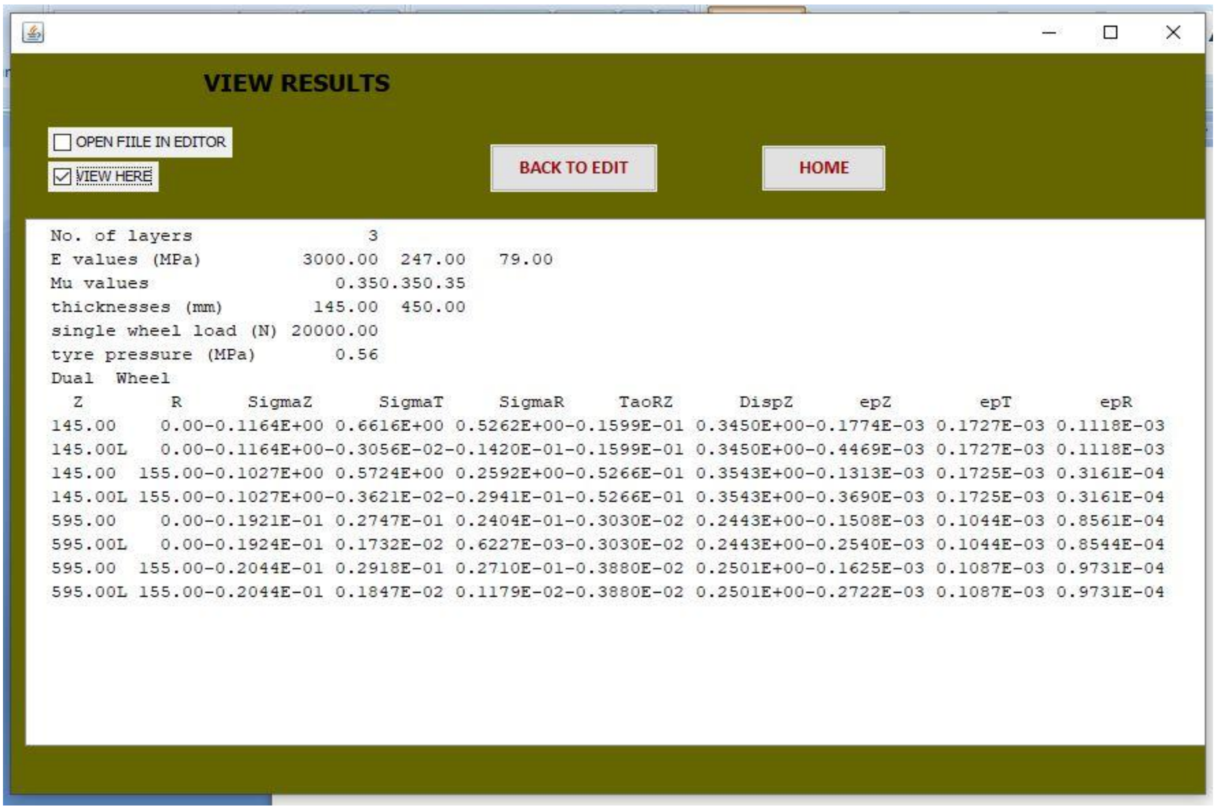


FIGURE 8.3 IIT-PAVE outputs for pavement evaluation

The output window shows 2 options for the result to be accessed either through “Open file in editor” or “view here”. We need to enter any of the above options, the output window shows all the entered values and also shows the calculated values of vertical and horizontal stresses, strains and deflections for the point where the depth of the location measured from surface, and the radial distance of the location taken from the centre of the circular contact region of the load selected. The mechanistic-empirical functions shown in the result window are: vertical stress as SigmaZ, tangential stress as SigmaT, radial stress as SigmaR, shear stress as TaoRZ, vertical deflection as DispZ, vertical strain as epz, horizontal tangential strain as epT, and horizontal radial strain as epR.

horizontal tensile strain (ε_t) will be the maximum between the tangential and radial strains at the base of the bitumen surface measured at two radial distances of ‘0’ and ‘155’and ε_t will be computed as 0.0001727 ($0.1727*10^{-3}$) which is the maximum of all the four strain outputs i.e., 0.0001727, 0.0001725, 0.0001118 and 0.00003161.

Similarly, vertical compressive strain (ε_v) will be shown from the outputs referring to the lower line of the dual groups of results taken for the common surface between granular layer and sub-grade. Thus, the ε_v value of 0.0002722 ($0.2722*10^{-3}$) greater of the two computed strain values taken from the intersection between the sub-grade and the granular layer i.e., 0.0002722 and 0.0002540.

