Overlay of Flexible Pavements: An ANN Approach

A Report Submitted in Partial Fulfilment

of the Requirements for the degree of

Bachelor of Technology

in

Civil Engineering

by

Sonal Gumansingh
Roll No.-110CE0069

Under Guidance of
Prof. Mahabir Panda

Department of Civil Engineering

National Institute of Technology Rourkela

Rourkela-769008, Orissa, India

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INDIA

CERTIFICATE

This is to certify that the thesis entitled, "**Overlay of Flexible Pavements: An ANN Approach**" submitted by Miss. **Sonal Gumansingh** in partial fulfilment of the requirement for the award of **Bachelor of Technology Degree** in **Civil Engineering** at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by her under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

Date:

Place: Rourkela

Prof. Mahabir Panda

Professor

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Sonal Gumansingh

Contents

ABSTRACT

Highway Pavements comprise of two types, flexible and rigid. In India Most of the roads are constructed as flexible pavements. The main problem in flexible pavement is deterioration due to traffic loading, material related factors and adverse climatic conditions. In order to avoid and mitigate such difficulties, maintenance is to be done instead of reconstruction. Among all the maintenance programs, the most common method adopted in India is to go for an asphalt overlay on the old surface to increase the serviceability of the existing road. Hence, designing and constructing the flexible overlay is very important regarding its performance. Designing an overlay is challenging given restricted boundary conditions that must be observed and designed for. Although, there is provided design code but some difficulties in solving process such as accurate field data, error prone design curve reading, less accurate conversion formula for temperature variation, time consuming calculations make it complex and dull to be used for everyday purpose. In addition, collection and use the necessary data in the HMA overlay design process needs spending a large amount of money and time and also the reliability and comprehensive data. Unavailability of design software leads to manual calculation which is prone to errors. Hence process should be implemented using a computer model to overcome complexity, recurring tasks and time consuming method. An artificial neural network approach can be used for the elimination of this drawback.

This study presents an attempt to apply artificial neural network to recommend asphalt overlay thickness (HMA). Though noted common methods need time, reliable and some essential data to be able to start designing process but artificial intelligence especially artificial neural network is a method based on learning process which can find possible relation between input and output sample data and is able to predict the output without any time with founded relation quickly. Results of this study reveal that artificial neural network is appropriate for implementation in predicting flexible overlay thickness.

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ABBREVIATIONS

SYMBOL

E_1 : Elastic modulus of A.C. layer.

E_2 : Elastic modulus of granular base layer.

E_3 : Elastic modulus of subgrade.

f_1, f_2, f_3 : Coefficients of fatigue criterion.

f_4, f_5 : Coefficients of permanent deformation criterion.

N_f : allowable number of load repetitions to prevent fatigue cracking.

Nd : maximum allowable number of load repetitions to limit permanent deformation,

Mr : Resilient modulus.

p : Mean normal stress (σ1 + 2 σ3) / 3.

P : Concentrated load.

εc : Vertical compressive strain on the surface of subgrade.

εr : Radial strain or recoverable strain.

εt : Tensile strain at bottom of asphalt layer.

εz : Vertical strain.

σ1,2,3 : Three principal stresses.

σz : Vertical stress.

τ : Shear stress.

μ : Poisson's ratio.

ANN: Artificial Neural Network

CHAPTER-1

INTRODUCTION

1.1 GENERAL

Pavements are of two types, flexible and rigid. In flexible layers, the common ones are Asphaltic wearing course above base and/or sub-base which rests on subgrade layer. Generally, failure of pavement occur due to factors affecting serviceability such as traffic loading and weather conditions. For preservation, Maintenance Rehabilitation (MR) activities should be done in well-timed manner. The most popular M and R activities is use of Hot Mix Asphalt (HMA) overlays. This improves the roadway by utilizing the existing layers of asphalt concrete and aggregate base as support for a new wearing surface. Adding a defined thickness of asphalt concrete provides structural reinforcement to the roadways, permits the designer to allow change in traffic use, addresses increasing traffic volume and weights, corrects riding qualities, and efficiently extends structural performance of the roadway for ten or even twenty years while maintaining factors like the structural capacity of each layer, and the variation of material properties due to seasonal and environmental changes, especially the temperature and moisture variations. A significant consideration during design and ultimately construction of overlay is the potential for existing pavement cracking of different severity to reflect through new wearing surface, with obvious aesthetic impacts. HMA overlay provides a reasonably fast, lucrative means of restoring satisfaction of user, rectifying deficiencies of existing surface, and promoting structural load-carrying capacity reckoning on the designed thickness.

Indian Road Congress (IRC) IRC : 81 – 1997 uses design curves relating characteristic pavement deflection to cumulative standard axle loads. Thus thickness of Bituminous Macadam has to be manually calculated which is time consuming and prone to error by user. Hence, it should be carried out in a computer environment to overcome complex and time consuming procedure. This study incorporates the practicability of application of ANN approach for recommendation of proper pavement overlay thickness based on knowledge from overlay design cases. For developing countries like India where dedicated software for the purpose are unavailable, this approach is productive in every manner.

1.2 FLEXIBLE PAVEMENTS

The main structural function of a pavement is to support the induced load by traffic and to distribute these loads safely to the foundation. Figure 1.1 shows the typical cross-section of a flexible pavement system. This pavement comprises a number of bituminous layers placed over the road base (unbound or bound material) over a similar unbound sub-base material placed on the natural subgrade. This pavement is referred to as "flexible" because the bituminous materials are capable of flexing slightly under traffic loading. For thinly surfaced pavements, the road base is often unbound granular material. The base course immediately beneath the surface course can be composed of crushed stone, crushed slag or other untreated or stabilized materials. The sub-base course is the layer beneath the base course. The reason that two different granular materials are used is for economy. Instead of using the more expensive base course material for the entire layer, local and cheaper materials can be used as a sub-base course on top of subgrade. (Huang, 2004), (Witczack and Yoder, 1975).

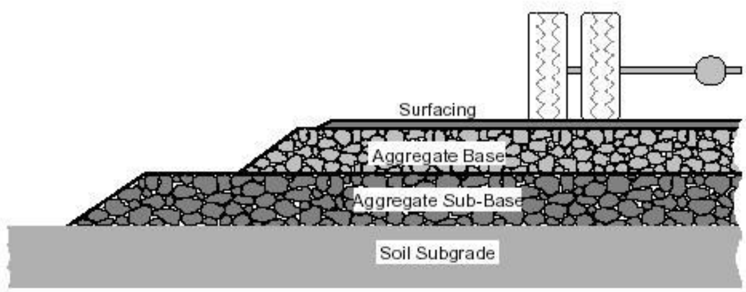


Figure 1-1 Typical cross-section of a flexible pavement system (COURAGE, 1999)

1.3 CRITICAL RESPONSES FOR FLEXIBLE PAVEMENTS AND PREDICTION OF LIFE

Kerkhoven and Dormon (1953) first suggested the use of vertical compressive strain on the surface of the subgrade as a failure criterion to reduce the permanent deformation of subgrade which is the main reason of subgrade rutting. After that Saal and Pell (1960) recommended the use of horizontal tensile strain at the bottom of the asphaltic concrete to minimize fatigue cracking which limits the fatigue life of pavements(*Huang, 2004*). Two main structural failure mechanisms for flexible pavements which are the fatigue cracking of the asphaltic concrete layer and permanent deformation of the subgrade (rutting) are also shown in figure 1-2.

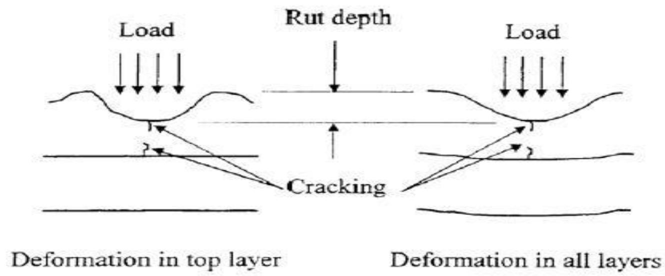


Figure 1-2 types of failure mechanisms in pavements (COURAGE,1999)

1.4 SCOPE OF THE STUDY

During the last three decades the approach to design of flexible pavements has begun to undergo transformation from empirical method to mechanistic method because of the improved understanding of the behaviour of materials and the availability of analytical tools for the analysis of pavements. In India also, a massive pavement performance study was undertaken during 1983 to 1993 [Research Schemes R-6, 1995; R-19 and R-56, 1999] as a result of which a new standard for design of flexible pavements was published by Indian Roads Congress [IRC: 37, 2001]. The new design method uses a mechanistic approach for the determination of design pavement thicknesses.

The main concern among the researchers in India in using the empirical relationships recommended by IRC is that there has not been any validation of the relationships for the specifications and construction practices adopted in India. Thus, it is essential to have adequate data for selection of realistic layer moduli appropriate for the conditions prevailing in India. Hence, a rational approach for prediction is desirable for the analytical design of pavements and overlays. Also Extensive calculation and time consuming design curve readings prone to reading error by user, makes road for alternative method which is less time consuming and efficient. Hence Artificial Neural Network finds its use in predicting overlay thickness from the learned relationship through repeated presentation of data and is capable of generalizing to new and previously unseen data. In using ANN though initially needs large amount of input data for learning database; it is quick at finding output for new data.

Chapter-2

LITERATURE REVIEW AND SCOPE OF THE STUDY

2.1 LITERATURE REVIEW

ANNs are helpful computation tools increasingly used for solving complex, resource-concentrated problems as an alternative to using traditional techniques. Thube et al. (2006) used ANNs for forecasting cracking, ravelling, rutting and roughness for Low Volume Roads (LVR) in India. This pavement condition prediction methodology using ANN used Road inventory data, as well as 6cycles of pavement performance data from in-service LVR pavement sections over a 3 year period in India. Ceylan et al. (2004) used ANNs as pavement structural analysis tools to be compared with calibrated HDM-4 models developed by World Bank. Meier et al. (1997) trained ANNs as surrogate to ELP analysis for back calculating pavement layer moduli and found a 42 times increase in processing speed for prediction of critical responses and deflection profiles of flexible pavements. Gucunski and Krstic (1996) and Khazanovich and Roesler (1997) reported similar ANN applications.

The research project team working on the development of the new, mechanistic based AASHTO Pavement Design (NCHRP 1-37A) has recognized ANN as non-traditional yet possessing very powerful computing techniques, taking advantage of ANN models in preparing the 2002 Design Guide concrete pavement analysis package. Gholamali et al.(2013) proposed an AASHTO revised method with the goodness of ANNs to reduce the time and the calculation procedure for selection of the asphalt overlay thickness (HMA) by back propagation network with 1-13-3 combination as the optimum network to estimate the overlay thickness. Retherford(2012) developed a systematic uncertainty management surrogate model with objective of addressing model uncertainty, reducing computational expense, incorporating uncertainty in pavement design for risk-based mechanistic-empirical (M-E) pavement design.

Mahoney et al.(1989) integrated non-destructive testing (NDT) for estimating layer resilient moduli, seasonal moduli adjustment, and failure criteria of asphalt concrete using EVERPAVE for Washington state flexible pavements. Terzi(2005) modelled ANN model for serviceability index of flexible pavement with higher regression value than AASHTO.

Gopalkrishnan(2010) discoursed the effect of training algorithm on neural networks when it is aiding pavement design.

Abdallah et al, (2000) developed ANN models for the determination of critical strains at layer interfaces for 3 and 4 layered flexible pavement systems. It could predict remaining life and required overlay thickness for an existing pavement using fatigue and rutting criteria. Ceylan et al.(2007), Gopalakrishnan and Thompson(2004) worked on FE solutions database to be used for predicting critical pavement response and layer moduli when incorporated with ANNs.

In addition, artificial neural networks (Attoh-Okine, 1994, 1999, 2001, 2002 ; Choi, Adams, and Bahia, 2004; Sundin and Braban-Ledoux, 2001; Roberts and Attoh-Okine, 1999; Alsugair and Al-Qudrah, 1998; Huang and Moore, 1997; Fwa and Chan, 1993) have recently been used in flexible pavement cracking prediction, condition ratings of jointed concrete pavements, pavement-performance prediction and simulating pavement deterioration. Several neural network studies, as explained above, have been conducted to assist engineers in selecting optimal maintenance and rehabilitation activities.

2.2 OBJECTIVE OF THE STUDY

The main objectives of the study are

a. To apply artificial neural network for recommending pavement overlay thickness based on learning from overlay design cases avoiding complicated and time consuming input file preparation, complexity procedures and repeated tasks under IRC Pavement Design Guide.
b. To bring forward advanced intelligent learning techniques for pavement designs into practical use.
c. To compare and find accuracy rate of predicted overlay thickness from ANN with calculated ones determined by the MORTH research scheme-81 attempting to use proper transfer function for better accuracy in definite time.

Chapter 3

THEORY

3.1 PAVEMENT STRUCTURE MODEL AND EVALUATION

The pavement is regarded as a multi-layered elastic system. The application of the multilayer elastic theory in pavement analysis involves several assumptions: (Burmister, 1943)

1. Material in the pavement layers is assumed to be elastic, homogenous and isotropic.
2. All layers, except the bottom one, are finite in depth and the bottom layer (subgrade) is assumed to be infinite depth.
3. All layers are assumed to be infinite in extent in the lateral direction.
4. The applied loads are static and load imprints are assumed to be circular.
5. Pavement materials are characterized by a modulus of elasticity and Poisson's ratio.
6. Full friction is assumed to have developed between layers at each interface.

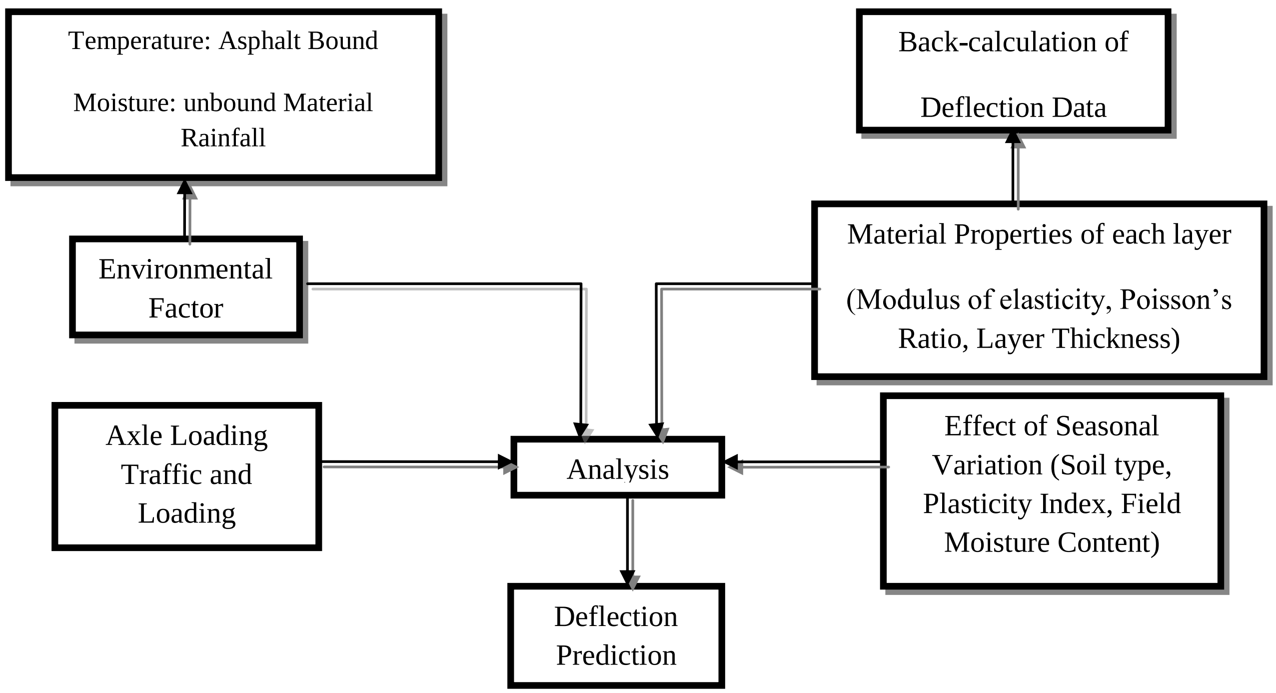
These assumptions may be found to be unrealistic for actual pavement conditions. However, the existing mechanistic procedures showed that applying the multi-layered elastic theory gave acceptable results. (Smith, 1986)

Structural evaluation of pavements commonly involves applying a standard load to the pavement and measuring its response which may be stress, strain or deflection. The most commonly measured response is deflection. Since its development in 1953, the Benkelman Beam has become a standard tool used by several agencies for non-destructive testing of pavements. Benkelman Beam is a 3.66 m long, portable instrument used to measure surface deflection of the pavement loaded by the rear axle of a standard truck. The main disadvantage with this equipment is that the support legs of the beam often lie within the deflection basin, which affects the measured deflections. Also, a single deflection does not give adequate information about the condition of various layers of the pavement. Hence Research scheme MORTH R-81 used dynamic loading type Falling Weight Deflectometer (FWD) for the purpose of calculation of deflection.

The basic working principle of the impulse loading equipment is to drop a mass on the pavement to produce an impulse load and measure the surface deflections. The mass is dropped on a spring system, which in turn transmits the load to the pavement through a loading plate. The resulting deflection bowl characteristics are observed and used in the back-calculation of pavement material properties. The two models developed at IIT Kharagpur in India [Kumar et al, 2001; Reddy et al, 2002a] can be listed in this category.

3.2 OVERLAY DESIGN PROCEDURE

In overlay design procedure, thicknesses are so calculated to put damages within the allowable limits in the existing pavement and the new overlay. Parameters affecting overlay thickness have been discussed in section 3.3. Diagrammatically it can be shown as follows:



3.2.1Modelling Pavement Response

Modelling pavement response is normally used for estimation of two most common distress types found in AC pavements: fatigue cracking and rutting distress. Fatigue cracking is caused by horizontal tensile strain at the bottom of asphalt layers, while rutting distress origin from vertical compressive strain on the top of the subgrade layer.

The failure criterion for fatigue cracking is expressed as generally;

$$Nf = f1\ (\epsilon_t)^{-f2}\ (E_1)^{-f3} \qquad [Huang,\ 2004]$$

Research Scheme MORTH R-81 uses 2.21E-4 , 3.89 , 0.854 for *f*1,*f*2,*f*3 respectively.

The failure criterion for permanent deformation is expressed as;

$$Nd= f4\ (\epsilon_c)^{-f5} \qquad [Huang, 2004]$$

As per Research Scheme MORTH R-81 values of $f4$ and $f5$ suggested as 4.1656E-8 and 4.4337.

3.3 DIFFERENT PARAMETERS OF PAVEMENT DESIGN

Parameters affecting pavement design also affects the selection of database for input preparation. For effective input parameters which will give better accuracy it is needed to consider below factors for its effect on moduli values and others.

3.3.1 Effect of Temperature on Bituminous Layer Modulus

Properties of bituminous mixes like stiffness get affected by change in temperature which affects deflection. Modulus values determined at different temperatures are normally adjusted to correspond to a standard temperature (35°C) for design of pavements and overlays. Different temperature adjustment factors and equations were given by various researchers for adjusting the modulus and/or deflections for temperature. Code says, correction for deflection values measured at pavement temperature other than 35°C should be 0.01mm for each degree change from standard temperature. WINFLEX uses the following relationship

$$E^n = \text{Intercept} - (\text{Slope X T}) \qquad \text{(WINFLEX, 2006)}$$

where, exponent n=0.35 and slope=0.12692

Examination of the deflections measured at different pavement temperatures indicates that the variation of deflections with temperature is maximum in the case of deflections close to the centre of the loading plate in NDT test. There is not much effect of temperature on the deflections measured away from the load. It is widely recognized that deflections at locations closer to the load are mostly dependent on the moduli of all the layers whereas defections, at large distances depend on modulus of subgrade only. (Research Scheme MORTH R-81)

3.3.2 Effect of Seasonal Variation

Deflection depends upon change in climate. Worst climate (after Monsoon) affects the pavement badly. It depends on subgrade soil and moisture content. Correction for seasonal variation in code depends on types of soil subgrade (sandy/gravelly or Clayey with PI<15or

Clayey with PI>15), field moisture content, average annual rainfall (<1300mm or>1300mm). In WINFLEX, climate zone 3 was considered which was nearer to hot climate zone.

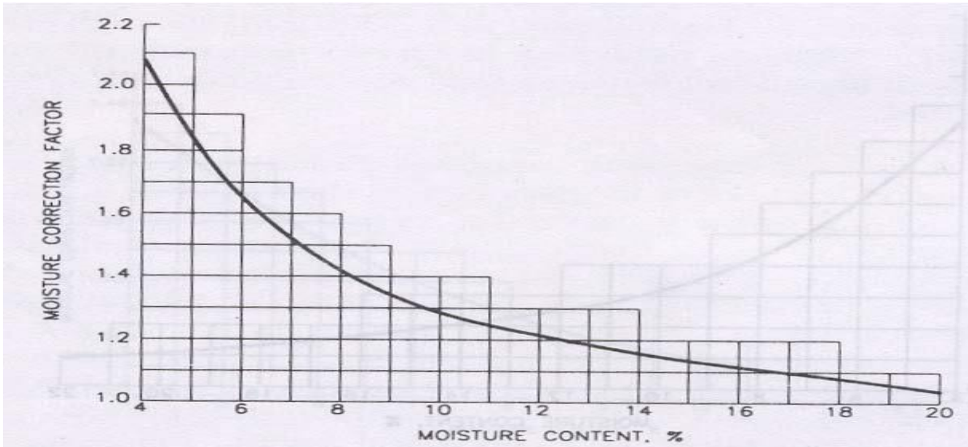


Figure 3-1 IRC Seasonal correction factor (clayey subgrade, PI>15,rainfall<1300) (IRC: 81-1997)

The summer deflections were lower whereas became larger soon after the monsoon. Even though the modulus of the bituminous bound layer is expected to be lower in summer when temperatures are high, the subgrade and granular layers have higher elastic modulus in summer resulting in lower overall deflections in case of thin bituminous surfacing layers. The behaviour of cracked bituminous layers is close to that of granular layers and has high elastic modulus in summer than the modulus obtained during the monsoon (MORTH R-81). Below is the graphical representation of subgrade modulus variation throughout year as per WINFLEX, 2006. This is closely similar to the one explained under MORTH R-81.

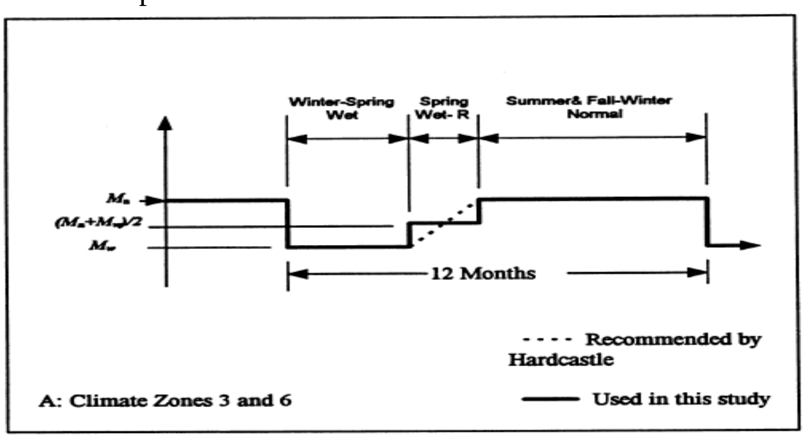


Figure 3-2 Graphical Representation of Subgrade Modulus Variations Throughout the year (WINFLEX,2006)

3.3.3 Effect of Poisson's ratio

For most of the pavement materials, the influence of Poisson's ratio (μ) on various critical parameters is normally small. This allows the use of typical values in the analysis rather than resorting to complex laboratory testing (Mitchell and Monismith, 1977).