- Permissible vertical compressive strain calculated using equation 3.1for a design traffic of 42 msa and for 90 percent reliability = 0.000456 (0.456×10^{-03})
- Permissible horizontal tensile strain computed at the base of bitumen layer using equation 3.4 for a design traffic of 42 msa, 90 percent reliability, air void content of 3 percent and effective binder volume of 11.5 percent, and a resilient modulus of 3000 MPa for rich bottom dense bituminous macadam layer = 0.000210 (0.210×10^{-03})
- Analysing the pavement design using IIT-PAVE software by giving the following inputs such as resilient modulus of 3000 MPa, 247 MPa and79 MPa for all three layers, Poisson’s ratio values of 0.35 are taken for all the respective layers, layer thicknesses of 145 mm & 450 mm as per our selected trial thicknesses. Our computed horizontal tensile strain = 0.000172 < 0.000210. Hence, our trial thickness and design is ok.
- Our calculated vertical compressive strain = 0.000272 < permissible strain of 0.000456.Hence, trial thickness and design is ok and can be adopted for construction.

8.4 Conclusions

- These procedures are followed as per IRC standards and flexible pavement design is analytical. The project can be used as the base for new project analysis; so as to remould the bases for updated changes as per technological advancements for superficial means of propagation. The limitations are checked and new innovations are incurred after following analytical and standard checks. The data given in this report are needed to be applied on the site pavement so as to check for the best supervision, if any, nearby the specified site. This will be highly remarkable for future modifications.
- We found that traffic survey is important to design any flexible pavement. These studies would help for designing and planning the up gradation of capacity in a phase wise manner. This would ensure that resources are spent prudently, relative with demand for travel.
- Flexible pavement are preferred over concrete roads because they have a great advantage that these can be build up and improved in stages with the increase in traffic and also their surfaces can be grind and re-used for repairing. The flexible pavements are more economical (minimum in investment and repair work).
- The span of flexible pavement is nearly about 15 years whose initial cost is less and needs a periodic maintenance after a certain time period. It is seen that flexible pavements are less expensive and effective for lesser volume of traffic.
- The pavement functions in the layers can be examined by the IITPAVE software, which takes inputs from in terms of count of layers, their respective thicknesses and resilient modulus. The trial pavement combinations and layer thicknesses are selected through IRC catalogues given in IRC guidelines and the structural functions at the critical points are given by using the IIT-PAVE software. The allowable strains and stress are calculated from the fatigue and rutting mechanistic-empirical model, for computed design traffic.
- All the above design procedures have been done according to IRC: 37-2018 or previous IRC guidelines.
- The traffic and sub-grade soil properties are important for designing any pavement. The latest IRC method of pavement design may be used to estimate the overall pavement thickness due to its easy and precise approach.

- This pavement design method will be helpful, if non-conventional pavement design is needed in the construction of pavement as it will provide better performance of the pavement surface thus adding to the life-span and leading to economical savings.

This project on construction of four-laning of national highway between Parwanoo and Solan has been really challenging but informative. The project is great for learning various aspects of design which need to be considered for construction of flexible pavement. During project work, all design procedures of flexible pavement have been covered such as traffic surveys, traffic forecasts, selection of design parameters, construction methodology, material investigation survey and material testing etc. During site visit, we went to actual construction and interacted with project engineers too. Also, we discussed problems faced during the actual project implementation along with their solutions. Overall, this Industry based Project is very helpful from learning aspect. Reference from various phases of this project will be highly useful for the future work in this area.

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APPENDIX

APPENDIX A: Recorded Traffic Data

Table A.1 Average Daily Traffic (ADT)

Categories	ADT (Parwanoo to Solan)		ADT (Solan to Parwanoo)	
	Vehicles	PCU	Vehicles	PCU
2 Wheeler	707	354	674	337
3 Wheeler	8	8	8	8
Cars	4200	4200	3766	3766
Mini LCV	412	412	403	403
Mini Bus	103	155	65	98
Standard Bus	245	735	239	717
LCV (4 Tyre)	81	122	105	158
LCV (6 Tyre)	412	618	382	573
2- Axle	223	669	242	726
3-Axle	30	90	22	66
MAV(4-6)	27	122	30	135
OSV(7++Axle)	-	-	-	-
HCM/EME	5	23	4	18
Tractors with trailer	1	5	1	5
Tractors without trailer	1	2	-	-
Bi-cycle	1	1	3	2
Cycle-Rickshaw	1	2	1	2
Hand Drawn	2	6	3	9
Exempted vehicle	56	56	60	60
Total Commercial Traffic	1126	2534	1089	2491
Total Tollable Traffic	5738	7146	5258	6660
Total Traffic	**6515**	**7580**	**6008**	**7083**