According to IRC: 37-2001 Asphalt layer has Poisson's ratio in the range of 0.35-0.5 while 0.5 is for temperature range of 35°C to 40°C and 0.35 for the range of 20°C to 30°C. The value off Poisson's ratio for granular layer and subgrade layer is 0.4.

3. 4 DEVELOPED COMPUTER APPLICATIONS

Mechanistic-based pavement design methods are being developed and used in different countries such as Europe and North America. For example in the USA, the Washington State Department of Transportation (WSDOT) uses ME design system in the computer program EVERPAVE 5.0, March 1999 which was developed at the University of Washington. Bayomy et al. (1996) developed WINFLEX under Idaho Department of Transportation (ITD) which also uses the same design system for flexible pavements and implemented in the computer program WINFLEX, May 2001. This program is available in internet and the link of which is provided in the reference. Here WINFLEX calculates overlay thickness for input design-cases which were to be checked with predicted ones for accuracy.

3.5 ARTIFICIAL NEURAL NETWORK

Neural networks are valuable intelligent tools which have been used significantly in engineering applications when it is difficult to prosecute conventional methods showing inferior performance (Fwa and Chan, 1993). Also Artificial Neural Networks (ANNs) have proved to outperform traditional modelling counterparts in solving various complex engineering problems. ANNs are intelligent systems based on uncomplicated computing models of biological structure of the human brain (Venayagamoorthy *et al*, 2002). The highly connected, distributed nature of it imparts high degree of fault tolerance, noise immunity, and generalization capability. It consists of parallelly operating simple elements, inspired by biological nervous systems. The network function of ANN is determined by the connections between elements which can be trained by adjusting the values of the connections (weights) between the elements. Batch training of a network proceeds by making weight and bias changes based on an entire set (batch) of input vectors. It may also be referred to as ‘‘on line’’ or ‘‘adaptive’’ training.

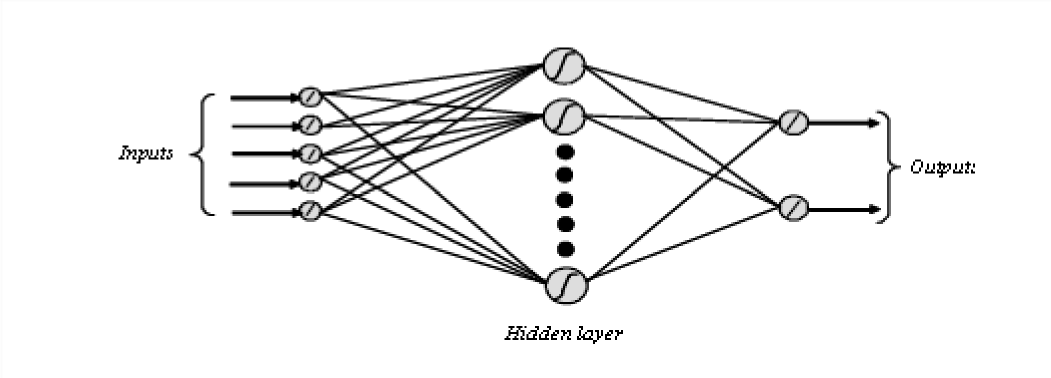


Figure 3-3 Multilayer feed-forward Neural network (Venayagamoorthy,2004)

Typically, in a Multilayer Feed-forward Neural Network (MLFNN), there is an input layer, one or more intermediate layers called the hidden layers and an output layer, which outputs the network's response to its inputs. The activity of the input units represents the raw information that is fed into the network, while that of each hidden unit is determined by the activities of the input units and the weights on the connections between the input and the hidden units. Behaviour of the output units depends on both. The different layers structure allows flexibility, more information capturing and relationship identification between variables. (Venayagamoorthy, 2004)

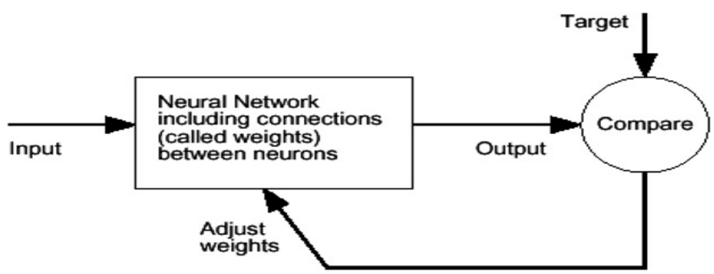


Figure 3-4 Basic Principle of Neural Network (Terzi, 2007)

Chapter-4

ANALYSIS METHODOLOGY

For developing an ANN-based overlay design thickness procedure, required is database of design cases. Hence broad analysis was done on suggested three typical flexible pavement cross sections: 3-layer, 4-layer, and 5-layer, considering new overlay and the subgrade. For each cross section, 7 failure cases to be controlled by the design have been selected creating 21 design cases. A range of input data has to be suggested for each design case. WINFLEX computer program, was used for calculating the overlay thickness. Consequently, design cases database can be created. Training data sets were then being selected to be used in training process for ANN approach. Matlab neural network toolbox was used in designing and training the neural network. Sensitivity analysis on the trained ANN has been conducted. Finally, testing or validating process was performed on the trained ANN. Figure 4-2 presents in details the analysis methodology adopted in this study (Mostafa, 2009), where it is divided into the following four main steps:

1. Design-case Database Development
2. Training and Testing process for accuracy of INPUT data
3. Sensitivity analysis on trained ANN
4. Testing Process on actual data obtained from MORTH R-81

4.1 DESIGN-CASE DATABASE DEVELOPMENT

For building design cases database, three different pavement cross sections have been suggested: 3-layer, 4-layer, and 5-layer as shown in Figure. The information to be taken into account are the material data inputs for each layer: elastic modulus (E), layer thickness (H), and Poisson ratios (ν) as shown. The assumption for elastic layer system is previously discussed in 3.1.

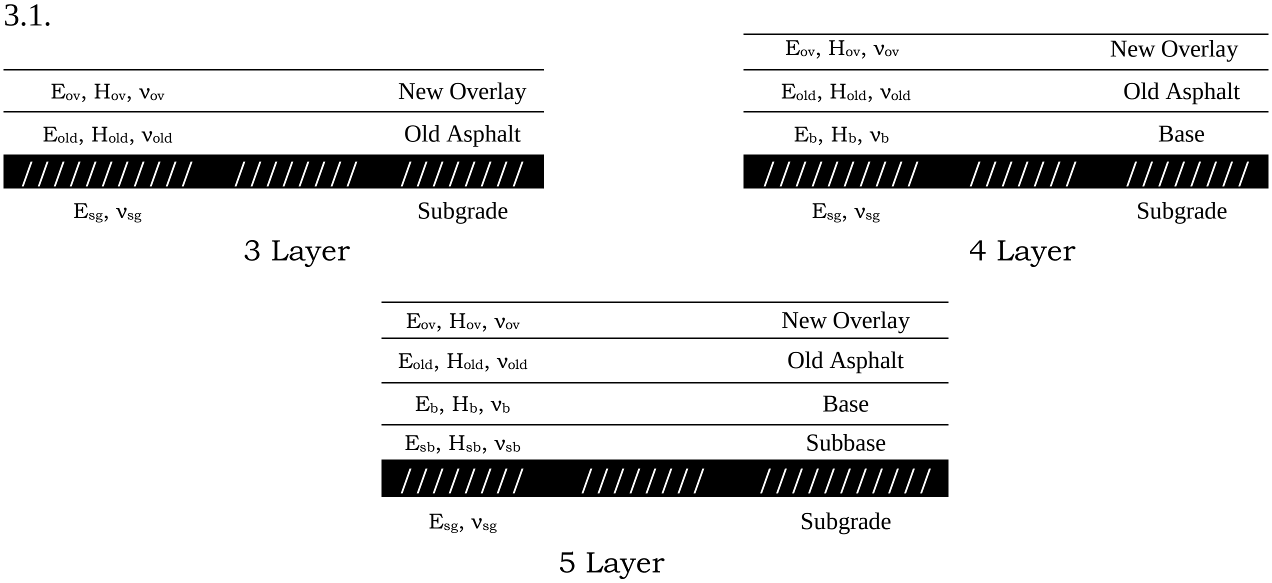


Figure 4-1 Multi layered Pavement Cross-section (Mostafa, 2009)

It is noteworthy that the overlay thickness, Hov, is the desired output to be calculated. Poisson ratios, performance prediction model for fatigue and rutting failure, and modulus-temperature adjustment for AC layers have been assumed to be constant for every design-case. Their values are discussed in theory section under 3.3.

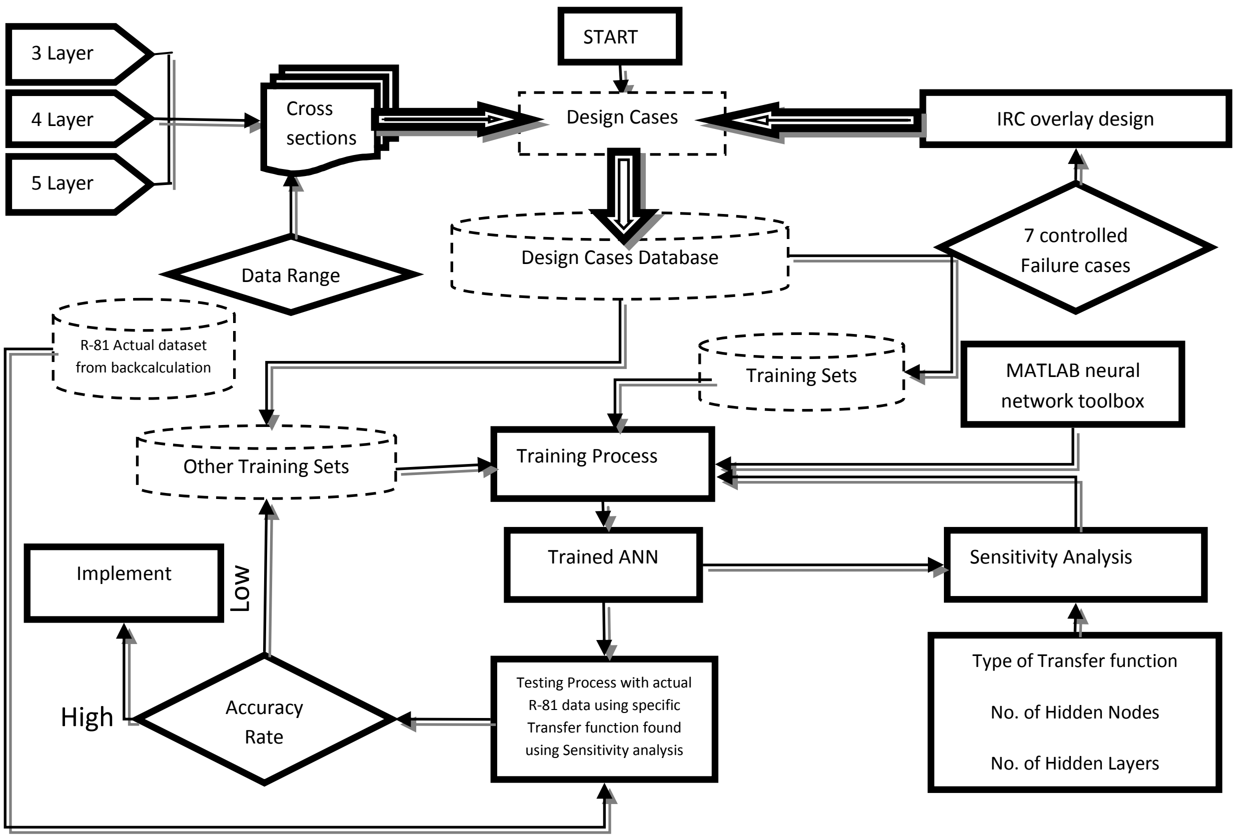
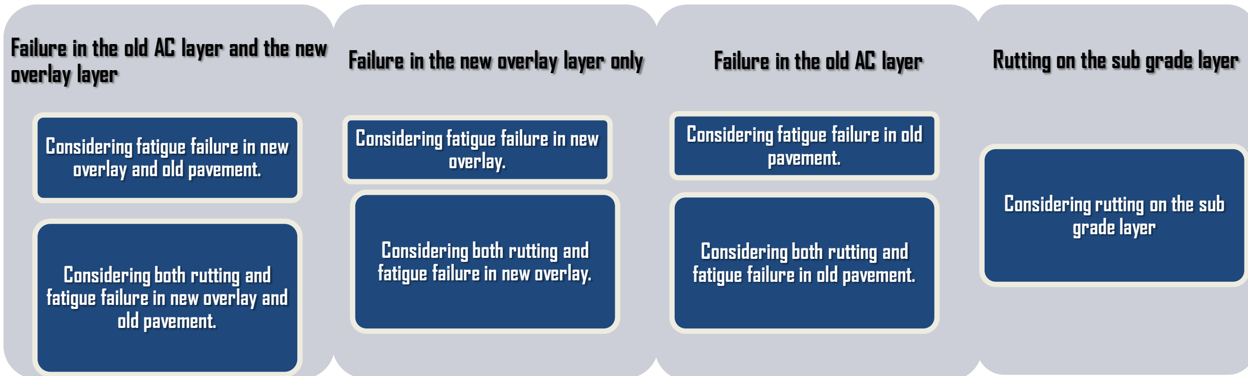


Figure 4-2 Methodology Used (Mostafa, 2009)

For each run, the overlay design software, WINFLEX, determines overlay thickness for the 3 cross sections based on controlling of both fatigue failure at the bottom of the bituminous layers and/or Rutting failure on the top of the subgrade layer. The fatigue failure mode is selected according to three conditions as follow:

- The first condition of fatigue failure is selected so that the design is controlled by considering fatigue failure in the old Asphalt and the new overlay layer.
- The second fatigue failure mode is selected so that only fatigue failure in the new overlay layer is considered.

➢ The last condition is chosen with the purpose of fatigue failure only in the old AC layer. As a result and account for rutting failure with/without, there are seven failure modes for each cross section, i.e., total of 21 design cases, as follow:



Using the data range, design cases database can be created through more than 600 runs for each databases. Range of data can be seen from the given picture (Mostafa, 2009)

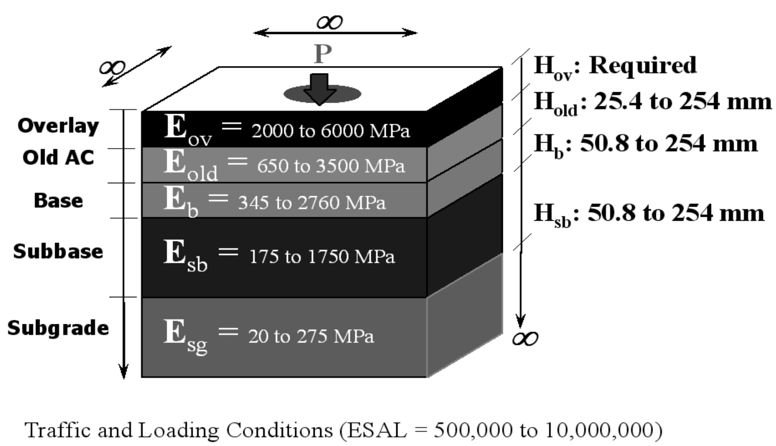


Figure 4-3 Data range of Input Values (Mostafa,2009)

It is noteworthy that pavement is considered to be failed when the total damage reaches 100%, whether it is due to fatigue or rutting. If the calculated overlay thickness is equal to 2.54 mm, which was specified as increment value in WINFLEX, this means that there is no need for overlay.

4.2 TRAINING AND TESTING PROCESS FOR ACCURACY OF INPUT DATA

In order to develop ANN-based overlay design approach, it must be well trained using training sets extracted from the developed database. In this analysis, Input datas are "crosssection", "Failure Mode", "E_{ov}", "E_{old}", "E_b", "E_{sb}", "E_{sg}", "H_{old}", "H_b", "H_{sb}", ESAL whereas the output is H_{ov}. The number of hidden layers and transfer function should be specified.

In this study, 2 hidden layers were used. Here requirement is to get best mapping for the input to the desired output (H_{ov}). Each input set produces output under ANN with varied random set of initial weigts. By training the network, the weights of the system continually adjust to incrementally reduce the difference between the output and the desired response. This difference is cited as the error and can be measured in different ways. The most common measurement is the Mean Squared Error (MSE). The MSE is the average of the squares of the difference between each output and the desired output.

4.3 SENSITIVITY ANALYSIS ON TRAINED ANN

The objective of the sensitivity analysis is to express the fitness of neural networks as an effective way in calculating overlay thickness with the most achievable accuracy that can be obtained for the most economical cost. The neural networks were influenced to several parameters that guarantee the greatest achievable accuracy such as type of transfer function, number of hidden nodes, and hidden layers. Gopalkrishnan (2010) tried to use different training algorithm of which transfer functions that were considered for each design cases were

- TRAINLM-Lavenberg-Marquardt
- TRAINSCG-Scaled Conjugate Gradient
- Radial Basis Function

4.3.1 Levenberg-Marquardt Backpropagation (LM)

The LM second-order numerical optimization technique combines the advantages of Gauss–Newton and steepest descent algorithms. While this method has better convergence properties than the conventional back-propagation method, it requires *O(N2)* storage and calculations of order *O(N2)* where N is the total number of weights in an MLP back-propagation. This algorithm is considered to be very efficient when training networks which have up to a few hundred weights. Although the computational requirements are much higher for each iteration of the LM training algorithm, this is more than made up for by the increased efficiency. This is especially true when high precision is required (MATLAB Toolbox, User's Guide, 2010).

4.3.2 Scaled Conjugate Gradient Backpropagation (SCG)

The SCG training algorithm was developed to avoid this time-consuming line search, thus significantly reducing the number of computations performed in each iteration, although it may require more iteration to converge than the other conjugate gradient algorithms. The storage requirements for the SCG algorithm are lesser than that of LM and it finds its use when no of input data is very high. (MATLAB Toolbox, User's Guide, 2010)

4.3.3 Radial Basis Function (RBF)

In MLP network weighing process of Input Variable is used while RBF gives equal importance to all Input parameters. This makes it less important at calculation of overlay design of flexible pavement as weighing process of different variables is important.

4.4 TESTING PROCESS ON ACTUAL DATA OBTAINED FROM MORTH RESEARCH SCHEME R-81

Once the network is trained, testing process should be started. The trained network should be exposed to the data sets obtained from ministry of Road Transport and Highways (Research scheme R-81) which gives falling weight deflectometer test result of pavements tested by IIT kharagpur. Different design cases were selected to represent training data sets which were taken as INPUT. The predicted overlay thickness using the trained network of ANN software should be compared with the actual ones from MORTH R-81 to come up with the accuracy rate or reliability. The transfer function to be used should be checked with sensitivity analysis result for optimal function for given database. If the accuracy rate is low, then the network is not properly trained and other training sets should be generated to retrain the network, otherwise, the network is considered to be reliable and ready for implementation. (Mostafa, 2009)

The implementation is solely dependent on accuracy of data. The accuracy and time taken to reach required accuracy are important in the sense of implementation in program for everyday use. The accuracy is highly subjected to input data which though randomly taken yet are in resonance with parameters affecting overlay thickness. If a set of input data doesn't give required accuracy in optimal number of runs, effort should be taken to change the dataset to keep it in resonance with parameters affecting overlay design. Effect of parameters is discussed in section 3.3. After getting accuracy in optimal number of runs a set of input can be universally used for the same design-case purpose at different instances i.e. it can be available for use in ANN based overlay design program.

Chapter-5

ANALYSIS AND RESULTS

5.1 DESIGNCASE DATABASE DEVELOPMENT

To build a design cases database, three different pavement cross sections have been suggested: 3-layer, 4-layer, and 5-layer. For each run, the overlay design software "WINFLEX" was used to determine an overlay thickness for the three cross sections based on controlling both fatigue failure at the bottom of the bituminous layers and/or Rutting failure on the top of the subgrade layer. The data range has already been suggested in 3.1. The data set was built taking into consideration of temperature, seasonal variation. 21 design-cases were designed with 600 runs per database were done. Most of the parameters are tried to be varied as ANN doesn't take constant variables into account. Hence to check for all input variables varied data for each is taken. Example of a output text file of WINFLEX is given at Appendix-A.

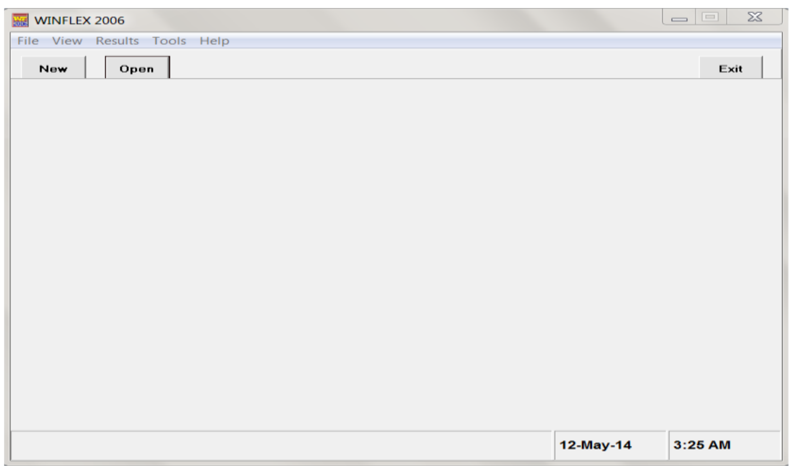


Figure 5-1 WINFLEX Program (WINFLEX, 2006)

5.2 TRAINING AND TESTING PROCESS FOR ACCURACY OF INPUT DATA

Here requirement is to get best mapping for the input to the desired output (H_{ov}). Each input set produces output under ANN with varied random set of initial weights. By training the network, the weights of the system continually adjust to incrementally reduce the difference between the output and the desired response. This difference is referred to as the error and here measured as the Mean Squared Error (MSE). The MSE is the average of the squares of the difference between each output and the desired output.

An example of trained ANN dataset along with performance, training set and regression plot can be seen at Appendix A.

5.3 SENSITIVITY ANALYSIS

The analysis indicates that changing the transfer function has a noticeable effect on the accuracy. Furthermore, the number of hidden nodes has an effect on the accuracy, where using more number of hidden nodes gives high accuracy. To achieve high accuracy, the number of hidden nodes is preferable to be more than 25 nodes. On the other hand, ANN predicts much better with the two hidden layers.

Hence for different transfer function (TRAINLM and TRAINSCG) for each design-cases ANN analysis was done using MATLAB. The no of hidden nodes were also changed for each transfer function. As number of nodes above 20 gives better results hence when plotted the Percent Accuracy Vs no. of hidden nodes, the transfer function which gave better accuracy between 20 to 50 was selected for that specific design-case. Graph between Percent accuracy and no of hidden nodes are presented here for different cases where x_y means the database refers to (x+1) layered initial structure and y design base, criteria of which is given earlier. For example, 1_2 means 3 layered initial structure and design case no. 2 which has been discussed in Section 4.1.

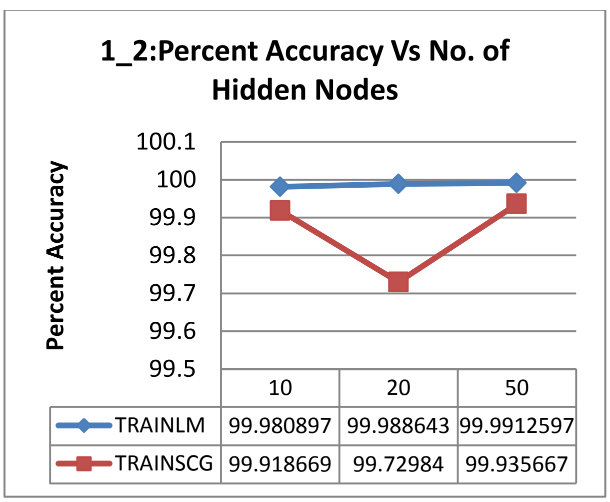


Figure5-2 Graph of Percent Accuracy Vs No. of Hidden Nodes for 3layered pavement: Design-case 2

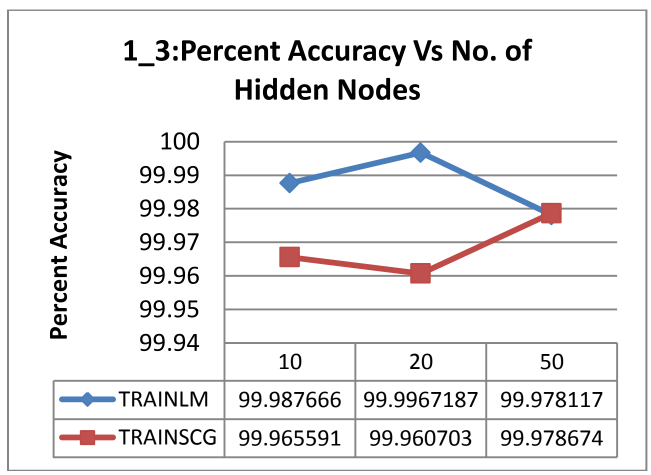


Figure 5-3 Graph of Percent Accuracy Vs No. of Hidden Nodes for 3layered Pavement: Design-case 3

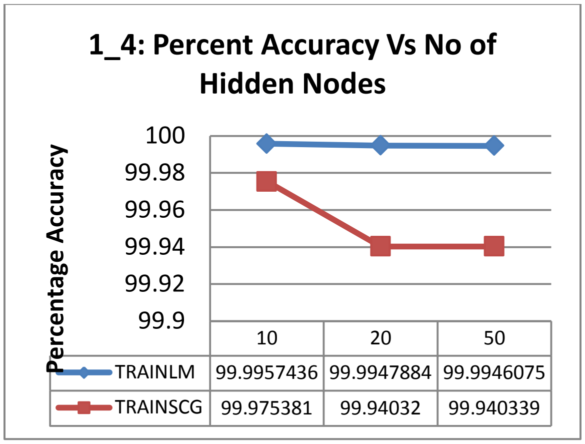


Figure 5-4 Graph of Percent Accuracy Vs No. of Hidden Nodes for 3layered Pavement: Design-case 4

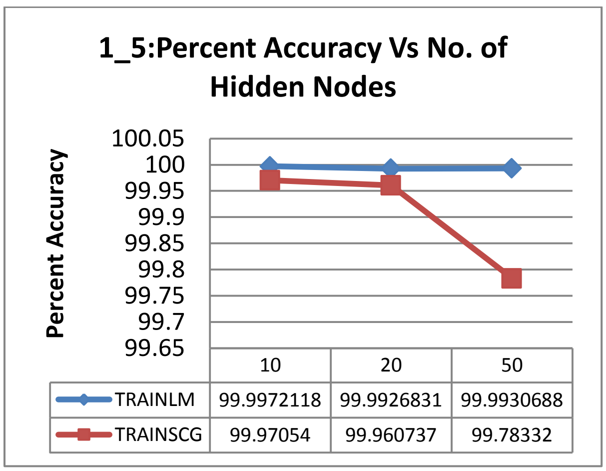


Figure 5-5 Graph of Percent Accuracy Vs No. of Hidden Nodes for 3layered Pavement: Design-case 5

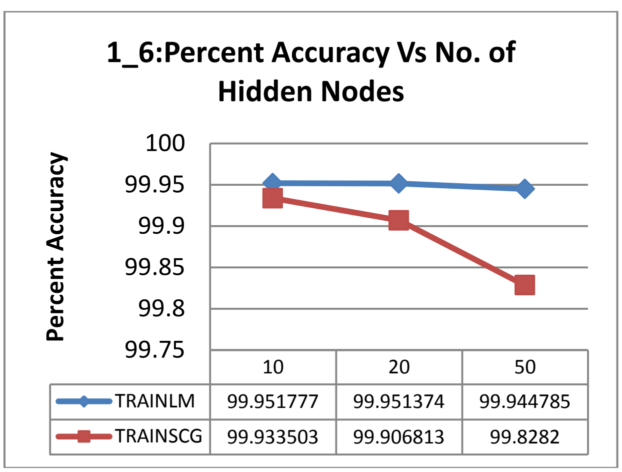


Figure 5-6 Graph of Percent Accuracy Vs No. of Hidden Nodes for 3layered Pavement: Design-case 6

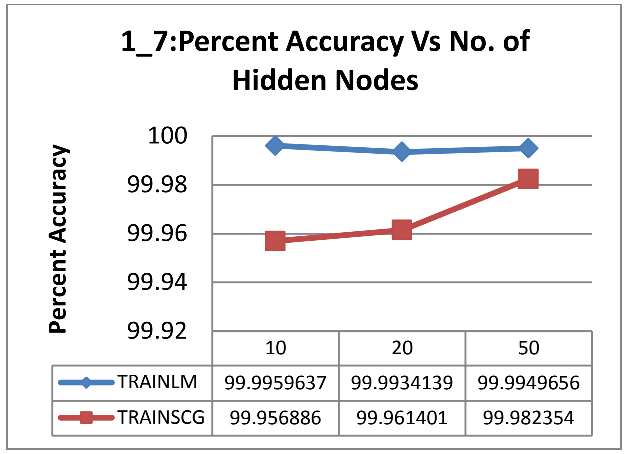


Figure 5-7 Graph of Percent Accuracy Vs No. of Hidden Nodes for 3layered Pavement: Design-case 7

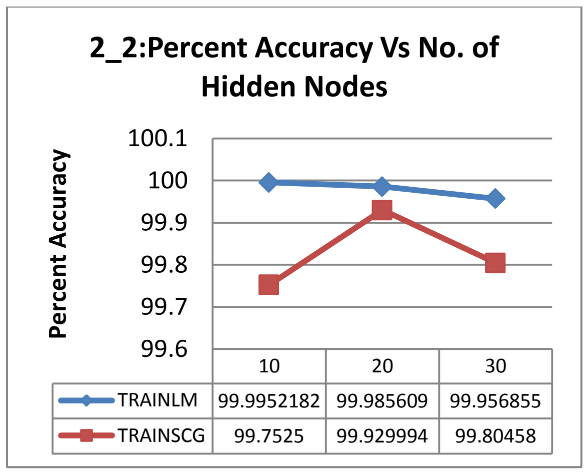


Figure 5-8 Graph of Percent Accuracy Vs No. of Hidden Nodes for 4layered Pavement: Design-case 2

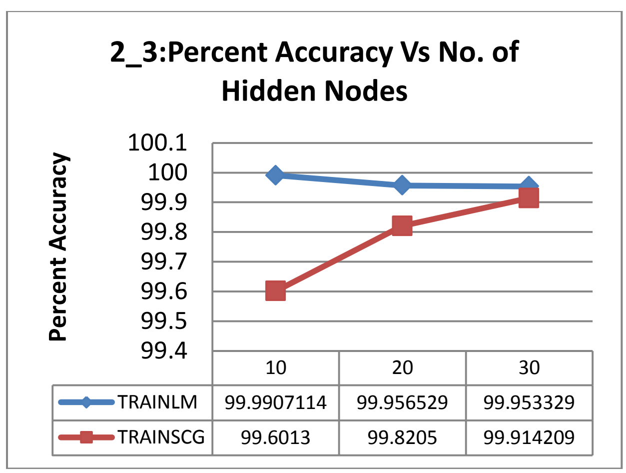


Figure 5-9 Graph of Percent Accuracy Vs No. of Hidden Nodes for 4layered Pavement: Design-case 3

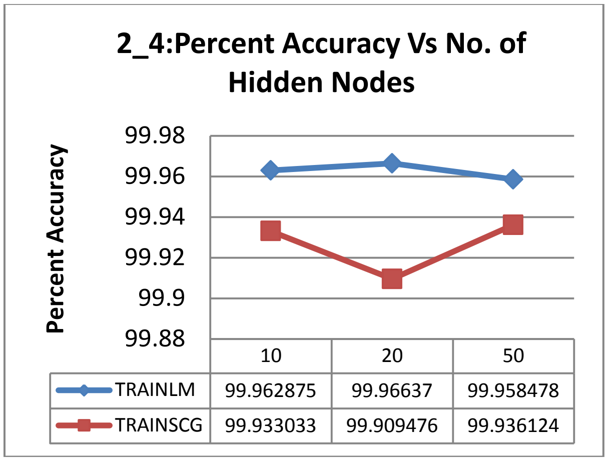


Figure 5-10 Graph of Percent Accuracy Vs No. of Hidden Nodes for 4layered Pavement: Design-case 4

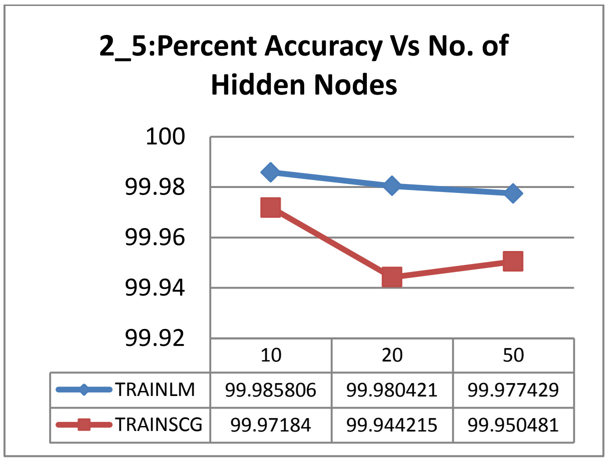


Figure 5-11 Graph of Percent Accuracy Vs No. of Hidden Nodes for 4layered Pavement: Design-case 5

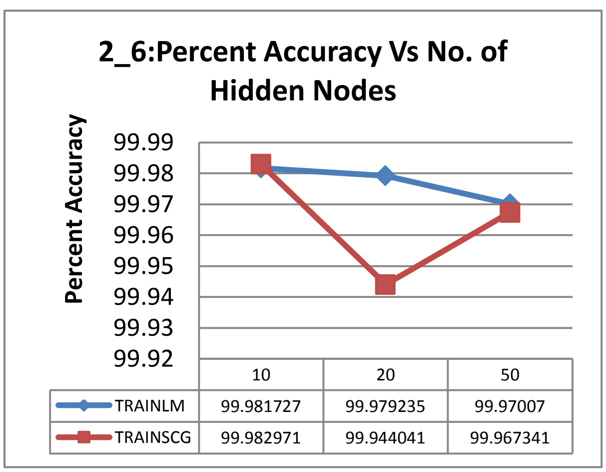


Figure 5-12 Graph of Percent Accuracy Vs No. of Hidden Nodes for 4layered Pavement: Design-case 6

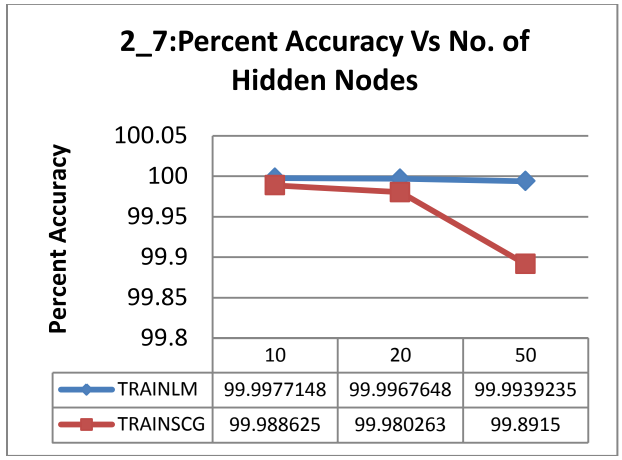


Figure 5-13 Graph of Percent Accuracy Vs No. of Hidden Nodes for 4layered Pavement: Design-case 7

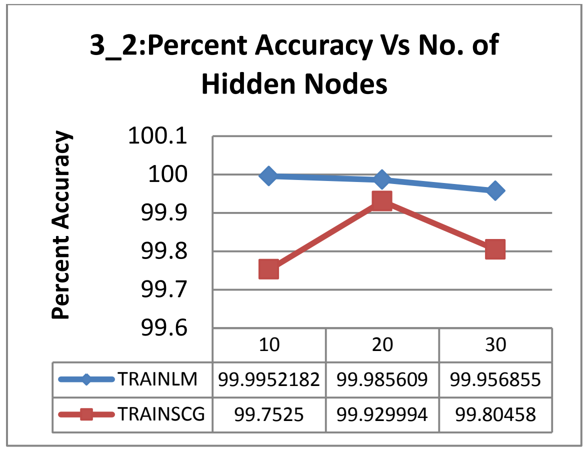


Figure 5-14 Graph of Percent Accuracy Vs No. of Hidden Nodes for 5layered Pavement: Design-case 2

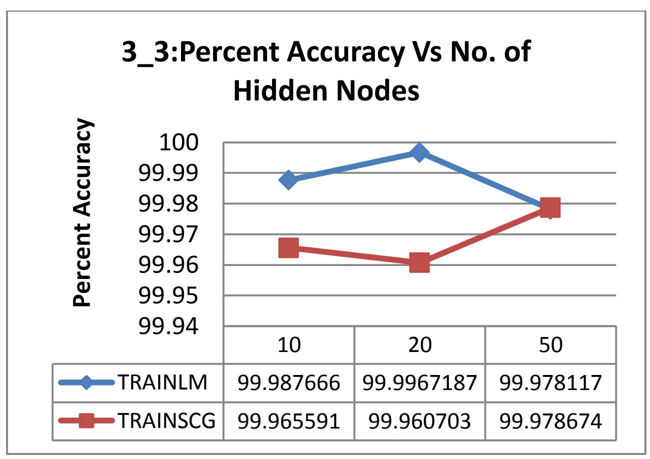


Figure 5-15 Graph of Percent Accuracy Vs No. of Hidden Nodes for 5layered Pavement: Design-case 3

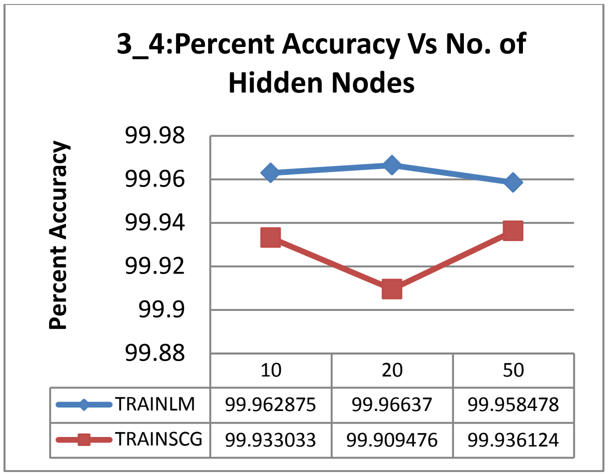


Figure 5-16 Graph of Percent Accuracy Vs No. of Hidden Nodes for 5layered Pavement: Design-case 4

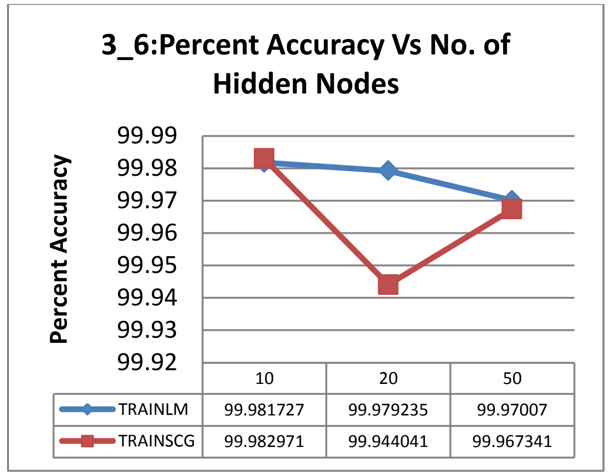


Figure 5-18 Graph of Percent Accuracy Vs No. of Hidden Nodes for 5layered Pavement: Design-case 6

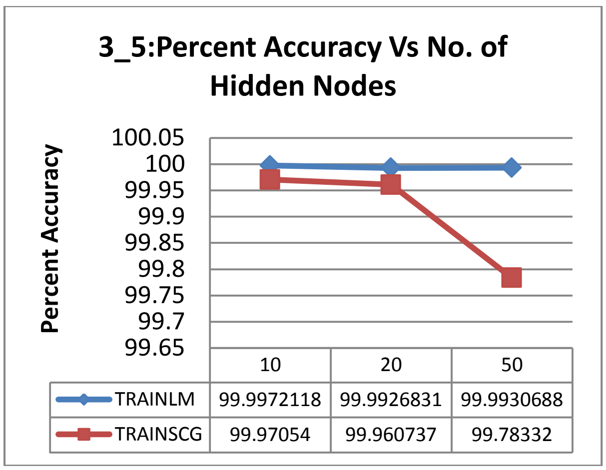


Figure 5-17 Graph of Percent Accuracy Vs No. of Hidden Nodes for 5layered Pavement: Design-case 5

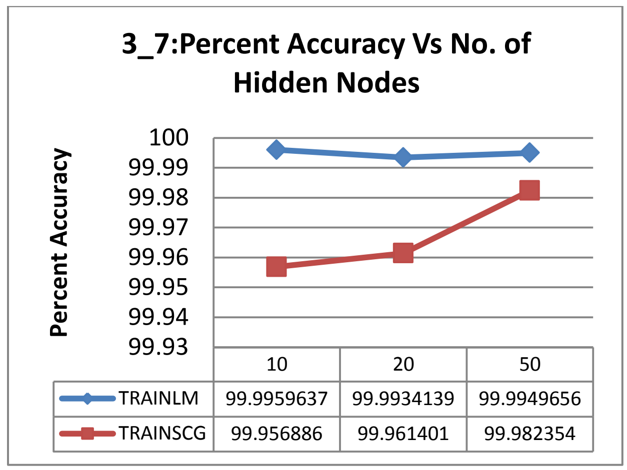


Figure 5-19 Graph of Percent Accuracy Vs No. of Hidden Nodes for 5layered Pavement: Design-case 7

Hence finally for testing process, transfer function for multilayer perception to be considered is given below.

3-LAYER DESIGN CRITERIA	TRANSFER FUNCTION
1. Considering fatigue failure in old pavement.	TRAINLM
2. Considering fatigue failure in new overlay.	TRAINLM
3. Considering fatigue failure in new overlay and old pavement.	TRAINSCG
4. Considering both rutting and fatigue failure in old pavement.	TRAINLM
5. Considering both rutting and fatigue failure in new overlay.	TRAINSCG

6. Considering both rutting and fatigue failure in new overlay and old pavement.	TRAINSCG
7. Considering rutting on the sub grade layer.	TRAINLM

Table 5-1 Transfer Function for 3layer pavement design

4-LAYER DESIGN CRITERIA	TRANSFER FUNCTION
1. Considering fatigue failure in old pavement.	TRAINLM
2. Considering fatigue failure in new overlay.	TRAINLM
3. Considering fatigue failure in new overlay and old pavement.	TRAINSCG
4. Considering both rutting and fatigue failure in old pavement.	TRAINSCG
5. Considering both rutting and fatigue failure in new overlay.	TRAINLM
6. Considering both rutting and fatigue failure in new overlay and old pavement.	TRAINSCG
7. Considering rutting on the sub grade layer.	TRAINLM

Table 5-2 Transfer function for 4 layer pavement Design

5-LAYER DESIGN CRITERIA	TRANSFER FUNCTION
1. Considering fatigue failure in old pavement.	TRAINLM
2. Considering fatigue failure in new overlay.	TRAINLM
3. Considering fatigue failure in new overlay and old pavement.	TRAINSCG
4. Considering both rutting and fatigue failure in old pavement.	TRAINLM
5. Considering both rutting and fatigue failure in new overlay.	TRAINLM
6. Considering both rutting and fatigue failure in new overlay and old pavement.	TRAINSCG
7. Considering rutting on the sub grade layer.	TRAINLM

Table 5-3 Transfer function for 5 layer pavement Design

Another analysis was done to compare neural models: MLP networks versus Radial Basis Function (RBF) networks. Results showed, MLP are more accurate than RBF networks The reason being equal importance given to all input variables in RBF networks, which is not the case with MLP networks. As such Weighting process of input variables is very much important in design of flexible pavements. Mostly between 200 to 300 no of neurons, the RBF function reaches required performance condition. This can be checked from examples of performance plot given in Appendix B.

5.4 TESTING PROCESS ON ACTUAL DATA OBTAINED FROM MORTH R-81

Once the network has been trained, the trained network should be exposed to the data sets obtained from ministry of Road Transport and Highways (Research scheme R-81) which gives falling weight deflectometer test result of pavements tested by IIT kharagpur. Therefore, design cases have been selected to represent training data sets distributed on the cross sections. Comparison is to be done between predicted overlay thickness using the trained network and the actual ones from MORTH R-81 to compute accuracy rate or reliability. If it is low, then the network is not accurately taught and other training sets are required for retraining purpose, otherwise, the network is considered consistent and ready for implementation.

In-service pavement sections

For the present study, some pavement sections in the states of West Bengal, Orissa and Jharkhand were selected for detailed investigation. Specification as per Research Scheme R-81, average daily two-way traffic on these roads ranged from 300 to 7000 commercial vehicles per day (cvpd). The granular sub-base and base of in-service pavements consisted of layers of sand, brickbat and crushed stone aggregates in varying thickness and they were treated as a single layer (granular base) for analysis. Similarly, the bituminous surfacing layer consisted mostly of bituminous macadam covered with premix carpet and seal coat. One or more layers of bituminous material placed over the granular layer at different times with varied thicknesses were also considered as one layer. Details of the selected test sections are given in Table.