Table A.2 Annual Average Daily Traffic (AADT)

Categories	AADT (Parwanoo to Solan)		AADT (Solan to Parwanoo)	
	Vehicles	PCU	Vehicles	PCU
2 Wheeler	707	354	674	337
3 Wheeler	8	8	8	8
Cars	4116	4116	3691	3691
Mini LCV	404	404	395	395
Mini Bus	101	152	64	96
Standard Bus	240	720	234	703
LCV (4 Tyre)	79	120	103	155
LCV (6 Tyre)	404	606	374	562
2- Axle	219	656	237	711
3-Axle	29	88	22	65
MAV(4-6)	26	120	29	132
OSV(7++Axle)	-	-	-	-
HCM/EME	5	23	4	18
Tractors with trailer	1	5	1	5
Tractors without trailer	1	2	-	-
Bi-cycle	1	1	3	2
Cycle-Rickshaw	1	2	1	2
Hand Drawn	2	6	3	9
Exempted vehicle	56	56	60	60
Total Commercial Traffic	1103	2485	1067	2442
Total Tollable Traffic	5623	7005	5153	6528
Total Traffic	**6400**	**7439**	**5903**	**6951**

Table A.3 Calculated VDF

Types of Vehicle	Total vehicles	Sample size	% sample	Empty vehicles	Average VDF
Parwanoo to Solan					
LCV	602	99	16%	7	1.3
2T	178	61	34%	0	5.28
3T	32	8	25%	4	4.8
MAV	30	7	23%	4	3.33
Total	**842**	**175**	**21%**	**15**	
Solan to Parwanoo					
LCV	483	88	18%	58	0.28
2T	236	50	21%	19	1.38
3T	22	11	50%	6	2.19
MAV	31	2	6%	0	4.85
Total	**772**	**151**	**20%**	**83**	

Table A.4 Recommended V.D.F values

Types of vehicles	Km 82.000	
	Parwanoo to Solan	Solan to parwanoo
LCV	1.3	1.3
Bus	0.8	0.8
2T	5.28	5.28
3T	4.8	4.8
MAV	4.85	4.85

APPENDIX B: Sub-grade Soil Testing Results Table/Observation Sheet

Table B.1 Observation Sheet For proctor test

Observations Mould Diameter 10cm Height 12.73 cm Volume 1000 cc Weight 1985.5 gm						
Density	Top			Bottom		
Determination No	1	2	3	4	5	6
Weight of water added (gm)	440	660	880	440	660	880
Weight of mould + compacted soil (gm)	4052.4	4177.9	4126.4	4059.1	4228	4140.9
Weight of compacted soil (gm)	2067	2192.4	2141	2073.6	2242.5	2155.4
Average moisture content, w%	8%	12%	16%	8%	12%	16%
Bulk density (gm/cc)	2.067	2.1924	2.141	2.0736	2.242	2.155
Dry density (gm/cc) = Bulk density/1+w	1.92	1.98	1.586	1.92	1.99	1.85
Water content	Top			Bottom		
Container no	8%	12%	16%	8%	12%	16%
Wt. of container (gm)	19.3	18.9	19.5	19.3	18.9	19.5
Wt. of container + wet soil (gm)	101.1	118.5	128	87.5	52.7	61.4
Wt. of container + dry soil (gm)	95.2	108.7	113.9	82.5	49	55.5
Water content	7.64%	11%	15%	7.91%	12.29%	16.38%

Table B.2 CBR Observation Sheet

TOP 500 mm			
	Sample-1	Sample-2	Sample-3
Penetration (mm)	Applied Load (kg)	Applied Load (kg)	Applied Load (kg)
0	0	0	0
0.5	12	13	12
1	30	33	31
1.5	71	75	71
2	109	111	108
2.5	139	142	140
3	163	165	166
4	191	196	191
5	210	215	212
CBR %	10.21%	10.46%	10.31%

Annexure A: Installation and Usage of IIT-Pave Software

IIT-Pave software is free software, available and distributed along with latest version of IRC: 37-2018. One can download and install it.

Installation of IITPAVE

For installing IIT-PAVE, just copy and paste the **IRC_37_IIT-PAVE** folder in your system and install Java by clicking on **jre-7u2-windows-i586.exe** file. You need to be connected to the internet till Installation.

How to use IITPAVE for analysis of flexible pavements?

The following steps may be referred for analysis of flexible pavements using IITPAVE

(i) Find and open **IRC_37_IIT-PAVE** folder.

(ii) Double-click on **IIT-PAVE_EX.exe** file in the IRC_37_IITPAVE folder. It will pop IIT-PAVE home screen as shown in Figure A.1

Figure A.1 Home-screen View

(iii) Click on design new pavement

(iv) Input pop up window will appear as shown below in figure A.2

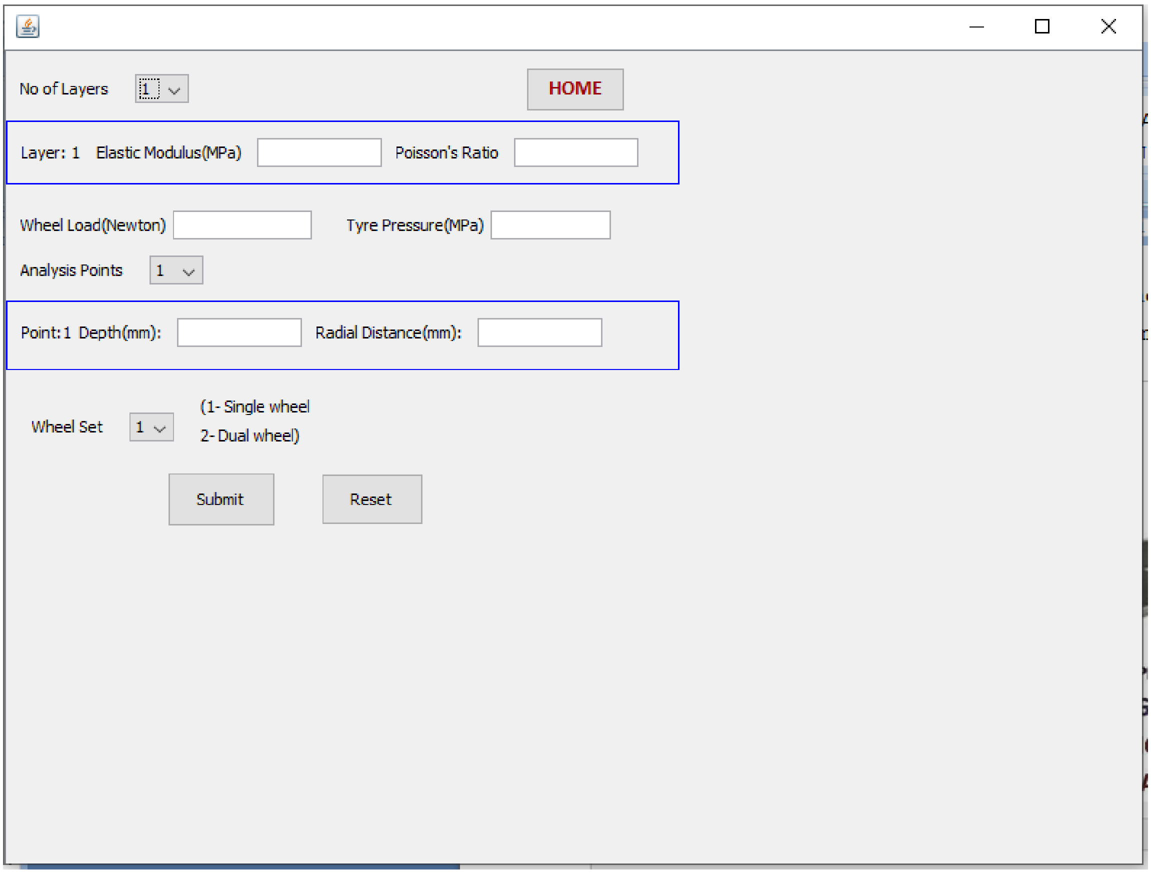

Figure A.2 Input-Screen View

No. of layers can be selected up to 10. Different layers thicknesses, their resilient modulus and Poisson's ratio value can be given as inputs. Wheel load and tyre pressure values need to be entered. And In last we have to select different analysis points where we want our different structural functions values. Depth and radial distance according to layer thickness and guidelines of IRC can be referred for input values.

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