Stretch	Name of the Road & State	Location Km	Carriage Way Width	Average thicknesses (mm)				Remarks
				Surface		Base		
				SDBC	B	WBM	S+CS	
	In-Service Pavements							
1	SH WB	1.820-2.000	5.5	--	45.0	279.1		Thin Pavement
2		2.895-3.000	5.5	---	45.0	282.0		
3		2.370-4.000	55	---	66.9	359.1		
4		4.625-5.000	5.5	---	63.5	340.5		
5	NH-60 WB	15.000-15.270	6.5	--	46.5	346.9		
6	NH-6 WB	123.750-124.000	7.0	---	95.0	124.8	395.5	Thick Pavement
7		125.000-125.270	7.0	---	95.0	298.0	326.5	
8		134.000-134.270	7.0	50.0	95.0	134.6	411.0	
9		134.800-134.860	7.0	50.0	94.2	130.2	421.0	
10		150.000-150.245	7.0	75.0	95.3	139.5	445.6	
11		151.000-151.305	7.0	75.0	95.4	133.8	375.3	
12		152.000-152.245	7.0	75.0	95.0	140.0	424.8	
13		153.000-153.245	7.0	75.0	95.3	131.0	345.6	
14	NH-6 JH	188.000-188.270	7.0	--	100.0	152.4	222.6	
15	NH- 6 OR	206.500-206.710	6.5	---	97.7	443.5		
16	NH-5 OR	270.00-270.300	7.0	--	87.0	424.9		
17	NH-33 JH	319.600-319.870	6.7	—	86.7	148.1	230.9	
New Pavements				BC	DBM	WMM	DL	
18	NH-6 WB	109.100	7.0	40	170	500	200	New Carriage-Way (CW)
19		112.000-112.540	7.0	40	170	500	200	
20		125.000-125.540	7.0	40	170	500	200	
21		126.000-126.540	7.0	40	170	500	200	
22		131.220-131.910	7.0	40	170	500	200	
23		131.020-131.200	7.0	--	100	217	225	Old CW

JH: Jharkhand State; WB: West Bengal State; OR: Orissa State; NH- National Highway; SH: State Highway

SDBC: Semi Dense Bituminous Concrete; DBM: Dense Bituminous Macadam; B: Bituminous; BC: Bituminous Concrete; WBM: Water Bound Macadam; S: Sand; CS: Crushed Stone; DL: Drainage Layer; WMM: Wet Mix Macadam

Table 5-4 Details of selected test sections (MORTH R-81)

The annual average rainfall in the region is about 1250mm and the pavement temperatures vary in the range from 20^{o}C to 50^{o}C. All the stretches have single carriageway carrying two-way Traffic. The average shoulder width was in the range of 1 to 2 m. It was observed at the time of investigation that some of the pavement sections were badly cracked and some were showing cracks covering nearly 20% of the pavement area. (MORTH R-81)

Back-calculated layer moduli

Deflection data obtained using the FWD was used to back-calculate effective pavement layer moduli and BACKGA program was used to compute the layer moduli. The pavement sections were considered as three layer elastic systems consisting of bituminous surfacing, granular base and subgrade. The inputs required for back-calculation analysis are the thicknesses of the first two layers and Poisson ratio values of all the three layers. Thicknesses measured by excavating test pits were used in the analysis. Since the moduli of granular bases and sub-bases are not much different, two layers were considered as a single granular layer termed as Granular Base (GB). Similarly, the thicknesses of different layers of bituminous materials were added for getting the surface course thickness. Poisson ratio values of bituminous layer, granular layer and subgrade were taken as 0.5, 0.4 and 0.4 respectively. The moduli ranges considered in the back-calculation for different situations are given in Table.

Type of Surfacing	Modulus Range (MPa)					
	Bituminous		Granular		Subgrade	
	Lower	Upper	Lower	Upper	Lower	Upper
Thin- PC	200	600	100	300	20	100
Thick-BM	200	1000	100	400	20	100
New	500	2200	100	500	20	100

Thin- PC: - Periodical application of 20mm Premix carpet (total surface thickness <75 mm)
Thick- BM: - Periodical application of bituminous macadam and Premix carpet (total surface thickness >75 mm)

Table 5-5 Modulus Range (MPa) for types of surfacing (MORTH R-81)

The surface loading considered for analysis is 40kN acting over a circular contract area with a radius of 50mm. Surface deflections measured at radial distances of 0, 300, 600, 900, 1200, 1500 and 1800 mm were the main inputs to BACKGA. These deflections were normalized to correspond to a load of 40 kN. The following GA parameters were used for the analysis.

Population Size = 60;

Maximum number of Generations = 60;

Probability of Crossover =0.74;

Probability of Mutation = 0.1 [MORTH R-81]

5.4.1 THIN OLD PAVEMENTS

Pavement sections with thickness of bituminous surfacing less than 75 mm were considered as thin pavements (Thin PC) in this investigation. Back-calculated pavement layer moduli, Sectional details, Surface deflections measured in different seasons using FWD are specified for each stretch in Appendix C. Here provided is the ANN analysis of the same using it as SAMPLE and previously obtained design database as INPUT.

When used with WINFLEX this gave the required overlay thickness which was checked with predicted value using ANN and error is calculated. Given below are some of the selected cases that were considered to check ANN's predicting capacity. There are cases where Accuracy is found to be more than 100%, it's because during actual use the thickness of overlay taken is less than code found thickness. When checked with ANN result these give greater than 100% accuracy. From sensitivity analysis, Design-case: " Both rutting failure in subgrade and fatigue failure in new overlay or old asphalt"

Transfer function: TRAINSCG.

CASE Thin_1: **for Km 1.865 to 2.000 of SH * (Salua Road) for the Deflection Data Collected during the Year 2001-02.**

Location Km	Temp (C)	Eov(MPa)	Eold(MPa)	Eb(MPa)	Esg(MPa)	Hold(mm)	Hb(mm)	ESAL	Hov(mm)	Hov PREDICTED(mm)	Accuracy(%)
2.000L	31	312.93	278.4	292.8	42.9	40	245	5000000	530.1247	473.3645378	89.29305
1.970L	31	312.93	302.1	288.8	42.3	45	264	5000000	516.9539	455.2845487	88.07063
1.940L	31	312.93	253.7	252.7	40.7	42	295	5000000	536.7101	450.6575404	83.96666
1.910L	31	312.93	248.8	227.9	40.7	43	253	5000000	559.759	467.1644197	83.45813
1.880L	31	312.93	276.3	266.4	46.2	52	279	5000000	513.6612	462.6918152	90.07724
1.865R	31	312.93	333.3	317.8	44.5	45	300	5000000	487.3196	443.2281918	90.95226
1.985R	31	312.93	336.5	256.3	43.1	46	270	5000000	523.5393	455.0231833	86.9129
1.955R	31	312.93	230.1	225.5	38.6	45	278	5000000	559.759	456.7093966	81.59036
1.925R	31	312.93	236.5	214.9	38.1	45	290	5000000	563.0517	455.2394029	80.85215
1.895R	31	312.93	320.4	269.5	39.7	52	300	5000000	510.3685	452.9436294	88.74835
2.000L	25	312.93	320.4	311.2	51	40	245	5000000	526.832	445.9600203	84.64938
1.970L	25	312.93	360.2	269.9	50.7	45	264	5000000	536.7101	448.4813899	83.5612
1.940L	25	312.93	346.2	309.9	48.2	42	295	5000000	513.6612	455.3030283	88.63878
1.910L	25	312.93	247.3	249.7	41.1	43	253	5000000	566.3444	474.372835	83.76049
1.880L	25	312.93	335.4	326.8	47.9	52	279	5000000	503.7831	450.6184391	89.44691
1.865R	25	312.93	341.3	286.6	44.1	45	300	5000000	526.832	455.6453741	86.48779
1.985R	25	312.93	321.6	291	43	46	270	5000000	533.4174	461.9540285	86.60273
1.955R	25	312.93	296.7	259.8	40	45	278	5000000	553.1736	464.1701211	83.91039
1.925R	25	312.93	283.8	306	42.7	45	290	5000000	523.5393	461.4700107	88.14429
1.895R	25	312.93	254.8	316.5	47.5	52	300	5000000	503.7831	452.9421795	89.90817
2.000L	41	312.93	332.8	316.1	53	40	245	5000000	424.7583	409.6491858	96.44289
1.910L	41	312.93	270.9	283.5	42	43	253	5000000	454.3926	424.4681603	93.41441
1.955R	41	312.93	367.7	262	45.1	45	278	5000000	428.051	417.0534505	97.43079

5-6 CASE Thin_1: ANN data for Km 1.865 to 2.000 of SH * (Salua Road) for the Deflection Data Collected during the Year 2001-02.

Avg Accuracy: 91.428%

CASE Thin_2:

for Km 2.850 to 3.000 of SH* (Salua Road) for the Deflection Data Collected during the Year 2001-02.

Location Km	Temp (C)	Eov (MPa)	Eold (MPa)	Eb (MPa)	Esg (MPa)	Hold (mm.)	Hb (mm)	ESAL	Hov (mm)	Hov PREDICTED (mm)	Accuracy (%)
3.000L	31	329.87	227.9	134.4	37.2	45	290	5000000	612.4422	598.8803706	97.78561
2.940L	31	329.87	241	197.7	40.8	45	295	5000000	566.3444	566.0938247	99.95576
2.910L	31	329.87	327.9	205.7	44.8	45	290	5000000	546.5882	541.283995	99.02958
2.940L	25	329.87	404.3	226.3	44.6	45	295	5000000	559.759	544.9175571	97.3486

2.910L	25	329.87	326.8	254.9	50.1	45	290	5000000	540.0028	525.4833337	97.31122
2.880L	25	329.87	289.2	278.3	53.8	45	270	5000000	530.1247	517.8199402	97.67889
2.850L	25	329.87	455.9	243.5	43.3	45	280	5000000	549.8809	549.3203667	99.89806
2.985R	25	329.87	308.6	232.5	55.5	45	282	5000000	549.8809	508.625111	92.49732
2.955R	25	329.87	405.3	271.2	51.8	45	270	5000000	530.1247	514.5074945	97.05405
2.895R	25	329.87	387	231.2	43.6	45	290	5000000	559.759	553.1407086	98.81765
3.000L	41	329.87	296.7	231.3	44.8	45	290	5000000	451.0999	447.7585232	99.25928
2.970L	41	329.87	333.3	276.1	44.9	45	279	5000000	431.3437	427.8491979	99.18986
2.940L	41	329.87	384.9	284.4	54	45	295	5000000	405.0021	404.9861363	99.99606
2.880L	41	329.87	375.2	259.8	52.8	45	270	5000000	421.4656	420.9473756	99.87704
2.850L	41	329.87	461.2	298.9	50.2	45	280	5000000	398.4167	397.3088509	99.72194
2.985R	41	329.87	338.7	308.7	57.4	45	282	5000000	405.0021	402.7085277	99.43369
2.925R	41	329.87	301	231.2	51.6	45	280	5000000	447.8072	439.5353365	98.15281
2.895R	41	329.87	395.4	245.8	52	45	290	5000000	421.4656	419.7968146	99.60405

5-7 CASE Thin_2: ANN data for Km 2.850 to 3.000 of SH* (Salua Road) for the Deflection Data Collected during the Year 2001-02.

Avg.Accuracy:99.583%

Case Thin_3:

for Km 4.625 to 5.000 of SH (IIT Bypass) for the Deflection Data Collected during the Year 2001-02.

Location Km	Temp (C)	Eov (MPa)	Eold (MPa)	Eb (MPa)	Esg (MPa)	Hold (mm)	Hb (mm)	ESAL	Hov (mm)	Hov PREDICTED (mm)	Accuracy (%)
5L	31	308.47	246.2	189	39	65	300	5000000	553.1736	501.8115004	90.71501
4.970L	31	308.47	216.1	191.6	41.9	65	250	5000000	563.0517	502.4126166	89.23028
4.940L	31	308.47	287	151.6	44.1	65	300	5000000	559.759	507.1280092	90.59756
4.910L	31	308.47	239.7	180.2	48.2	60	390	5000000	536.7101	504.6410464	94.02488
4.695L	31	308.47	265.5	182.4	50.8	63	360	5000000	530.1247	490.6132866	92.54677
4.925R	31	308.47	297.8	163.4	41.7	67	395	5000000	540.0028	498.725505	92.3561
4.9R	31	308.47	264.3	184.9	42.3	60	320	5000000	549.8809	507.5506819	92.30193
4.705R	31	308.47	233.3	193.4	40.8	60	345	5000000	546.5882	509.4084729	93.19785
4.645R	31	308.47	261.2	173.1	40.4	65	395	5000000	543.2955	504.5831208	92.87453
4.625R	31	308.47	231.1	157.7	39.6	65	350	5000000	566.3444	513.6313554	90.6924
5L	25	308.47	262.3	194.7	41.8	65	300	5000000	572.9298	500.1308245	87.29356
4.970L	25	308.47	290.3	240.9	54.6	65	250	5000000	540.0028	479.1519223	88.73138
4.940L	25	308.47	337.6	214.5	55.6	65	300	5000000	540.0028	478.790504	88.66445
4.910L	25	308.47	387	190.7	58.8	60	390	5000000	540.0028	491.098148	90.94363
4.695L	25	308.47	329	214.9	61.1	63	360	5000000	526.832	478.3732172	90.80185
4.925R	25	308.47	387.2	192.5	53.6	67	395	5000000	536.7101	482.5067326	89.90081
4.9R	25	308.47	290.3	235.1	54	60	320	5000000	533.4174	486.0155778	91.11356
4.705R	25	308.47	241.9	215.3	49.2	60	345	5000000	546.5882	505.4560198	92.47474
4.645R	25	308.47	234.4	209.6	50.2	65	395	5000000	536.7101	499.5972026	93.08511
4.625R	25	308.47	305.3	252.7	53.5	65	350	5000000	513.6612	471.8363183	91.8575
5L	41	308.47	373.1	227.2	45	65	300	5000000	401.7094	396.7964893	98.777

4.970L	41	308.47	298.9	236	55.1	65	250	5000000	411.5875	401.4183113	97.52928
4.940L	41	308.47	395.6	203	58.1	65	300	5000000	395.124	386.6609507	97.85813
4.910L	41	308.47	411.8	189	60.7	60	390	5000000	395.124	383.5635296	97.07422
4.695L	41	308.47	368.8	202.2	66.5	63	360	5000000	391.8313	372.3786021	95.03544
4.925R	41	308.47	391.3	186.8	55.7	67	395	5000000	391.8313	378.6495023	96.63585
4.9R	41	308.47	392.4	236.5	54.5	60	320	5000000	391.8313	381.6827018	97.40996
4.705R	41	308.47	286.6	206.1	50.7	60	345	5000000	421.4656	407.2239297	96.62092
4.645R	41	308.47	370.9	219.7	57.2	65	395	5000000	381.9532	372.2135667	97.45005
4.625R	41	308.47	358	232.9	57.7	65	350	5000000	385.2459	369.9210455	96.02206

5-8 **Case Thin_3:ANN data for Km 4.625 to 5.000 of SH (IIT Bypass) for the Deflection Data Collected during the Year 2001-02.**

Avg.Accuracy:93.127%

CASE Thin_4:
for Km 3.370 to 4.000 of SH (IIT Bypass) for the Deflection Data Collected during the Year 2001-02

Location Km	Temp (C)	Eov (MPa)	Eold (MPa)	Eb(MPa)	Esg (MPa)	Hold (mm)	Hb (mm)	ESAL	Hov (mm)	Hov PREDICTED (mm)	Accuracy (%)
4.000L	31	464.51	406.7	155.9	42.5	68	285	5000000	530.1247	496.2128286	93.60304
3.985R	31	464.51	330.8	144.3	43.6	67	282	5000000	546.5882	506.0797607	92.58886
3.970L	31	464.51	506.3	130.1	36.9	68	480	5000000	516.9539	488.3848731	94.47358
3.955R	31	464.51	430.6	103.7	35.7	61	390	5000000	559.759	524.2414069	93.65484
3.940L	31	464.51	380.1	101.7	37.5	60	390	5000000	566.3444	531.4542801	93.83942
3.925R	31	464.51	460.3	100.9	43.3	65	370	5000000	546.5882	503.8281945	92.17692
3.910L	31	464.51	439.1	139.3	41.3	67	280	5000000	536.7101	502.3148555	93.59147
3.710R	31	464.51	390.3	124.4	43.7	66	280	5000000	549.8809	510.601368	92.85672
3.695L	31	464.51	400.1	130.7	49.1	70	400	5000000	523.5393	481.7938832	92.02631
3.680R	31	464.51	444.2	100.7	46.9	67	390	5000000	540.0028	497.8678695	92.19728
3.665L	31	464.51	380.7	131.2	44	64	280	5000000	546.5882	511.3904677	93.56047
3.650R	31	464.51	360.7	126.5	44.4	68	290	5000000	546.5882	507.9300259	92.92737
3.400L	31	464.51	340.2	114.1	68.4	70	430	5000000	526.832	465.5351464	88.36501
3.385R	31	464.51	330.5	115.5	61.9	70	420	5000000	530.1247	475.9308149	89.77714
3.370L	31	464.51	490.7	116.3	72	72	420	5000000	497.1977	437.3461034	87.96221
4.000L	25	464.51	412.5	165.7	52.7	68	285	5000000	553.1736	492.5401053	89.03898
3.985R	25	464.51	400.8	146.7	66.6	67	282	5000000	553.1736	486.4891655	87.94512
3.970L	25	464.51	453.3	130.7	41	68	480	5000000	566.3444	520.8481981	91.96669
3.955R	25	464.51	454.7	119.7	41.3	61	390	5000000	586.1006	527.0051136	89.91718
3.940L	25	464.51	438.3	159.2	43	60	390	5000000	559.759	516.9116847	92.3454
3.925R	25	464.51	360.6	121.4	40.3	65	370	5000000	592.686	524.9581656	88.57273
3.910L	25	464.51	599.4	120.1	56	67	280	5000000	563.0517	492.257148	87.42663
3.710R	25	464.51	607	156.7	49	66	280	5000000	549.8809	489.7148312	89.05835
3.695L	25	464.51	505.2	177.3	66	70	400	5000000	513.6612	454.5319284	88.48866
3.680R	25	464.51	451.6	206.4	52.9	67	390	5000000	513.6612	472.4640718	91.97971
3.665L	25	464.51	533.3	146.1	46.1	64	280	5000000	566.3444	500.5779422	88.38755

3.650R	25	464.51	547.5	125.4	63.2	68	290	5000000	556.4663	485.3492042	87.21987
3.400L	25	464.51	643.1	269.5	73.5	70	430	5000000	447.8072	398.5322169	88.99638
3.385R	25	464.51	341.2	215.4	75	70	420	5000000	493.905	443.0285184	89.69914
3.370L	25	464.51	560	274.1	80	72	420	5000000	444.5145	391.8814265	88.15942
4.000L	41	464.51	412	189.8	61.7	68	285	5000000	395.124	387.1366956	97.97853
3.985R	41	464.51	404.4	161.1	69.7	67	282	5000000	401.7094	389.2200996	96.89096
3.970L	41	464.51	488	120.2	56.5	68	480	5000000	401.7094	391.655995	97.49734
3.955R	41	464.51	460.1	119	45.8	61	390	5000000	431.3437	417.0680278	96.69042
3.940L	41	464.51	549.5	145.1	53	60	390	5000000	401.7094	389.0892107	96.85838
3.925R	41	464.51	368.4	117.9	43	65	370	5000000	444.5145	426.8814748	96.03319
3.910L	41	464.51	501.1	170.2	65.5	67	280	5000000	388.5386	385.5842253	99.23962
3.710R	41	464.51	477.1	150.3	56	66	280	5000000	408.2948	406.3044146	99.51251
3.695L	41	464.51	594	189.2	77.3	70	400	5000000	352.3189	330.1705548	93.71355
3.680R	41	464.51	464.7	179.5	65.9	67	390	5000000	378.6605	361.8807867	95.56867
3.665L	41	464.51	454.6	168.9	48.7	64	280	5000000	414.8802	409.9455999	98.8106
3.650R	41	464.51	646.2	161.5	72.4	68	290	5000000	365.4897	362.5524529	99.19635
3.400L	41	464.51	627.1	271.3	77.1	70	430	5000000	316.0992	309.2812492	97.8431
3.385R	41	464.51	635	272.1	65.2	70	420	5000000	322.6846	315.1739329	97.67244
3.370L	41	464.51	649.5	269.4	88.5	72	420	5000000	309.5138	298.7257169	96.51451

5-9 CASE Thin_4: ANN data for Km 3.370 to 4.000 of SH (IIT Bypass) for the Deflection Data Collected during the Year 2001-02

Avg.Accuracy:92.9516%

CASE Thin_5:
for Km 15.000 to 15.270 of NH-60 for the Deflection Data Collected during the Year 2001-02

Location Km	Temp (C)	Eov (MPa)	Eold (MPa)	Eb (MPa)	Esg (MPa)	Hold (mm)	Hb (mm)	ESAL	Hov (mm)	Hov PREDICTED (mm)	Accuracy (%)
15.090R	31	321.27	302	172.9	49.5	61	373	5000000	533.4174	521.479065	97.76191
15.120L	31	321.27	298	145.8	40.9	50	373	5000000	572.9298	572.7875235	99.97517
15.150R	31	321.27	357.1	146	39.7	49	311	5000000	572.9298	567.3541474	99.02682
15.180L	31	321.27	243.8	150.1	35.1	42	291	5000000	605.8568	604.1041327	99.71071
15.240L	31	321.27	328.3	141.9	39.5	35	340	5000000	592.686	579.6577884	97.80184
15.270R	31	321.27	268.4	139.4	40.1	36	318	5000000	602.5641	596.3714095	98.97228
15.090R	25	321.27	301.2	134.7	44.6	61	373	5000000	605.8568	599.9107949	99.01858
15.180L	25	321.27	485.9	145	42.6	42	291	5000000	609.1495	602.1567007	98.85204
15.240L	25	321.27	305	141.4	46.5	35	340	5000000	615.7349	471.1958493	76.52577
15.270R	25	321.27	411	156	41.1	36	318	5000000	609.1495	555.7219941	91.22916
15.030R	41	321.27	276.2	182.3	43.5	50	370	5000000	457.6853	453.4063378	99.06509
15.060L	41	321.27	216.2	289.4	46.3	50	375	5000000	414.8802	413.5405411	99.6771
15.090R	41	321.27	282.1	189.2	45.4	61	373	5000000	431.3437	420.5125406	97.48897
15.120L	41	321.27	203.1	129.3	50.6	50	373	5000000	493.905	484.8574459	98.16816
15.150R	41	321.27	228.5	167.5	46.6	49	311	5000000	480.7342	468.8628235	97.53057
15.180L	41	321.27	234.8	169.2	47.1	42	291	5000000	493.905	486.9194667	98.58565
15.210R	41	321.27	321.2	153.9	48.5	41	334	5000000	480.7342	478.4751486	99.53008

15.240L	41	321.27	436.9	149.3	51.6	35	340	5000000	474.1488	470.282895	99.18466
15.270R	41	321.27	468.3	154.8	43.2	36	318	5000000	477.4415	472.393318	98.94266

5-10 CASE Thin_5: ANN data for Km 15.000 to 15.270 of NH-60 for the Deflection Data Collected during the Year 2001-02

Avg.Accuracy:98.898%

5.4.2 THICK OLD PAVEMENTS

The pavement sections considered in the present study also included a number of thick pavements bituminous layer thickness with more than 75 mm. The bituminous surface consisted of repeated application of bituminous macadam (BM) and premix carpet over a period of time. Sectional details of the pavements, Deflection data and backcalculated layer moduli are provided at Appedix C. Thickness of bituminous layer thicknesses ranged from 90 to 200 mm. A few sections had bituminous concrete overlay of 50 mm thickness. The thicknesses granular base varied from 300 to 690 mm. Results from ANN analysis is given below for each Section.

When used with WINFLEX this gave the required overlay thickness which was checked with predicted value using ANN and error is calculated.

From sensitivity analysis,

Design-case: " only fatigue cracking in new overlay or old asphalt and rutting failure in subgrade"

Transfer function: TRAINLM.

Since the thickness of the granular layer is very large (585 mm), Road Research R-56 [1999] has clearly established that only fatigue criteria will be applicable to such cases and number of standard axle load for causing 20 mm rutting is very large.

CASE Thick_1:

for Km 123.795 to 124.000 of NH-6 for the Deflection Data collected during the Year 2000-01 (Kumar, 2001)

Location Km	Temp (C)	Eov (MPa)	Eold (MPa)	Eb(MPa)	Esg (MPa)	Hold (mm)	Hb (mm)	ESAL	Hov (mm)	Hov PREDICTED (mm)	Accuracy (%)
124.000L	31	761.97	721.6	209	55	95	134.9716	10000000	510.3685	495.7778296	97.14115
123.995R	31	761.97	742	160.7	49.5	95	130.925	10000000	523.5393	506.0729502	96.66379
123.950L	31	761.97	640.5	180.4	46.3	95	119.061	10000000	540.0028	500.6662731	92.7155
123.945R	31	761.97	841.9	164.4	41.6	95	145.9509	10000000	523.5393	503.6910726	96.20884
123.900L	31	761.97	719.4	159.4	36	95	127.4587	10000000	549.8809	498.4779016	90.65198
123.895R	31	761.97	802.2	162.8	39.6	95	139.9609	10000000	530.1247	499.1641357	94.15976
123.850L	31	761.97	854.4	200.2	41.9	95	152.9562	10000000	510.3685	495.5176829	97.09018
123.845R	31	761.97	866.5	137.5	36.7	95	145.6173	10000000	533.4174	507.0363565	95.05433
123.800L	31	761.97	500.4	210.5	32.1	95	103.1069	10000000	582.8079	467.8207394	80.27014
123.795R	31	761.97	761.6	170.4	35.5	95	135.1746	10000000	543.2955	493.7858636	90.88716
124.000L	25	761.97	956.2	242.9	56.1	95	173.9141	10000000	526.832	459.7753823	87.27173

123.995R	25	761.97	856.2	252.9	55.2	95	160.8607	10000000	536.7101	454.0580636	84.60025
123.950L	25	761.97	690.2	233.7	54.1	95	133.9998	10000000	563.0517	458.4101341	81.41528
123.945R	25	761.97	995.4	380.6	72.2	95	199.5711	10000000	464.2707	446.1210969	96.09073
123.900L	25	761.97	954.8	399.3	63.1	95	196.3948	10000000	470.8561	433.5689367	92.08099
123.895R	25	761.97	745.3	251.3	58.4	95	144.544	10000000	546.5882	460.5460368	84.25832
123.850L	25	761.97	790.4	260.5	63.2	95	152.4196	10000000	530.1247	460.0519328	86.78183
123.845R	25	761.97	968.5	396.5	80	95	197.9757	10000000	457.6853	441.4487754	96.45247
123.800L	25	761.97	893.9	393.1	51.2	95	186.6628	10000000	493.905	417.6567769	84.56217
123.795R	25	761.97	543.5	384.2	55	95	134.551	10000000	536.7101	425.8619884	79.34674

5-11 CASE Thick_1: ANN data for Km 123.795 to 124.000 of NH-6 for the Deflection Data collected during the Year 2000-01 (Kumar, 2001)

Avg.Accuracy:99.27%

CASE Thick_2:
for Km 125.000 to 125.270 of NH-6 for the Deflection Data collected during Summer Season of the Year 2001-02.

Location Km	Temp (C)	Eov (MPa)	Eold (MPa)	Eb (MPa)	Esg (MPa)	Hold (mm)	Hb (mm)	ESAL	Hov (mm)	Hov PREDICTED (mm)	Accuracy (%)
125.000L	31	478.7	603.7	268.5	66.4	100	614.9977	10000000	498.6617	428.051	85.83996
125.030R	31	478.7	595.9	247	62.4	100	619.9977	10000000	494.5416	441.2218	89.21834
125.060L	31	478.7	359.3	291.2	62.2	100	624.9977	10000000	478.7385	451.0999	94.22678
125.090R	31	478.7	488.4	296.3	63.8	100	619.9977	10000000	477.1178	428.051	89.716
125.120L	31	478.7	355.4	295.5	59.8	100	619.9977	10000000	478.8325	447.8072	93.52064
125.150R	31	478.7	618.5	276.7	63.2	100	639.9976	10000000	483.9381	421.4656	87.09082
125.180L	31	478.7	450.2	268.1	62.6	100	624.9977	10000000	489.7616	447.8072	91.4337
125.210R	31	478.7	532.3	230.6	59	100	624.9977	10000000	494.9887	460.978	93.12899
125.240L	31	478.7	375.9	278.7	60.3	100	629.9977	10000000	486.3162	454.3926	93.43562
125.270R	31	478.7	407.2	284.5	59.7	100	624.9977	10000000	481.0252	447.8072	93.09434

5-12 CASE Thick_2: ANN data for Km 125.000 to 125.270 of NH-6 for the Deflection Data collected during Summer Season of the Year 2001-02.

Avg.Accuracy:91.07%

CASE Thick_3:
for Km 134.000 to 134.270 of NH-6 for the Deflection Data collected during the Year 2001-2002.

Location Km	Temp (C)	Eov (MPa)	Eold (MPa)	Eb (MPa)	Esg (MPa)	Hold (mm)	Hb (mm)	ESAL	Hov (mm)	Hov PREDICTED (mm)	Accuracy (%)
134.000L	31	363.26	311.8	156.8	50.5	145	544.998	10000000	514.0629	516.9539	100.5624
134.030R	31	363.26	352.8	172.4	54.6	145	539.998	10000000	506.974	490.6123	96.77267
134.120L	31	363.26	329	148.9	53.5	145	559.9979	10000000	516.8361	513.6612	99.38571
134.180L	31	363.26	280.6	178	49	145	544.998	10000000	509.191	507.0758	99.58459
134.210R	31	363.26	372	169.2	35.3	145	534.998	10000000	480.969	510.3685	106.1126
134.240L	31	363.26	308.6	152.9	51.2	145	539.998	10000000	516.1497	520.2466	100.7937
134.000L	41	363.26	447.3	217.1	66.6	145	544.998	10000000	420.2466	322.6846	76.78458

134.030R	41	363.26	424.7	196	71.5	145	539.998	10000000	453.4039	332.5627	73.348
134.060L	41	363.26	402.1	230.7	60.6	145	544.998	10000000	395.8248	325.9773	82.35395
134.090R	41	363.26	348.3	204.4	53.6	145	537.998	10000000	388.4469	352.3189	90.69937
134.120L	41	363.26	353.7	197.3	60.1	145	559.9979	10000000	409.5879	349.0262	85.214
134.150R	41	363.26	304.6	209.8	62.3	145	557.9979	10000000	420.377	352.3189	83.81022
134.180L	41	363.26	376.3	265.1	64.2	145	544.998	10000000	400.1394	319.3919	79.82016
134.210R	41	363.26	365.5	215.8	68.4	145	534.998	10000000	436.2103	335.8554	76.99392
134.240L	41	363.26	396.7	250.1	64	145	539.998	10000000	402.6937	322.6846	80.13152
134.270R	41	363.26	364.5	223.7	65.1	145	549.998	10000000	418.1329	332.5627	79.53517

5-13 CASE Thick_3: ANN Data for Km 134.000 to 134.270 of NH-6 for the Deflection Data collected during the Year 2001-2002.

Avg.Accuracy:99.85%

CASE Thick_4: for Km 150.000 to 150.245 of NH-6 for the Deflection Data collected during the Year 2001-02

Location Km	Temp (C)	Eov (MPa)	Eold (MPa)	Eb (MPa)	Esg (MPa)	Hold (mm)	Hb (mm)	ESAL	Hov (mm)	Hov PREDICTED(mm)	Accuracy (%)
150.000L	31	366.87	254.8	203.9	44.9	170	705.9974	10000000	460.978	451.0436558	97.84494
150.060L	31	366.87	404.6	192.9	44.9	170	544.998	10000000	447.8072	446.0985014	99.61843
150.120L	31	366.87	384.9	162.1	48	170	534.998	10000000	474.1488	468.0078975	98.70486
150.240L	31	366.87	377.4	169.2	47.4	170	534.998	10000000	470.8561	466.2313766	99.01781
150.005R	31	366.87	375.2	162.1	47.6	170	534.998	10000000	474.1488	469.4604235	99.0112
150.065R	31	366.87	393.5	139.5	44.8	170	684.9975	10000000	480.7342	465.9809495	96.9311
150.245R	31	366.87	266.6	134.4	47.9	170	534.998	10000000	523.5393	478.1953157	91.33895
150.000L	25	366.87	401	198.6	73.1	170	705.9974	10000000	484.0269	371.8436037	76.82292
150.060L	25	366.87	375.2	239.1	57.4	170	544.998	10000000	474.1488	419.4227519	88.45804
150.120L	25	366.87	329	169.9	55.8	170	534.998	10000000	540.0028	399.8810961	74.05167
150.180L	25	366.87	375.2	190.7	54.9	170	574.9979	10000000	513.6612	416.7294829	81.12925
150.240L	25	366.87	448.3	210.9	56.9	170	534.998	10000000	487.3196	434.7305134	89.2085
150.005R	25	366.87	489.2	328.4	63.1	170	534.998	10000000	401.7094	374.0588003	93.11677
150.065R	25	366.87	375.2	322.7	57.4	170	684.9975	10000000	405.0021	389.4219748	96.15308
150.125R	25	366.87	376.3	218.4	63.6	173	664.9975	10000000	474.1488	382.6871245	80.71034
150.185R	25	366.87	423.6	274.7	70	170	534.998	10000000	437.9291	387.6045624	88.50852
150.245R	25	366.87	387.2	248.9	59.4	170	534.998	10000000	464.2707	417.4523487	89.91572

5-14 CASE Thick_4: ANN data for Km 150.000 to 150.245 of NH-6 for the Deflection Data collected during the Year 2001-02

Avg.Accuracy:98.25%

CASE Thick_5:
for Km 151.000 to 151.245 of NH-6 for the Deflection Data collected during the Year 2001-02

Location Km	Temp (C)	Eov (MPa)	Eold (MPa)	Eb (MPa)	Esg (MPa)	Hold (mm)	Hb (mm)	ESAL	Hov (mm)	Hov PREDICTED (mm)	Accuracy (%)
151.005R	31	400.13	501.3	201.6	46.6	170	469.9983	10000000	431.3437	410.3830613	95.14062
151.060L	31	400.13	306.1	264.6	32.6	170	545.998	10000000	434.6364	434.5238559	99.97411
151.065R	31	400.13	424	236	75.4	170	539.998	10000000	401.7094	391.4814664	97.4539

151.180L	31	400.13	361.2	189.5	48	170	489.9982	10000000	464.2707	462.7589019	99.67437
151.185R	31	400.13	408.2	265.3	47.2	173	474.9982	10000000	408.2948	404.7379867	99.12886
151.240L	31	400.13	324.7	202.6	74	170	534.998	10000000	441.2218	415.7991649	94.23813
151.000L	25	400.13	422.5	246.1	70	170	489.9982	10000000	460.978	400.290612	86.83508
151.005R	25	400.13	358	246.6	57.4	170	469.9983	10000000	477.4415	426.0573216	89.2376
151.060L	25	400.13	374.1	212.3	64.1	171	545.998	10000000	487.3196	402.8976887	82.67627
151.065R	25	400.13	375.2	204.3	57.4	170	539.998	10000000	500.4904	418.5411919	83.62622
151.120L	25	400.13	412.9	317	73.7	170	469.9983	10000000	418.1729	370.6786837	88.64245
151.125R	25	400.13	346.2	201.7	57.3	170	459.9983	10000000	513.6612	421.1626429	81.9923
151.180L	25	400.13	339.7	190.9	54.3	170	489.9982	10000000	523.5393	418.3471965	79.90751
151.185R	25	400.13	324.7	271.7	57.6	173	474.9982	10000000	460.978	416.7215611	90.39945
151.240L	25	400.13	340.8	218.9	63.6	170	534.998	10000000	490.6123	399.6192902	81.45317
151.245R	25	400.13	375.2	270.3	63.3	170	614.9977	10000000	441.2218	394.307613	89.36721

5-15 CASE Thick_5: ANN data for Km 151.000 to 151.245 of NH-6 for the Deflection Data collected during the Year 2001-02

Avg.Accuracy:97.73%

CASE Thick_7:
for Km 152.000 to 152.245 of NH-6 for the Deflection Data collected during the Year 2001-02

Location Km	Cross section	Temp (C)	Eov (MPa)	Eold (MPa)	Eb (MPa)	Esg (MPa)	Hold (mm)	Hb (mm)	ESAL	Hov (mm)	Hov PREDICTED (mm)	Accuracy (%)
152.000L	3	31	397.83	372	199.1	47.8	170	546.998	10000000	455.3433	447.8072	98.34497
152.240L	3	31	397.83	410.7	181	59.1	170	544.998	10000000	459.1589	444.5145	96.81061
152.005R	3	31	397.83	308.6	201.7	49.4	170	543.998	10000000	467.2065	460.978	98.66685
152.065R	3	31	397.83	423.6	205.2	44.7	170	591.9978	10000000	433.9455	431.3437	99.40043
152.125R	3	31	397.83	381.7	227.2	55.7	170	516.9981	10000000	440.9743	424.7583	96.32268
152.185R	3	31	397.83	350.5	186.3	44.9	173	549.998	10000000	459.085	460.978	100.4123
152.245R	3	31	397.83	358	198.6	46	170	577.9979	10000000	457.0038	451.0999	98.70812
152.000L	3	41	397.83	451.6	371.9	88.1	170	546.998	10000000	458.5471	237.0744	51.70121
152.060L	3	41	397.83	511.8	274.7	82.5	170	529.998	10000000	450.3846	263.416	58.48691
152.120L	3	41	397.83	405.3	201.3	57.4	170	627.9977	10000000	355.6898	309.5138	87.0179
152.180L	3	41	397.83	382.7	203.5	58.6	170	529.998	10000000	363.1026	316.0992	87.05505
152.240L	3	41	397.83	478.4	240	83.5	170	544.998	10000000	454.293	279.8795	61.60771
152.005R	3	41	397.83	411.8	185.9	67.2	170	543.998	10000000	397.7194	312.8065	78.65006
152.065R	3	41	397.83	361.2	223.3	55	170	591.9978	10000000	344.8566	312.8065	90.70626
152.125R	3	41	397.83	470.4	287.3	79.1	170	516.9981	10000000	428.9684	266.7087	62.17443
152.185R	3	41	397.83	430.1	273.9	76	173	549.998	10000000	407.6098	273.2941	67.04796
152.245R	3	41	397.83	431.1	260.7	73	170	577.9979	10000000	401.3656	279.8795	69.73182

5-16 CASE Thick_7: ANN data for Km 152.000 to 152.245 of NH-6 for the Deflection Data collected during the Year 2001-02

Avg.Accuracy:96.327%

CASE Thick_8:
for Km 153.000 to 153.245 on NH-6 for the Deflection Data collected during the Year 2001-02

Location Km	Temp (C)	Eov (MPa)	Eold (MPa)	Eb (MPa)	Esg (MPa)	Hold (mm)	Hb (mm)	ESAL	Hov (mm)	Hov PREDICTED (mm)	Accuracy (%)
153.000L	31	505.47	814.5	204.8	57.5	170	557.9979	10000000	394.8484	368.7824	93.39848
153.060L	31	505.47	967.1	262	53.9	170	429.9984	10000000	385.895	342.4408	88.73937
153.240L	31	505.47	986.3	182.2	47.3	170	457.9983	10000000	405.8143	375.3678	92.49743
153.005R	31	505.47	543.5	163.8	37.9	170	574.9979	10000000	412.8309	444.5145	107.6747
153.065R	31	505.47	543.5	164.7	38.7	170	416.9984	10000000	413.8214	457.6853	110.5997
153.245R	31	505.47	388.3	167.8	45	170	444.9983	10000000	459.3886	477.4415	103.9298
153.000L	41	505.47	546.3	394.8	80	170	557.9979	10000000	461.6679	223.9036	48.49885
153.060L	41	505.47	672.3	398.3	79.9	170	429.9984	10000000	488.8166	220.6109	45.13163
153.120L	41	505.47	307.5	240.9	79.9	170	538.998	10000000	434.8789	309.5138	71.17241
153.180L	41	505.47	325.3	223.1	73.9	170	434.9984	10000000	419.2442	319.3919	76.18279
153.240L	41	505.47	317.1	334.6	79.6	170	457.9983	10000000	405.9187	283.1722	69.76082
153.005R	41	505.47	395.7	356.7	79.9	170	574.9979	10000000	418.4076	250.2452	59.80896
153.065R	41	505.47	388.3	205.5	79.6	170	416.9984	10000000	445.9874	312.8065	70.13798
153.125R	41	505.47	534.7	272.1	79.5	170	443.9983	10000000	433.9585	270.0014	62.21825
153.185R	41	505.47	453.3	244.3	79.9	173	464.9983	10000000	430.5286	286.4649	66.53795
153.245R	41	505.47	323.6	265.9	78	170	444.9983	10000000	419.8183	306.2211	72.94134

5-17 CASE Thick_8: ANN data for Km 153.000 to 153.245 on NH-6 for the Deflection Data collected during the Year 2001-02

Avg.Accuracy: 98.15%

5.4.3 EVALUATION OF COLD-MIX RECYCLED PAVEMENT SECTION

One pavement section on NH-6 was considered for the structural evaluation before and after cold-mix recycling was done using cement and bitumen emulsion. Using cold mix recycling process, it is possible to rectify asphalt-aging problems and also to improve the structural condition of the pavement. In the case of high traffic volume it is normally necessary to go for overlay of one or more layers of hot-mixed asphalt on top of the recycled layer to further strengthen the pavement to serve for the design life.

The pavement section Km 131.000 on NH-6 consisted of different layers of bituminous material with a thickness of about 200 mm. Water Bound Macadam (WBM), morum, boulders and sand formed the base course. The deflection data collected before recycling and after 7 and 28 days of recycling was used to compute the effective layer moduli. Table gives the moduli values for the recycled section.

Layer Moduli of Recycled Pavement Stretch

Location (Km)	Backcalculated Layer Moduli (MPa)											
	Just before Recycling			RMSE (%)	7 days after Recycling			RMSE (%)	28 days after Recycling			RMSE (%)
	Bitu	GB	Sub		Bitu	GB	Sub		Bitu	GB	Sub	
131.020	305.5	233.7	55.2	0.99	410.2	240.3	58.8	3.29	481.8	254.2	55.9	0.87
131.040	323.9	241.2	60.4	0.73	434.1	223.1	60.2	1.03	549.6	253.1	56.6	3.22
131.060	482.0	249.7	56.3	0.92	680.4	233.7	57.2	2.45	807.6	228.7	55.7	1.45
131.080	304.8	235.7	56.4	0.97	458.1	248.9	58.6	1.28	781.6	219.6	55.9	1.65
131.105	358.8	253.3	60.5	0.47	631.2	222.3	60.1	3.96	472.6	236.9	55.8	0.88
131.120	486.8	217.3	58.6	0.64	518.9	238.4	58.9	0.77	517.6	227.1	58.8	0.68
131.140	343.8	257.1	60.3	0.69	456.7	244.3	59.1	0.79	494.3	239.2	60.4	0.51
131.160	306.8	216.9	51.9	0.91	538.1	245.1	56.9	0.79	575.1	223.2	58.2	1.10
131.180	368.4	237.6	54.0	0.95	366.3	221.6	54.9	0.92	489.5	234.1	59.6	1.12
131.200	607.2	214.8	60.0	0.64	456.7	213.7	61.5	0.91	408.1	266.1	58.7	0.47
Maximum	607.2	257.1	60.5	0.99	680.4	248.9	61.5	3.96	807.6	266.1	60.4	3.22
Minimum	304.8	214.8	51.9	0.47	366.3	213.7	54.9	0.78	408.1	219.6	55.7	0.47
Average	388.8	235.7	57.4	0.79	495.1	233.1	58.6	1.62	557.8	238.2	57.6	1.20
Std .Dev	102.3	15.4	3.1	0.18	98.4	12.13	1.8	1.18	132.7	15.1	1.78	0.32
COV (%)	26.3	6.5	5.4		19.8	5.2	3.1		23.7	6.3	3.1	

Table 5-18 back calculated layer Moduli Range for Recycled Pavement Stretch (MORTH R-81)

The average modulus of the existing bituminous layer before recycling is about 390 Mpa indicating low strength. This is due to the presence of excessive fatigue cracks on the surface of the bituminous layer. The modulus value of the recycled layer has been found to increase to about 560 MPa. Recycling resulted in significant increase in strength as evident even from the 7-day modulus value.

Location Km	Time	Temp (C)	Eov (MPa)	Eold (MPa)	Eb (MPa)	Esg (MPa)	Hold (mm)	Hb (mm)	ESAL	Hov (mm)	Hov PREDICTED (mm)	Accuracy (%)
131.02	Just before	31	388.8	305.5	233.7	55.2	100	419.9984	10000000	547.0096197	520.2466	95.1074
131.04	Just before	31	388.8	323.9	241.2	60.4	100	419.9984	10000000	542.4303544	507.0758	93.48219
131.06	Just before	31	388.8	482	249.7	56.3	100	429.9984	10000000	492.8714292	480.7342	97.53745
131.08	Just before	31	388.8	304.8	235.7	56.4	100	434.9984	10000000	546.6215301	513.6612	93.97017
131.105	Just before	31	388.8	358.8	253.3	60.5	100	419.9984	10000000	527.0786628	493.905	93.70613
131.12	Just before	31	388.8	486.8	217.3	58.6	100	424.9984	10000000	512.9343757	493.905	96.2901
131.14	Just before	31	388.8	343.8	257.1	60.3	100	424.9984	10000000	527.368038	493.905	93.65471
131.16	Just before	31	388.8	306.8	216.9	51.9	100	419.9984	10000000	550.9865597	530.1247	96.21373
131.18	Just before	31	388.8	368.4	237.6	54	100	419.9984	10000000	523.6555755	507.0758	96.83384
131.2	Just before	31	388.8	607.2	214.8	60	100	429.9984	10000000	499.4741662	477.4415	95.58883
131.02	7 days after	31	495.1	410.2	240.3	58.8	100	419.9984	10000000	520.1448889	474.1488	91.15706
131.04	7 days after	31	495.1	434.1	223.1	60.2	100	419.9984	10000000	526.8653689	480.7342	91.24422
131.06	7 days after	31	495.1	680.4	233.7	57.2	100	429.9984	10000000	481.9705705	444.5145	92.22856
131.08	7 days after	31	495.1	458.1	248.9	58.6	100	434.9984	10000000	504.1205216	464.2707	92.09518
131.105	7 days after	31	495.1	631.2	222.3	60.1	100	419.9984	10000000	495.6919594	454.3926	91.66834
131.12	7 days after	31	495.1	518.9	238.4	58.9	100	424.9984	10000000	498.5944653	460.978	92.4555
131.14	7 days after	31	495.1	456.7	244.3	59.1	100	424.9984	10000000	508.0240887	467.5634	92.03568
131.16	7 days after	31	495.1	538.1	245.1	56.9	100	419.9984	10000000	487.2803022	457.6853	93.92649
131.18	7 days after	31	495.1	366.3	221.6	54.9	100	419.9984	10000000	535.7262846	493.905	92.19354
131.2	7 days after	31	495.1	456.7	213.7	61.5	100	429.9984	10000000	529.5742406	480.7342	90.77749

131.02	28 days after	31	557.8	481.8	254.2	55.9	100	419.9984	10000000	489.9635006	474.1488	96.77227
131.04	28 days after	31	557.8	549.6	253.1	56.6	100	419.9984	10000000	482.1606963	467.5634	96.97252
131.06	28 days after	31	557.8	807.6	228.7	55.7	100	429.9984	10000000	480.6663328	447.8072	93.16384
131.08	28 days after	31	557.8	781.6	219.6	55.9	100	434.9984	10000000	483.7300523	454.3926	93.93516
131.105	28 days after	31	557.8	472.6	236.9	55.8	100	419.9984	10000000	499.2203865	484.0269	96.95656
131.12	28 days after	31	557.8	517.6	227.1	58.8	100	424.9984	10000000	503.0110882	480.7342	95.57129
131.14	28 days after	31	557.8	494.3	239.2	60.4	100	424.9984	10000000	506.7643347	477.4415	94.21371
131.16	28 days after	31	557.8	575.1	223.2	58.2	100	419.9984	10000000	494.2090389	477.4415	96.6072
131.18	28 days after	31	557.8	489.5	234.1	59.6	100	419.9984	10000000	507.592131	480.7342	94.70876
131.2	28 days after	31	557.8	408.1	266.1	58.7	100	429.9984	10000000	506.0157852	477.4415	94.35308

5-19 ANN data for Cold-mix Recycled pavement Stretch

Avg.Accuracy:
Just before recycling:95.238%
7days after recycling:91.978%
28days after recycling:95.325%

5.4.4 EFFECT OF TEMPERATURE ON PAVEMENT LAYER MODULI

Pavement layer moduli, especially that of bituminous layer varies with pavement temperature. In order to study the effect on pavement temperature on the back-calculated moduli, FWD tests were conducted on a few sections. The pavement temperature was recorded at a depth of 25 mm during testing at each location. The deflections were measured at temperatures of 25, 30, 35 and 40°C.

The back-calculated layer moduli values are shown in the Table.

Layer Moduli for the Deflection Data collected on KM 112. 000 to 112.540 of NH-6 at Different Pavement Temperatures

Location (Km)	Backcalculated Layer Moduli (MPa) at Average Pavement Temperature of 41° C			RMSE (%)	Backcalculated Layer Moduli (MPa) Average Pavement Temperature of 35° C			RMSE (%)	Backcalculated Layer Moduli (MPa) Average Pavement Temperature of 31.5° C			RMSE (%)
	Bitu	GB	Sub		Bitu	GB	Sub		Bitu	GB	Sub	
112.000	755.1	289.2	67.1	4.01	1037.5	285.7	64.9	0.53	1390.2	291.3	62.9	0.258
112.060	885.4	282.9	68.9	4.08	1016.4	303.3	66.8	0.40	1448.5	276.6	60.6	0.494
112.120	775.1	313.1	66.4	3.49	1038.7	287.3	65.1	0.51	1415.5	273.2	62.4	0.597
112.180	778.6	313.1	65.6	3.58	1049.8	281.4	63.1	0.82	1489.4	282.3	63.2	0.626
112.240	823.5	317.4	68.1	3.57	1003.5	297.9	63.8	0.47	1219.2	282.2	62.3	0.635
112.300	861.8	295.8	65.3	4.06	1031.2	301.7	66.4	0.54	1498.8	318.5	58.7	0.799
112.360	1031.9	285.7	69.5	4.47	1007.0	275.9	66.7	0.58	1429.6	268.5	60.2	0.881
112.420	898.2	295.5	67.5	4.05	937.2	259.1	68.9	0.64	1489.4	263.7	61.1	0.809
112.480	896.7	293.4	69.1	4.17	1221.8	235.7	66.7	0.73	1390.9	277.9	59.7	0.687
112.540	926.4	292.4	66.1	5.50	1073.1	261.9	66.9	0.38	NC	NC	NC	NC
Maximum	1031.9	317.4	69.5	5.50	1221.8	303.3	68.9	0.82	1498.8	318.5	63.2	0.88
Minimum	755.1	282.9	65.3	3.49	937.2	235.7	63.1	0.38	1219.2	263.7	58.7	0.25
Average	863.3	297.8	67.4	4.10	1041.6	278.9	65.9	0.56	1419.1	281.6	61.2	0.64
Std. Dev	3.9	12.3	1.5	0.58	72.9	21.5	1.7	0.13	85.7	16.0	1.6	0.18
COV (%)	0.45	4.1	2.2		6.9	7.7	2.5	23.2	6.0	5.7	2.6	

NC: Data not collected

table 5-20 Layer Moduli for the Deflection Data collected on KM 112. 000 to 112.540 of NH-6 at Different Pavement Temperatures (MORTH R-81)

Location Km	Temp (C)	Eov (MPa)	Eold (MPa)	Eb (MPa)	Esg (MPa)	Hold (mm)	Hb (mm)	ESAL	Hov (mm)	Hov PREDICTED (mm)	Accuracy (%)
112	41	863.3	755.1	289.2	67.1	95	554.9979	10000000	329.27	234.291946	71.15496
112.06	41	863.3	885.4	282.9	68.9	95	542.998	10000000	319.3919	186.7475134	58.46971
112.12	41	863.3	775.1	313.1	66.4	95	549.998	10000000	319.3919	230.5773873	72.19262
112.18	41	863.3	778.6	313.1	65.6	95	539.998	10000000	322.6846	233.131469	72.24747
112.24	41	863.3	823.5	317.4	68.1	95	539.998	10000000	316.0992	210.9650918	66.74015
112.3	41	863.3	861.8	295.8	65.3	95	559.9979	10000000	319.3919	200.3087934	62.71568
112.36	41	863.3	1031.9	285.7	69.5	95	564.9979	10000000	306.2211	124.8815405	40.78149
112.42	41	863.3	898.2	295.5	67.5	95	409.9985	10000000	325.9773	199.5391869	61.2126
112.48	41	863.3	896.7	293.4	69.1	95	419.9984	10000000	325.9773	194.7504955	59.74358
112.54	41	863.3	926.4	292.4	66.1	95	519.9981	10000000	316.0992	181.9450528	57.55948
112	35	1041.6	1037.5	285.7	64.9	95	554.9979	10000000	355.6116	212.6968201	59.81155
112.06	35	1041.6	1016.4	303.3	66.8	95	542.998	10000000	352.3189	218.0637766	61.89386
112.12	35	1041.6	1038.7	287.3	65.1	95	549.998	10000000	355.6116	213.3037151	59.98222
112.18	35	1041.6	1049.8	281.4	63.1	95	539.998	10000000	358.9043	216.8542789	60.4212
112.24	35	1041.6	1003.5	297.9	63.8	95	539.998	10000000	355.6116	228.6896952	64.30884
112.3	35	1041.6	1031.2	301.7	66.4	95	559.9979	10000000	352.3189	210.1219163	59.63969
112.36	35	1041.6	1007	275.9	66.7	95	564.9979	10000000	362.197	215.4433847	59.48238
112.42	35	1041.6	937.2	259.1	68.9	95	409.9985	10000000	381.9532	246.258318	64.47343
112.48	35	1041.6	1221.8	235.7	66.7	95	419.9984	10000000	368.7824	190.3942516	51.6278
112.54	35	1041.6	1073.1	261.9	66.9	95	519.9981	10000000	362.197	207.5476852	57.30243
112	31.5	1419.1	1390.2	291.3	62.9	95	554.9979	10000000	362.197	187.1289499	51.66496
112.06	31.5	1419.1	1448.5	276.6	60.6	95	542.998	10000000	365.4897	182.929748	50.05059
112.12	31.5	1419.1	1415.5	273.2	62.4	95	549.998	10000000	365.4897	185.3988355	50.72615
112.18	31.5	1419.1	1489.4	282.3	63.2	95	539.998	10000000	358.9043	178.8396314	49.82934
112.24	31.5	1419.1	1219.2	282.2	62.3	95	539.998	10000000	375.3678	226.5703795	60.35957
112.3	31.5	1419.1	1498.8	318.5	58.7	95	559.9979	10000000	349.0262	173.8897123	49.82139
112.36	31.5	1419.1	1429.6	268.5	60.2	95	564.9979	10000000	365.4897	180.8847945	49.49108
112.42	31.5	1419.1	1489.4	263.7	61.1	95	409.9985	10000000	375.3678	218.6251191	58.24291
112.48	31.5	1419.1	1390.9	277.9	59.7	95	419.9984	10000000	378.6605	232.9813633	61.52777

5-21 ANN data for effect of temperature on pavement section

It can be seen that effect of temperature doesn't give very good accuracy. Reason being IRC analysis doesn't take any linear or nonlinear relationship for temperature variation other than correction for deflection values measured at pavement temperature other than 35°C should be 0.01mm for each degree change from standard temperature. While in use a linear relationship is taken into account which is given earlier in theory section.

Finally, results indicate that the trained network of overlay thickness will give a quite close approximation to the calculated values for the pavement cross sections. Accordingly, ANN can be effectively used to determine the overlay thickness.

SUMMARY

ANN has recently received lots of attention and it has also contributed in a wide variety of applications in civil engineering as well as in other fields. In this study, ANN-based pavement overlay design tool has been developed using MATLAB software. Several network architectures were trained using training data sets developed by M-E overlay design program, one being used in this study being WINFLEX (obtained through internet given in reference).

Trained network has been tested using different in field testing data sets to determine the predicted overlay thickness, while the calculated ones have been determined by the WINFLEX program. The calculated and the predicted overlay thicknesses have been compared together to come up with the accuracy rate. From the sensitivity analysis and testing process using actual data from MORTH Research scheme R-81, the average accuracy is found to be between 90 to 100% for almost all the design-cases. Other than thin and thick pavements, Cold mixed pavement section was also used to check for usability of ANN. Effect of temperature variation was also checked for and the accuracy of it was low due to unavailability of any linear relationship for temperature variation in code. Finally, the results indicate that the ANN technology can be used to predict the pavement overlay thickness with high accuracy for both thin and thick pavements.

.

FUTURE SCOPE OF WORK

This ANN based Pavement design Procedure can be implemented in a program to get overlay thickness as IRC based overlay thickness design procedure is yet to see dedicated software for the same. Also dedicated MATLAB toolbox may be designed for the same.

Effect of temperature can be predicted using Linear relationship where regression linear equation solving method may be used.

The pavement overlay design method can be extended to other types of overlay design similar to cold mix based pavement design etc. whose straight calculation is unavailable in IRC.

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Appendix-A

A-1 EXAMPLE OF WINFLEX OUTPUT FILE

WINFLEX 2006's REPORT FOR MULTIPLE LOCATIONS 05-May-14 9:51:00 AM
FILE:

DESCRIPTION: ONLY FATIGUE

1. SUMMARY OF INPUT DATA

1.1 TRAFFIC DATA

DESIGN WHEEL LOAD (lb) = 4500
DESIGN DUAL TIRE SPACING (in.) = 13.5
TIRE PRESSURE (psi) = 80
DESIGN FUTURE TRAFFIC (ESALs) = 10,000,000
FATIGUE SHIFT FACTOR FOR NEW ASPHALT = 1
FATIGUE SHIFT FACTOR FOR OLD ASPHALT = 1

1.2 SEASONAL VARIATION DATA

SUBGRADE VARIATION

No.	WINTER	SPRING
1	0.79	0.90
2	0.80	0.90
3	0.81	0.91
4	0.81	0.91
5	0.82	0.91
6	0.81	0.91
7	0.81	0.91
8	0.82	0.91
9	0.83	0.92
10	0.82	0.91
11	0.79	0.90
12	0.79	0.90
13	0.79	0.90
14	0.78	0.89
15	0.78	0.89
16	0.79	0.90
17	0.78	0.89
18	0.77	0.89
19	0.80	0.90
20	0.79	0.90
21	0.78	0.89
22	0.79	0.90
23	0.78	0.89
24	0.79	0.90
25	0.77	0.89
26	0.77	0.89
27	0.77	0.89
28	0.78	0.89

29	0.80	0.90
30	0.78	0.89

	WINTER	SPRING	SUMMER	FALL
	------	------	------	----
SUBGRADE VARIATION			1.00	1.00
BASE/SBASE VARIATION	0.65	0.85	1.00	1.00
TRAFFIC VARIATION	1.00	1.00	1.00	1.00
TEMPERATURE VARIATION(F)	44.00	58.00	66.00	36.00
PERIOD (MONTHS)	3.00	1.00	4.00	4.00

1.3 PAVEMENT DATA

CLIMATIC ZONE : 3 (Idaho Zone)

	POISSON'S RATION
OLD AC LAYER	0.40
BASE LAYER	0.40
SUBGRADE	0.50

SUBGRADE TYPE: LINEAR

BASE TYPE: LINEAR

MODULI AND THICKNESSES DATA (From ETF FILE:THICK OLD Km 123.795 to 124.000 of NH-6.etf)

****

No.	MILE POST	TEMP. (F)	E1(ksi)	E2(ksi)
-----	---------	-----------	-------	-------
1	124	87.8	104.6592043	30.3128793
2	123.995	87.8	107.6179734	23.30755839
3	123.95	87.8	92.89664685	26.16480108
4	123.945	87.8	122.1072396	23.84419788
5	123.9	87.8	104.3401214	23.11900938
6	123.895	87.8	116.3492429	23.61213756
7	123.85	87.8	123.9202109	29.03654754
8	123.845	87.8	125.6751671	19.94268375
9	123.8	87.8	72.57686508	30.53043585
10	123.795	87.8	110.4607123	24.71442408
11	124	77	138.6850487	35.22965733
12	123.995	77	124.1812787	36.68003433
13	123.95	77	100.1050205	33.89531049
14	123.945	77	144.3705266	55.20134862
15	123.9	77	138.481996	57.91355361
16	123.895	77	108.0965978	36.44797401
17	123.85	77	114.6377981	37.78232085
18	123.845	77	140.4690125	57.50744805
19	123.8	77	129.6492	57.01431987
20	123.795	77	78.82798995	55.72348434
21	124	105.8	75.05700975	45.12122847
22	123.995	105.8	140.0629069	29.51517195
23	123.95	105.8	95.21725005	42.75711396
24	123.945	105.8	89.0531478	36.23041746
25	123.9	105.8	91.93939803	29.66020965
26	123.895	105.8	115.8561148	46.80366579
27	123.85	105.8	117.5965672	45.77389812
28	123.845	105.8	95.04320481	40.36399191

29	123.8	105.8	94.21648992	24.71442408
30	123.795	105.8	123.6011279	31.64722614

****

MODULI AND THICKNESSES DATA (Cont'd)

****

No.	E3(ksi)	H1(in.)	H2(in.)
-----	-------	-------	-------
1	7.9770735	2.8851595	4.099115677
2	7.17936615	2.8851595	3.976221493
3	6.71524551	2.8851595	3.61590808
4	6.03356832	2.8851595	4.432559752
5	5.2213572	2.8851595	3.870946547
6	5.74349292	2.8851595	4.250641122
7	6.07707963	2.8851595	4.645312049
8	5.32288359	2.8851595	4.422428691
9	4.65571017	2.8851595	3.13137904
10	5.14883835	2.8851595	4.10528241
11	8.13661497	2.8851595	5.281807015
12	8.00608104	2.8851595	4.885374164
13	7.84653957	2.8851595	4.069603453
14	10.47172194	2.8851595	6.061017807
15	9.15187887	2.8851595	5.96455248
16	8.47020168	2.8851595	4.389833101
17	9.16638264	2.8851595	4.629014254
18	11.603016	2.8851595	6.012564903
19	7.42593024	2.8851595	5.668989766
20	7.9770735	2.8851595	4.086341729
21	10.08012015	2.8851595	3.649825113
22	8.62974315	2.8851595	5.150103212
23	9.47096181	2.8851595	4.190295232
24	9.05035248	2.8851595	3.804874405
25	10.63126341	2.8851595	3.692992245
26	11.12439159	2.8851595	4.939993801
27	11.08088028	2.8851595	4.961577368
28	9.47096181	2.8851595	4.112330105
29	7.16486238	2.8851595	3.611943751
30	9.97859376	2.8851595	4.714908038

****

1.4 OVERLAY DATA

OVERLAY MODULUS(ksi) = 110.5144 AT TEMPERATURE (F) = 87.8
POISSON'S RATIO = 0.35
MINIMUM THICKNESS(in.)= 1

2. RESULTS

2.1 OVERLAY RESULTS

****

No.	OVERLAY(in.)	DAMA1	DAMA2	DAMA3	DAMA4
-----	-----------	-----	-----	-----	-----
1	15.5	0.24164	0.98129	0	0.00026
2	15.9	0.24371	0.99913	0	0.00026
3	16.4	0.26717	0.98382	0	0.00027
4	15.9	0.2222	0.97351	0	0.00029

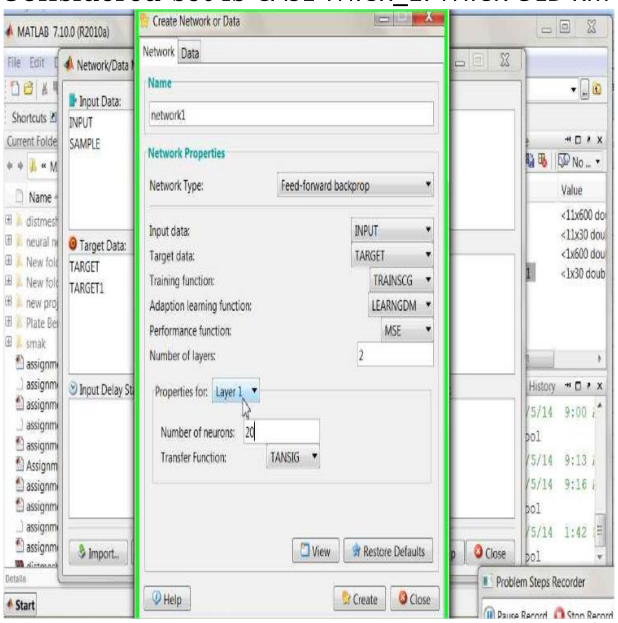
5	16.7	0.25571	0.98612	0	0.00031
6	16.1	0.23617	0.99361	0	0.0003
7	15.5	0.22238	0.99939	0	0.00033
8	16.2	0.22407	0.9819	0	0.0003
9	17.7	0.31533	0.98748	0	0.00032
10	16.5	0.24464	0.97675	0	0.00032
11	16	0.33058	0.98231	0	0.00025
12	16.3	0.35581	0.97829	0	0.00026
13	17.1	0.40021	0.98218	0	0.00025
14	14.1	0.33261	0.98845	0	0.00025
15	14.3	0.34982	0.9979	0	0.0003
16	16.6	0.38443	0.97319	0	0.00024
17	16.1	0.38174	0.99923	0	0.00024
18	13.9	0.33768	0.97081	0	0.00023
19	15	0.36725	0.99275	0	0.00034
20	16.3	0.50072	0.97425	0	0.00031
21	12.3	0.08527	0.97643	0	0.00036
22	11.3	0.0359	0.97747	0	0.00043
23	11.8	0.06325	0.9902	0	0.00041
24	12.3	0.0736	0.98372	0	0.00037
25	12.1	0.06926	0.99239	0	0.0003
26	10.8	0.04127	0.99453	0	0.00042
27	10.8	0.04047	0.99421	0	0.00042
28	11.9	0.06416	0.98525	0	0.00039
29	12.9	0.07807	0.99436	0	0.00037
30	11.3	0.0428	0.99954	0	0.00038

****

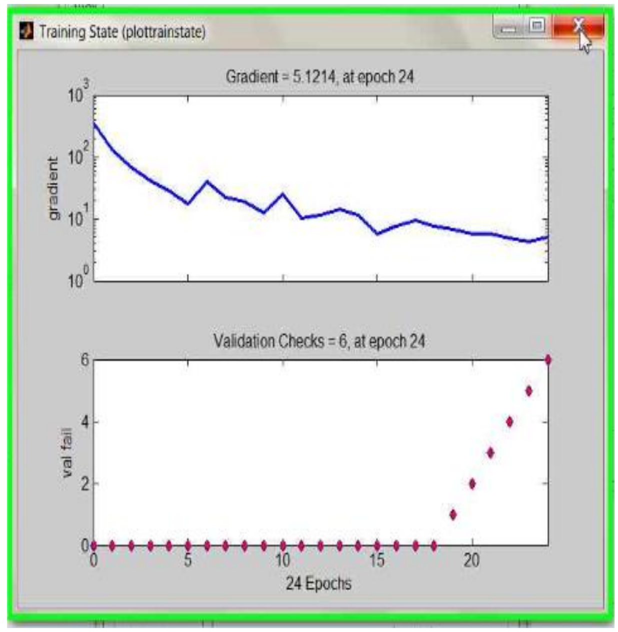
DAMA1 = FATIGUE DAMAGE ON OVERLAY
DAMA2 = FATIGUE DAMAGE ON OLD AC
DAMA3 = FATIGUE DAMAGE ON BTB
DAMA4 = RUTTING DAMAGE

A-2 EXAMPLE OF TRAINED ANN DATASET ALONG WITH PERFORMANCE, TRAINING SET AND REGRESSION PLOT

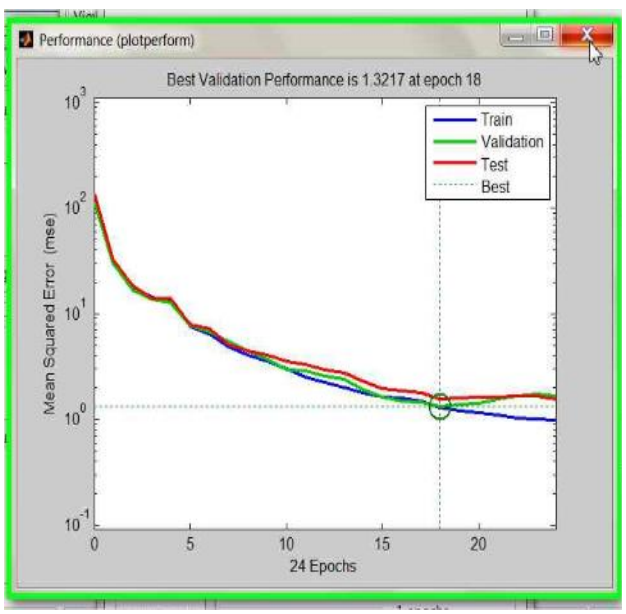
Considered set is CASE THICK_1: THICK OLD Km 123.795 to 124.000 of NH 6



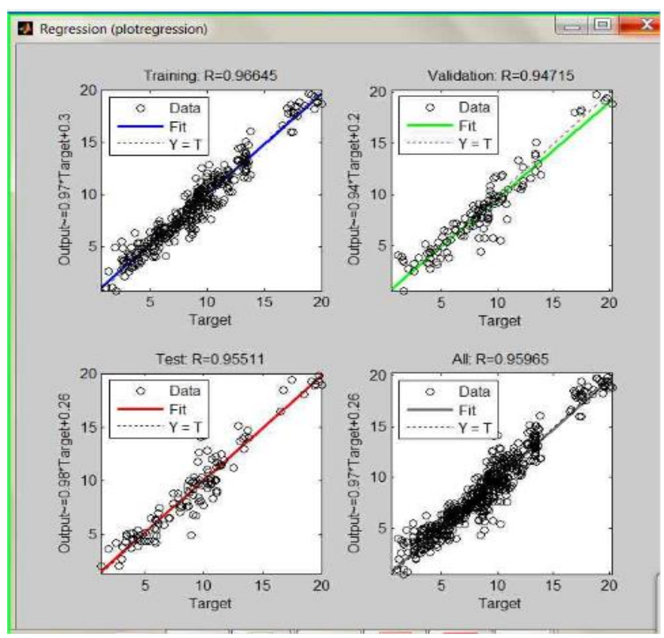
A-1 Matlab screen shot for THICK OLD Km 123.795 to 124.000 of NH 6



A-3 Training State Plot



A-2 Performance Data

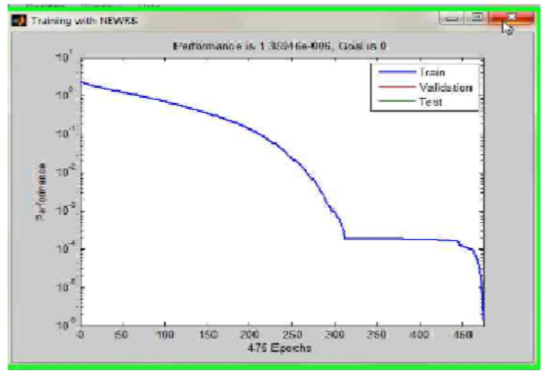


A-4 Regression Plot

Appendix B

RADIAL BASIS FUNCTION DATA UNDER ANN FOR DIFFERENT DESIGNCASES

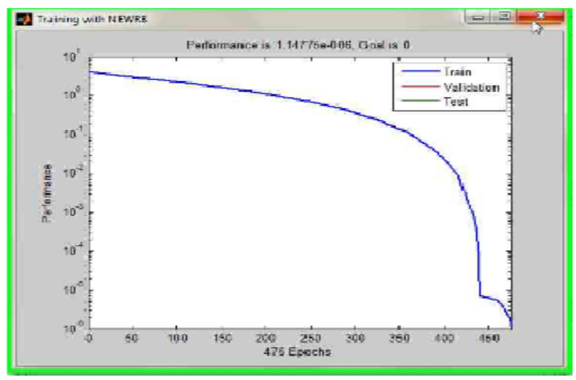
```
>> nntool
NEWRB, neurons = 0, MSE = 2.31472
NEWRB, neurons = 25, MSE = 1.61446
NEWRB, neurons = 50, MSE = 1.2246
NEWRB, neurons = 75, MSE = 0.943401
NEWRB, neurons = 100, MSE = 0.707037
NEWRB, neurons = 125, MSE = 0.503249
NEWRB, neurons = 150, MSE = 0.346788
NEWRB, neurons = 175, MSE = 0.230177
NEWRB, neurons = 200, MSE = 0.135884
NEWRB, neurons = 225, MSE = 0.065096
NEWRB, neurons = 250, MSE = 0.0230418
NEWRB, neurons = 275, MSE = 0.00610481
NEWRB, neurons = 300, MSE = 0.000872403
NEWRB, neurons = 325, MSE = 0.000182286
NEWRB, neurons = 350, MSE = 0.000181036
NEWRB, neurons = 375, MSE = 0.000179053
NEWRB, neurons = 400, MSE = 0.000175673
NEWRB, neurons = 425, MSE = 0.000168664
NEWRB, neurons = 450, MSE = 0.000119629
NEWRB, neurons = 475, MSE = 1.35946e-006
```



1_2 Radial basis data

B-1 RBF data for 3layered pavement: Design-case 2

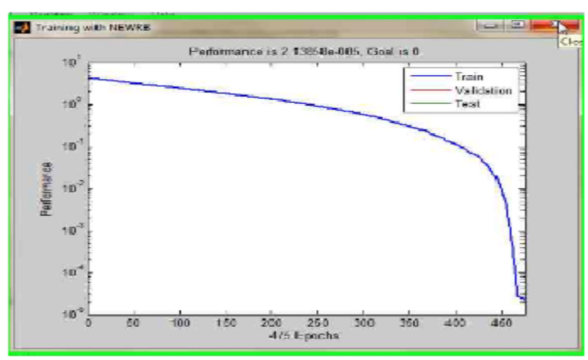
```
>> nntool
NEWRB, neurons = 0, MSE = 4.07036
NEWRB, neurons = 25, MSE = 3.41723
NEWRB, neurons = 50, MSE = 2.94892
NEWRB, neurons = 75, MSE = 2.61198
NEWRB, neurons = 100, MSE = 2.22759
NEWRB, neurons = 125, MSE = 1.89884
NEWRB, neurons = 150, MSE = 1.58132
NEWRB, neurons = 175, MSE = 1.3372
NEWRB, neurons = 200, MSE = 1.09316
NEWRB, neurons = 225, MSE = 0.861026
NEWRB, neurons = 250, MSE = 0.67744
NEWRB, neurons = 275, MSE = 0.506605
NEWRB, neurons = 300, MSE = 0.35589
NEWRB, neurons = 325, MSE = 0.234872
NEWRB, neurons = 350, MSE = 0.136176
NEWRB, neurons = 375, MSE = 0.0637759
NEWRB, neurons = 400, MSE = 0.0223349
NEWRB, neurons = 425, MSE = 0.00208338
NEWRB, neurons = 450, MSE = 6.22947e-006
NEWRB, neurons = 475, MSE = 1.14775e-006
```



1_3 Radial basis data

B-2 RBF data for 3layered Pavement: Design-case 3

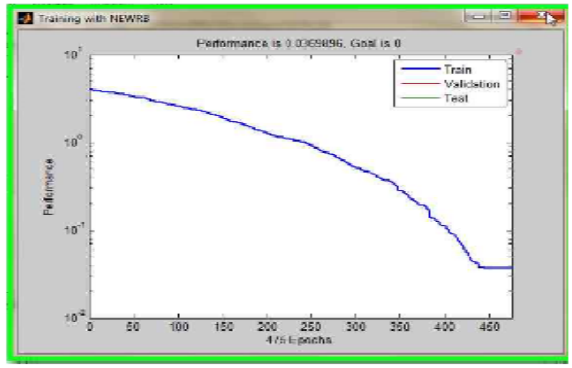
```
>> nntool
NEWRB, neurons = 0, MSE = 4.2867
NEWRB, neurons = 25, MSE = 3.69089
NEWRB, neurons = 50, MSE = 3.16133
NEWRB, neurons = 75, MSE = 2.7588
NEWRB, neurons = 100, MSE = 2.41497
NEWRB, neurons = 125, MSE = 2.10063
NEWRB, neurons = 150, MSE = 1.82221
NEWRB, neurons = 175, MSE = 1.5464
NEWRB, neurons = 200, MSE = 1.32043
NEWRB, neurons = 225, MSE = 1.10018
NEWRB, neurons = 250, MSE = 0.901498
NEWRB, neurons = 275, MSE = 0.733982
NEWRB, neurons = 300, MSE = 0.573155
NEWRB, neurons = 325, MSE = 0.429075
NEWRB, neurons = 350, MSE = 0.296881
NEWRB, neurons = 375, MSE = 0.190158
NEWRB, neurons = 400, MSE = 0.111319
NEWRB, neurons = 425, MSE = 0.0566194
NEWRB, neurons = 450, MSE = 0.00835541
NEWRB, neurons = 475, MSE = 2.13858e-005
```



1_5 Radial basis data

B-3 RBF data for 3layered Pavement: Design-case 5

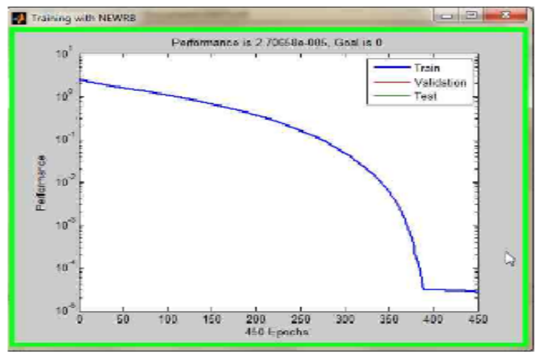
```
>> nntool
NEWRB, neurons = 0, MSE = 3.99335
NEWRB, neurons = 25, MSE = 3.68794
NEWRB, neurons = 50, MSE = 3.32611
NEWRB, neurons = 75, MSE = 2.90869
NEWRB, neurons = 100, MSE = 2.57775
NEWRB, neurons = 125, MSE = 2.2967
NEWRB, neurons = 150, MSE = 1.90515
NEWRB, neurons = 175, MSE = 1.57703
NEWRB, neurons = 200, MSE = 1.27172
NEWRB, neurons = 225, MSE = 1.09126
NEWRB, neurons = 250, MSE = 0.923987
NEWRB, neurons = 275, MSE = 0.722622
NEWRB, neurons = 300, MSE = 0.514013
NEWRB, neurons = 325, MSE = 0.408264
NEWRB, neurons = 350, MSE = 0.278047
NEWRB, neurons = 375, MSE = 0.19214
NEWRB, neurons = 400, MSE = 0.111153
NEWRB, neurons = 425, MSE = 0.0562626
NEWRB, neurons = 450, MSE = 0.0370274
NEWRB, neurons = 475, MSE = 0.0369896
```



1_6 Radial basis data

B-4 RBF data for 3layered Pavement: Design-case 6

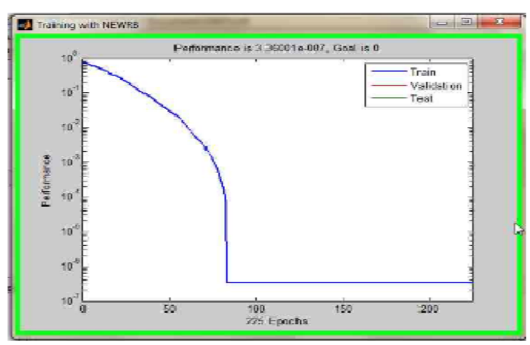
```
>> nntool
NEWRB, neurons = 0, MSE = 2.54071
NEWRB, neurons = 25, MSE = 1.92286
NEWRB, neurons = 50, MSE = 1.58518
NEWRB, neurons = 75, MSE = 1.31608
NEWRB, neurons = 100, MSE = 1.06813
NEWRB, neurons = 125, MSE = 0.851243
NEWRB, neurons = 150, MSE = 0.660884
NEWRB, neurons = 175, MSE = 0.500366
NEWRB, neurons = 200, MSE = 0.365743
NEWRB, neurons = 225, MSE = 0.250207
NEWRB, neurons = 250, MSE = 0.15864
NEWRB, neurons = 275, MSE = 0.0952681
NEWRB, neurons = 300, MSE = 0.0474625
NEWRB, neurons = 325, MSE = 0.0201179
NEWRB, neurons = 350, MSE = 0.00606796
NEWRB, neurons = 375, MSE = 0.000565966
NEWRB, neurons = 400, MSE = 3.01049e-005
NEWRB, neurons = 425, MSE = 2.93029e-005
NEWRB, neurons = 450, MSE = 2.70658e-005
NEWRB, neurons = 475, MSE = 7.33428e-006
```



1_7 Radial basis data

B-5 RBF data for 3 layered Pavement: Design-case 7

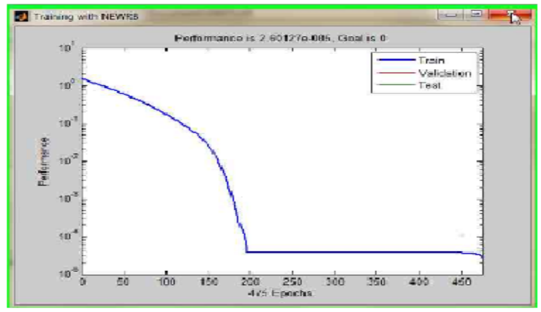
```
>> nntool
NEWRB, neurons = 0, MSE = 0.787468
NEWRB, neurons = 25, MSE = 0.209971
NEWRB, neurons = 50, MSE = 0.0304573
NEWRB, neurons = 75, MSE = 0.00106338
NEWRB, neurons = 100, MSE = 3.36557e-007
NEWRB, neurons = 125, MSE = 3.36478e-007
NEWRB, neurons = 150, MSE = 3.36386e-007
NEWRB, neurons = 175, MSE = 3.36279e-007
NEWRB, neurons = 200, MSE = 3.36153e-007
NEWRB, neurons = 225, MSE = 3.36001e-007
NEWRB, neurons = 250, MSE = 3.35817e-007
NEWRB, neurons = 275, MSE = 3.35586e-007
NEWRB, neurons = 300, MSE = 3.3529e-007
NEWRB, neurons = 325, MSE = 3.34895e-007
NEWRB, neurons = 350, MSE = 3.34345e-007
NEWRB, neurons = 375, MSE = 3.33524e-007
NEWRB, neurons = 400, MSE = 3.32165e-007
NEWRB, neurons = 425, MSE = 3.29483e-007
NEWRB, neurons = 450, MSE = 3.219e-007
NEWRB, neurons = 475, MSE = 2.26552e-007
```



2_2 Radial basis data

B-6 RBF data for 4layered pavement: Design-case 2

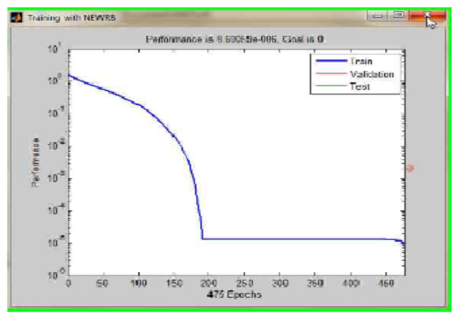
```
>> nntool
NEWRB, neurons = 0, MSE = 1.63034
NEWRB, neurons = 25, MSE = 0.96714
NEWRB, neurons = 50, MSE = 0.601678
NEWRB, neurons = 75, MSE = 0.339356
NEWRB, neurons = 100, MSE = 0.17019
NEWRB, neurons = 125, MSE = 0.0784227
NEWRB, neurons = 150, MSE = 0.025983
NEWRB, neurons = 175, MSE = 0.00190268
NEWRB, neurons = 200, MSE = 3.77536e-005
NEWRB, neurons = 225, MSE = 3.77398e-005
NEWRB, neurons = 250, MSE = 3.77231e-005
NEWRB, neurons = 275, MSE = 3.77024e-005
NEWRB, neurons = 300, MSE = 3.76757e-005
NEWRB, neurons = 325, MSE = 3.76404e-005
NEWRB, neurons = 350, MSE = 3.75911e-005
NEWRB, neurons = 375, MSE = 3.75179e-005
NEWRB, neurons = 400, MSE = 3.73976e-005
NEWRB, neurons = 425, MSE = 3.71629e-005
NEWRB, neurons = 450, MSE = 3.65036e-005
NEWRB, neurons = 475, MSE = 2.60127e-005
```



2_3 Radial basis data

B-7 RBF data for 4layered Pavement: Design-case 3

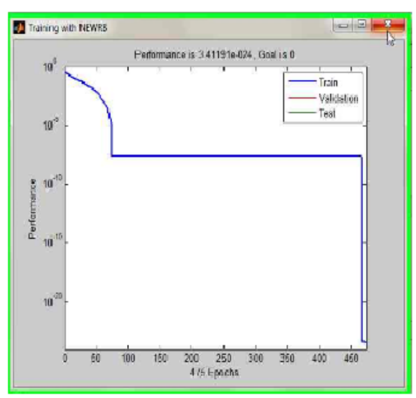
```
>> nntool
NEWRB, neurons = 0, MSE = 1.63604
NEWRB, neurons = 25, MSE = 0.915138
NEWRB, neurons = 50, MSE = 0.56866
NEWRB, neurons = 75, MSE = 0.340371
NEWRB, neurons = 100, MSE = 0.185055
NEWRB, neurons = 125, MSE = 0.0755403
NEWRB, neurons = 150, MSE = 0.0203525
NEWRB, neurons = 175, MSE = 0.00170997
NEWRB, neurons = 200, MSE = 1.32135e-005
NEWRB, neurons = 225, MSE = 1.32083e-005
NEWRB, neurons = 250, MSE = 1.32019e-005
NEWRB, neurons = 275, MSE = 1.3194e-005
NEWRB, neurons = 300, MSE = 1.31839e-005
NEWRB, neurons = 325, MSE = 1.31704e-005
NEWRB, neurons = 350, MSE = 1.31517e-005
NEWRB, neurons = 375, MSE = 1.3124e-005
NEWRB, neurons = 400, MSE = 1.30783e-005
NEWRB, neurons = 425, MSE = 1.29896e-005
NEWRB, neurons = 450, MSE = 1.2742e-005
NEWRB, neurons = 475, MSE = 8.69059e-006
```



2_5 Radial basis data

B-8 RBF data for 4layered Pavement: Design-case 5

```
>> nntool
NEWRB, neurons = 0, MSE = 0.379785
NEWRB, neurons = 25, MSE = 0.0554455
NEWRB, neurons = 50, MSE = 0.007475
NEWRB, neurons = 75, MSE = 2.50902e-008
NEWRB, neurons = 100, MSE = 2.50845e-008
NEWRB, neurons = 125, MSE = 2.50785e-008
NEWRB, neurons = 150, MSE = 2.50716e-008
NEWRB, neurons = 175, MSE = 2.50636e-008
NEWRB, neurons = 200, MSE = 2.50542e-008
NEWRB, neurons = 225, MSE = 2.50429e-008
NEWRB, neurons = 250, MSE = 2.5029e-008
NEWRB, neurons = 275, MSE = 2.50118e-008
NEWRB, neurons = 300, MSE = 2.49896e-008
NEWRB, neurons = 325, MSE = 2.49602e-008
NEWRB, neurons = 350, MSE = 2.4919e-008
NEWRB, neurons = 375, MSE = 2.48577e-008
NEWRB, neurons = 400, MSE = 2.47562e-008
NEWRB, neurons = 425, MSE = 2.45561e-008
NEWRB, neurons = 450, MSE = 2.40555e-008
NEWRB, neurons = 475, MSE = 3.41191e-024
```



2_7 Radial basis data

B-9 RBF data for 4 layered Pavement: Design-case 7

Appendix-C

FIELD EVALUATION OF PAVEMENT USING FWD

Backcalculated Layer moduli from FWD test and Thickness details of different Stretches are given here. [MORTH Research Scheme R-81]

C-1 THIN PAVEMENTS

CASE Thin_1: **Km 1.865 to 2.000 of SH * (Salua Road) for the Deflection Data Collected during the Year 2001-02.**

Location (Km)	Backcalculated Layer Moduli (MPa)											
	Monsoon			RMSE (%)	Winter			RMSE (%)	Summer			RMSE (%)
	Bitu	GB	Sub		Bitu	GB	Sub		Bitu	GB	Sub	
2.000L	278.4	292.8	42.9	1.19	320.4	311.2	51.0	1.51	332.8	316.1	53.0	2.40
1.970L	302.1	288.8	42.3	1.59	360.2	269.9	50.7	1.93	324.7	322.7	51.4	2.14
1.940L	253.7	252.7	40.7	3.70	346.2	309.9	48.2	1.74	374.1	348.2	52.6	2.18
1.910L	248.8	227.9	40.7	1.52	247.3	249.7	41.1	2.36	270.9	283.5	42.0	2.66
1.880L	276.3	266.4	46.2	3.28	335.4	326.8	47.9	2.71	397.9	309.5	50.6	2.91
1.865R	333.3	317.8	44.5	0.73	341.3	286.6	44.1	2.47	325.8	333.7	53.2	1.90
1.985R	336.5	256.3	43.1	1.70	321.6	291.0	43.0	2.60	394.6	312.1	50.0	2.05
1.955R	230.1	225.5	38.6	1.71	296.7	259.8	40.0	2.09	367.7	262.0	45.1	2.44
1.925R	236.5	214.9	38.1	1.95	283.8	306.0	42.7	2.81	341.9	297.5	50.0	2.10
1.895R	320.4	269.5	39.7	2.52	254.8	316.5	47.5	1.38	334.4	338.1	49.3	1.93
Maximum	336.5	317.8	46.2	3.70	346.2	316.5	51.0	2.81	374.1	348.2	53.0	2.91
Minimum	230.1	214.9	38.1	0.73	247.3	249.7	40.0	1.38	270.9	262.0	42.0	1.90
Average	281.6	261.3	41.7	1.99	310.7	292.7	45.6	2.16	346.5	312.3	49.7	2.27
Std. Dev	39.7	32.8	2.59	0.92	38.8	25.9	3.9	0.51	38.2	26.1	3.6	0.33
COV (%)	14.09	12.55	6.21		14.48	8.84	8.55		11.02	8.35	7.24	
A. Moduli	Bitu: 312.93 MPa				GB: 288.77 MPa				Sub: 45.67 MPa			

Bitu- Bituminous Material; GB- Granular Base; Sub- Subgrade; Std. Dev- Standard Deviation
A Moduli- Average of Moduli for three seasons; L: Left-Towards Salua; R-Right- Towards Kharagpur;
**SH: State Highway*

Table C-1 CASE Thin_1: Km 1.865 to 2.000 of SH * (Salua Road) for the Deflection Data Collected during the Year 2001-02. (MORTH Research Scheme R-81)

Thickness Details for the Stretch from Km 1.820 to 2.000 of SH*(SALUA Road):

Location (Km)	Layer Thickness (mm)		Location	Layer Thickness (mm)	
	Surface	Base		Surface	Base
	Bituminous	WBM		BM	WBM
2.000L	40.0	245.0	1.895R	52.0	300.0
1.985R	46.0	270.0	1.880L	52.0	279.0
1.970L	45.0	264.0	1.865R	45.0	300.0
1.955R	45.0	278.0	1.850L	45.0	290.0
1.940L	42.0	295.0	1.835R	41.0	279.0
1.925R	45.0	290.0	1.820L	45.0	285.0
1.910L	43.0	253.0			

Statistical Details

Parameter	Bituminous, mm	WBM, mm
Maximum	52.00	300.0
Minimum	40.00	245.0
Average	45.08	279.1
Std. Dev	3.57	17.2

WBM: Water Bound Macadam; L: Left side - towards Salua; R: Right side- towards Kharagpur; MDR: Major District Road

Table C-2 Thickness Details for the Stretch from Km 1.820 to 2.000 of SH*(SALUA Road) (MORTH Research Scheme R-81)

CASE Thin_2: **Km 2.850 to 3.000 of SH* (Salua Road) for the Deflection Data Collected during the Year 2001-02.**

Location (Km)	Backcalculated Layer Moduli (MPa)											
	Monsoon			RMSE	Winter			RMSE	Summer			RMSE
	Bitu	GB	Sub	(%)	Bitu	GB	Sub	(%)	Bitu	GB	Sub	(%)
3.000L	227.9	134.4	37.2	3.93	304.3	203.5	39.8	1.67	296.7	231.3	44.8	4.44
2.970L	325.0	207.0	38.9	3.53	347.1	226.1	41.1	1.67	333.3	276.1	44.9	2.69
2.940L	241.0	197.7	40.8	8.39	404.3	226.3	44.6	6.34	384.9	284.4	54.0	4.76
2.910L	327.9	205.7	44.8	1.73	326.8	254.9	50.1	2.15	463.4	274.7	55.8	2.80
2.880L	193.5	214.0	38.6	5.33	289.2	278.3	53.8	2.59	375.2	259.8	52.8	2.28
2.850L	229.0	226.8	38.8	6.88	455.9	243.5	43.3	2.29	461.2	298.9	50.2	1.04
2.985R	295.6	230.7	43.6	1.66	308.6	232.5	55.5	1.29	338.7	308.7	57.4	4.07
2.955R	225.8	192.5	42.2	3.01	405.3	271.2	51.8	1.11	497.8	295.0	52.1	1.80
2.925R	213.9	195.1	34.3	2.92	283.8	243.1	44.7	4.06	301.0	231.2	51.6	1.82
2.895R	258.0	204.3	38.2	3.27	387.0	231.2	43.6	1.66	395.4	245.8	52.0	4.28
Maximum	327.9	230.7	44.8	8.39	455.9	278.3	55.5	6.34	497.8	308.7	57.4	4.76
Minimum	193.5	134.4	34.3	1.66	283.8	203.5	39.8	1.11	296.7	231.2	44.8	1.04
Average	253.7	200.8	39.7	4.07	351.2	241.1	46.8	2.48	384.7	270.6	51.6	3.00
Std. Dev	46.9	26.5	3.14	2.18	58.7	22.4	5.5	1.59	70.4	27.7	4.11	1.30
COV (%)	18.48	13.19	7.90		18.62	9.29	11.7		18.29	10.23	7.96	
A. Moduli	Bitu: 329.87 MPa				GB: 237.50 MPa				Sub: 46.03 MPa			

Bitu- Bituminous Material; GB- Granular Base; Sub- Subgrade; Std. Dev- Standard Deviation
A Moduli- Average of Moduli for three seasons; L: Left-Towards Salua; R-Right- Towards Kharagpur
**SH: State Highway*

Table C-3 **CASE Thin_2: Km 2.850 to 3.000 of SH* (Salua Road) for the Deflection Data Collected during the Year 2001-02. (MORTH Research Scheme R-81)**

Thickness Details for the Stretch from Km 2.850 to 3.000 of SH (SALUA Road)

Location (Km)	Layer Thickness (mm)		Location	Layer Thickness (mm)	
	Surface	Base		Surface	Base
	Bituminous	WBM		Bituminous	WMM
3.000L	45	290	2.925R	45	280
2.985R	45	282	2.910L	45	290
2.970L	45	279	2.895R	45	290
2.955R	45	270	2.880L	45	270
2.940L	45	295	2.850R	45	280

Statistical Details

Parameter	Bituminous Macadam, mm	WBM, mm
Maximum	45.00	295.00
Minimum	45.00	270.00
Average	45.00	282.00
Std. Dev	0.00	8.58

Table C-4 **Thickness Details for the Stretch from Km 2.850 to 3.000 of SH (SALUA Road) (MORTH Research Scheme R-81)**

Case Thin_3: **Km 4.625 to 5.000 of SH (IIT Bypass) for the Deflection Data Collected during the Year 2001-02.**

Location (Km)	Backcalculated Layer Moduli (MPa)											
	Monsoon			RMSE (%)	Winter			RMSE (%)	Summer			RMSE (%)
	Bitu	GB	Sub		Bitu	GB	Sub		Bitu	GB	Sub	
5.000 L	246.2	189.0	39.0	3.38	262.3	194.7	41.8	1.42	373.1	227.2	45.0	2.23
4.970L	216.1	191.6	41.9	2.40	290.3	240.9	54.6	1.79	298.9	236.0	55.1	2.19
4.940L	287.0	151.6	44.1	1.14	337.6	214.5	55.6	1.07	395.6	203.0	58.1	0.50
4.910L	239.7	180.2	48.2	1.87	387.0	190.7	58.8	0.46	411.8	189.0	60.7	0.65
4.695L	265.5	182.4	50.8	1.41	329.0	214.9	61.1	0.98	368.8	202.2	66.5	3.55
4.925 R	297.8	163.4	41.7	0.98	387.2	192.5	53.6	0.45	391.3	186.8	55.7	0.27
4.900 R	264.3	184.9	42.3	1.00	290.3	235.1	54.0	2.69	392.4	236.5	54.5	0.67
4.705 R	233.3	193.4	40.8	3.44	241.9	215.3	49.2	3.00	286.6	206.1	50.7	1.03
4.645R	261.2	173.1	40.4	3.78	234.4	209.6	50.2	3.64	370.9	219.7	57.2	0.80
4.625R	231.1	157.7	39.6	1.31	305.3	252.7	53.5	1.15	358.0	232.9	57.7	0.90
Maximum	287.0	193.4	48.2	3.78	387.2	252.7	61.1	3.64	411.8	236.0	66.5	3.55
Minimum	216.1	157.7	39.0	0.98	234.4	190.7	41.8	0.45	286.6	186.8	45.0	.027
Average	254.2	176.7	42.9	2.19	306.5	216.1	53.2	1.67	364.7	213.9	56.1	1.28
Std. Dev	25.7	14.7	3.8	1.10	54.1	21.1	5.4	1.10	41.2	18.9	5.7	1.04
COV (%)	10.11	8.35	8.85		17.65	9.76	10.1		11.29	8.83	10.16	
A. Moduli	Bitu: 308.47MPa				GB: 202.23 MPa				Sub: 50.73 MPa			

Bitu- Bituminous Material; GB- Granular Base; Sub- Subgrade; Std. Dev- Standard Deviation
A Moduli- Average Moduli for three seasons; L: Left-Towards Salua; R-Right- Towards Kharagpur

Table C-5 Case Thin_3: Km 4.625 to 5.000 of SH (IIT Bypass) for the Deflection Data Collected during the Year 2001-02. (MORTH Research Scheme R-81)

Thickness Details for the Stretch from Km 4.625 to 5.000 of SH (IIT Bypass)

Location (Km)	Layer Thickness (mm)		Location	Layer Thickness (mm)	
	Surface	Base		Surface	Base
	Bituminous	WBM		Bituminous	WBM
5.000 L	65	300	4.925 R	67	395
4.970L	65	250	4.900 R	60	320
4.940L	65	300	4.705 R	60	345
4.910L	60	390	4.645R	65	395
4.695L	63	360	4.625R	65	350

Statistical Details

Parameter	Bituminous, mm	WBM, mm
Maximum	67.00	395.00
Minimum	60.00	250.00
Average	63.50	340.50
Std. Dev	2.59	48.04

WBM: Water Bound Macadam; L: Left side - towards Salua; R: Right side - towards Kharagpur

Table C-6Thickness Details for the Stretch from Km 4.625 to 5.000 of SH (IIT Bypass) (MORTH Research Scheme R-81)

CASE Thin_4: **Km 3.370 to 4.000 of SH (IIT Bypass) for the Deflection Data Collected during the Year 2001-02**

Location (Km)	Backcalculated Layer Moduli (MPa)											
	Monsoon			RMSE	Winter			RMSE	Summer			RMSE
	Bitu	GB	Sub	(%)	Bitu	GB	Sub	(%)	Bitu	GB	Sub	(%)
4.000L	406.7	155.9	42.5	1.53	412.5	165.7	52.7	1.89	412.0	189.8	61.7	1.12
3.985R	330.8	144.3	43.6	2.39	400.8	146.7	66.6	1.11	404.4	161.1	69.7	0.78
3.970L	506.3	130.1	36.9	1.08	453.3	130.7	41.0	0.98	488.0	120.2	56.5	1.38
3.955R	430.6	103.7	35.7	1.80	454.7	119.7	41.3	1.26	460.1	119.0	45.8	0.89
3.940L	380.1	101.7	37.5	1.10	438.3	159.2	43.0	1.15	549.5	145.1	53.0	1.13
3.925R	460.3	100.9	43.3	1.52	360.6	121.4	40.3	0.95	368.4	117.9	43.0	1.14
3.910L	439.1	139.3	41.3	1.71	599.4	120.1	56.0	1.08	501.1	170.2	65.5	0.83
3.710R	390.3	124.4	43.7	1.57	607.0	156.7	49.0	1.22	477.1	150.3	56.0	0.95
3.695L	400.1	130.7	49.1	1.21	505.2	177.3	66.0	0.66	594.0	189.2	77.3	0.72
3.680R	444.2	100.7	46.9	1.20	451.6	206.4	52.9	1.35	464.7	179.5	65.9	0.51
3.665L	380.7	131.2	44.0	1.62	533.3	146.1	46.1	1.94	454.6	168.9	48.7	1.49
3.650R	360.7	126.5	44.4	5.72	547.5	125.4	63.2	3.27	646.2	161.5	72.4	2.85
3.400L	340.2	114.1	68.4	0.87	643.1	269.5	73.5	0.77	627.1	271.3	77.1	0.51
3.385R	330.5	115.5	61.9	1.00	341.2	215.4	75.0	1.25	635.0	272.1	65.2	0.56
3.370L	490.7	116.3	72.0	0.67	560.0	274.1	80.0	1.28	649.5	269.4	88.5	0.38
Maximum	506.3	155.9	72.0	5.72	643.1	274.1	80.0	3.27	643.5	272.1	88.5	2.85
Minimum	330.5	100.7	35.7	0.67	341.2	119.7	40.3	0.66	368.4	117.9	43.0	0.38
Average	406.1	122.4	47.4	1.66	487.2	168.9	56.4	1.34	515.4	179.0	63.1	1.01
Std. Dev	55.2	16.8	11.1	1.20	92.1	51.1	13.	0.63	94.7	52.8	12.8	0.60
COV (%)	13.59	13.72	23.4		18.90	30.25	23.7		18.37	29.49	20.2	
A. Moduli	464.51 MPa				167.16 MPa				52.38 MPa			

Table C-7 CASE Thin_4: Km 3.370 to 4.000 of SH (IIT Bypass) for the Deflection Data Collected during the Year 2001-02 (MORTH Research Scheme R-81)

Thickness Details for the Stretch from Km 3.370 to 4.000 of SH (IIT Bypass)

Location (Km)	Layer Thickness (mm)		Location	Layer Thickness (mm)	
	Surface	Base		Surface	Base
	Bituminous	WBM		Bituminous	WBM
4.000L	68	285.0	3.695L	70.0	400.0
3.985R	67	282.0	3.680R	67.0	390.0
3.970L	68	480.0	3.665L	64.0	280.0
3.955R	61	390.0	3.650R	68.0	290.0
3.940L	60	390.0	3.400L	70.0	430.0
3.925R	65	370.0	3.385R	70.0	420.0
3.910L	67	280.0	3.370L	72.0	420.0
3.710R	66	280.0			

Statistical Details

Parameter	Bituminous, mm	WBM, mm
Maximum	72.0	480.0
Minimum	60.0	280.0
Average	66.9	359.1
Std. Dev	3.3	69.1

Table C-8 Thickness Details for the Stretch from Km 3.370 to 4.000 of SH (IIT Bypass) (MORTH Research Scheme R-81)

CASE 5: **Km 15.000 to 15.270 of NH-60 for the Deflection Data Collected during the Year 2001-02**

Location (Km)	Backcalculated Layer Moduli (MPa)											
	Monsoon			RMSE (%)	Winter			RMSE (%)	Summer			RMSE (%)
	Bitu	GB	Sub		Bitu	GB	Sub		Bitu	GB	Sub	
15.000L	263.7	201.2	37.9	1.67	340.1	191.9	47.3	1.87	304.0	230.5	45.1	2.00
15.030R	228.9	195.4	41.9	2.01	330.8	157.6	43.6	1.45	276.2	182.3	43.5	1.94
15.060L	333.5	215.4	58.6	0.88	448.1	231.7	43.2	2.90	216.2	289.4	46.3	0.67
15.090R	302.0	172.9	49.5	3.04	301.2	134.7	44.6	3.81	282.1	189.2	45.4	0.94
15.120L	298.0	145.8	40.9	3.70	433.1	173.8	41.5	1.47	203.1	129.3	50.6	1.76
15.150R	357.1	146.0	39.7	2.29	407.0	148.5	42.8	0.99	228.5	167.5	46.6	1.88
15.180L	243.8	150.1	35.1	1.59	485.9	145.0	42.6	1.92	234.8	169.2	47.1	2.43
15.210R	261.8	169.2	39.4	4.19	319.0	201.0	44.6	1.20	321.2	153.9	48.5	3.22
15.240L	328.3	141.9	39.5	3.59	305.0	141.4	46.5	2.77	436.9	149.3	51.6	1.40
15.270R	268.4	139.4	40.1	2.00	411.0	156.0	41.1	1.04	468.3	154.8	43.2	0.76
Maximum	357.1	215.4	58.6	3.70	485.9	231.7	47.3	3.81	468.3	289.4	46.8	3.22
Minimum	228.9	139.4	35.1	0.88	301.2	134.7	41.1	0.99	203.1	129.3	43.2	0.76
Average	288.5	167.7	42.3	2.50	278.1	168.1	43.7	1.94	297.1	181.5	51.6	1.70
Std. Dev	41.99	27.7	6.82	1.08	66.6	31.1	2.02	0.93	90.7	46.7	2.77	0.79
COV (%)	14.55	16.51	16.1		23.94	18.50	4.62		30.52	25.73	5.36	
A. Moduli	321.27 MPa				172.48 MPa				44.28 Mpa			

Table C-9 CASE 5: Km 15.000 to 15.270 of NH-60 for the Deflection Data Collected during the Year 2001-02 (MORTH Research Scheme R-81)

Thickness Details for the Stretch from Km 15.000 to 15.270 of NH-60

Location (Km)	Layer Thickness (mm)		Location	Layer Thickness (mm)	
	Surface	Base		Surface	Base
	Bituminous	WBM		Bituminous	WBM
15.000L	51	384	15.150R	49	311
15.030R	50	370	15.180L	42	291
15.060L	50	375	15.210R	41	334
15.090R	61	373	15.240L	35	340
15.120L	50	373	15.270R	36	318

Statistical Details

Parameter	Bituminous Macadam, mm	WBM, mm
Maximum	61.00	384.00
Minimum	35.00	291.00
Average	46.50	346.90
Std. Dev	7.93	32.53

Table C-10 Thickness Details for the Stretch from Km 15.000 to 15.270 of NH-60 (MORTH Research Scheme R-81)

C-2 THICK PAVEMENTS

CASE Thick_1: **for Km 123.795 to 124.000 of NH-6 for the Deflection Data collected during the Year 2000-01 (Kumar, 2001)**

Location (Km)	Backcalculated Layer Moduli (MPa)											
	Monsoon			RMSE	Winter			RMSE	Summer			RMSE
	Bitu	GB	Sub	(%)	Bitu	GB	Sub	(%)	Bitu	GB	Sub	(%)
124.000L	721.6	209.0	55.0	0.48	956.2	242.9	56.1	0.87	517.5	311.1	69.5	0.23
123.995R	742.0	160.7	49.5	1.18	856.2	252.9	55.2	7.23	965.7	203.5	59.5	0.49
123.950L	640.5	180.4	46.3	1.77	690.2	233.7	54.1	3.09	656.5	294.8	65.3	1.87
123.945R	841.9	164.4	41.6	0.46	995.4	380.6	72.2	3.59	614.0	249.8	62.4	0.28
123.900L	719.4	159.4	36.0	0.48	954.8	399.3	63.1	5.88	633.9	204.5	73.3	0.24
123.895R	802.2	162.8	39.6	0.74	745.3	251.3	58.4	4.33	798.8	322.7	76.7	0.16
123.850L	854.4	200.2	41.9	1.49	790.4	260.5	63.2	8.03	810.8	315.6	76.4	1.12
123.845R	866.5	137.5	36.7	0.57	968.5	396.5	80.0	6.88	655.3	278.3	65.3	3.78
123.800L	500.4	210.5	32.1	3.84	893.9	393.1	51.2	2.20	649.6	170.4	49.4	3.32
123.795R	761.6	170.4	35.5	2.74	543.5	384.2	55.0	3.66	852.2	218.2	68.8	0.64
Maximum	866.5	210.5	55.0	3.84	968.5	396.5	80.0	8.03	965.7	322.7	76.6	3.78
Minimum	500.4	137.5	32.1	0.46	543.5	233.7	51.2	0.87	517.5	170.4	49.4	0.16
Average	734.8	175.3	41.8	1.38	825.5	318.7	61.6	4.58	715.4	256.9	66.6	1.21
Std. Dev	129.7	26.7	8.1	1.14	163.5	76.7	10.4	2.34	135.4	55.0	8.3	1.34
COV (%)	17.65	15.23	19.3		19.80	24.06	16.8		18.92	21.41	12.4	
A. Moduli	Bitu: 761.97 MPa				GB: 249.8 MPa				Sub: 56.5 MPa			

Table C-11 CASE Thick_1: Km 123.795 to 124.000 of NH-6 for the Deflection Data collected during the Year 2000-01 (Kumar, 2001) (MORTH Research Scheme R-81)

Thickness Details for the Stretch from Km 123.795 to 124.000 of NH-6

Location (Km)	Layer Thickness (mm)			Location	Layer Thickness (mm)		
	Surface	Base			Surface	Base	
	Bituminous	WBM	CS		Bituminous	WBM	CS
123.795R	95	125	395	123.900L	95	125	415
123.800L	95	125	295	123.945R	95	120	420
123.845R	95	125	285	123.950L	95	125	425
123.850L	95	128	437	123.995R	95	123	420
123.895R	95	125	435	124.000L	95	127	428
Statistical Details							
Parameter	Bituminous		WBM, mm		CS, mm		
Maximum	95.00		128.00		437.00		
Minimum	95.00		120.00		285.00		
Mean	95.00		124.80		395.50		
Std. Dev	0.00		2.15		56.86		

WBM: Water Bound Macadam; CS: Crushed Stone; L: left side- Towards Kolkata; R: Right Side- Towards Kharagpur

Table C-12 Thickness Details for the Stretch from Km 123.795 to 124.000 of NH-6 (MORTH Research Scheme R-81)

CASE Thick_2: **for Km 125.000 to 125.270 of NH-6 for the Deflection Data collected during Summer Season of the Year 2001-02.**

Location (Km)	Backcalculated Layer Moduli (MPa))			RMSE (%)	Location (Km)	Backcalculated Layer Moduli (MPa)			RMSE (%)
	Bitu	GB	Sub			Bitu	GB	Sub	
125.000L	603.7	268.5	66.4	3.29	125.150R	618.5	276.7	63.2	1.38
125.030R	595.9	247.0	62.4	4.03	125.180L	450.2	268.1	62.6	1.13
125.060L	359.3	291.2	62.2	1.07	125.210R	532.3	230.6	59.0	1.73
125.090R	488.4	296.3	63.8	1.17	125.240L	375.9	278.7	60.3	1.69
125.120L	355.4	295.5	59.8	1.17	125.270R	407.2	284.5	59.7	1.64
Maximum	618.5	296.3	66.4						
Minimum	359.3	230.6	59.0						
Average	478.7	273.7	61.9						
COV (%)	21.78	7.78	3.68						
Std. Dev	104.3	21.3	2.28						

Bitu- Bituminous Material; GB- Granular Base; Sub- Subgrade; Std. Dev- Standard Deviation
L- Left side: Towards Kharagpur; R-Right side: Towards Kolkata

Table C-13 CASE Thick_2: Km 125.000 to 125.270 of NH-6 for the Deflection Data collected during Summer Season of the Year 2001-02. (MORTH Research Scheme R-81)

Thickness Details for the Stretch from Km 125.000 to 125.270 of NH-6

Location (Km)	Layer Thickness (mm)			Location	Layer Thickness (mm)		
	Surface	Base			Surface	Base	
	Bituminous	WBM	CS		Bituminous	WBM	CS
125.000L	100.0	300.0	315.0	125.150R	100.0	300.0	340.0
125.030R	100.0	310.0	310.0	125.180L	100.0	290.0	335.0
125.060L	100.0	285.0	340.0	125.210R	100.0	295.0	330.0
125.090R	100.0	300.0	320.0	125.240L	100.0	300.0	330.0
125.120L	100.0	300.0	320.0	125.270R	100.0	300.0	325.0
Statistical Details							
Parameter	Bituminous		WBM, mm		CS, mm		
Maximum	100.0		310.0		340.0		
Minimum	100.0		285.0		310.0		
Mean	100.00		298.0		326.5		
Std. Dev	0.00		6.7		10.3		

Table C-14 Thickness Details for the Stretch from Km 125.000 to 125.270 of NH-6 (MORTH Research Scheme R-81)

CASE Thick_3: **Km 134.000 to 134.270 of NH-6 for the Deflection Data collected during the Year 2001-2002.**

Location (Km)	Backcalculated Layer Moduli (MPa)											
	Monsoon			RMSE (%)	Winter			RMSE (%)	Summer			RMSE (%)
	Bitu	GB	Sub		Bitu	GB	Sub		Bitu	GB	Sub	
134.000L	311.8	156.8	50.5	0.80	454.8	197.8	61.2	0.43	447.3	217.1	66.6	1.14
134.030R	352.8	172.4	54.6	0.06	423.6	214.7	62.9	0.41	424.7	196.0	71.5	0.91
134.060L	270.2	151.4	48.2	0.07	440.8	196.4	58.1	0.72	402.1	230.7	60.6	2.25
134.090R	308.6	138.4	36.6	3.74	332.2	185.4	48.5	1.40	348.3	204.4	53.6	1.95
134.120L	329.0	148.9	53.5	0.95	375.2	115.5	56.5	6.98	353.7	197.3	60.1	1.08
134.150R	320.4	146.7	52.3	1.09	350.5	181.5	51.1	1.48	304.6	209.8	62.3	1.38
134.180L	280.6	178.0	49.0	1.36	444.0	221.1	60.5	0.37	376.3	265.1	64.2	2.22
134.210R	372.0	169.2	35.3	5.01	357.3	210.5	61.7	0.70	365.5	215.8	68.4	1.27
134.240L	308.6	152.9	51.2	1.64	413.9	216.7	60.8	0.44	396.7	250.1	64.0	0.98
134.270R	289.2	156.8	46.8	1.15	378.4	210.9	59.0	0.84	364.5	223.7	65.1	0.59
Maximum	372.0	178.0	54.6	3.73	454.8	221.1	62.9	6.98	447.3	265.1	71.5	2.25
Minimum	270.2	138.4	35.3	0.06	332.2	115.5	48.5	0.37	304.6	196.0	53.6	0.59
Average	314.3	157.2	47.8	1.59	397.1	155.1	58.0	1.38	378.4	221.0	63.6	1.38
Std. Dev	31.30	12.44	6.68	1.58	43.70	30.98	4.75	2.01	40.98	22.42	4.95	0.57
COV (%)	9.95	7.91	13.9		11.00	19.97	8.18		10.82	10.14	7.78	
A. Moduli	Bitu: 363.26 MPa				GB: 175.3 MPa				Sub: 56.5 MPa			

Bitu- Bituminous Material; GB- Granular Base; Sub- Subgrade; Std. Dev- Standard Deviation

A. Moduli- Average Moduli of the Three Seasons; L-Left: Towards Bahoragora; R-Right: Towards Kharagpur

Table C-15 CASE Thick_3: Km 134.000 to 134.270 of NH-6 for the Deflection Data collected during the Year 2001-2002. (MORTH Research Scheme R-81)

Thickness Details for the Stretch from Km 134.000 to 134.270 of NH-6

Location (Km)	Layer Thickness (mm)				Location	Layer Thickness (mm)			
	Surface		Base			Surface		Base	
	Over	BM	WBM	CS		Over	BM	WBM	CS
134.000L	50	95	135	410	134.150R	50	95	136	422
134.030R	50	95	133	407	134.180L	50	95	135	410
134.060L	50	95	135	410	134.210R	50	95	135	400
134.090R	50	95	135	403	134.240L	50	95	132	408
134.120L	50	95	135	425	134.270R	50	95	135	415

Statistical Details

Parameter	Over, mm	BM, mm	WBM, mm	CS, mm
Maximum	50.00	95.00	136.00	425.00
Minimum	50.00	95.00	132.00	400.00
Average	50.00	95.00	134.60	411.00
Std. Dev	0.00	0.00	1.17	7.79

Table C-16 Thickness Details for the Stretch from Km 134.000 to 134.270 of NH-6 (MORTH Research Scheme R-81)

CASE Thick_4: **for Km 150.000 to 150.245 of NH-6 for the Deflection Data collected during the Year 2001-02**

Location (Km)	Backcalculated Layer Moduli (MPa)											
	Monsoon			RMS (%)	Winter			RMS (%)	Summer			RMS (%)
	Bitu	GB	Sub		Bitu	GB	Sub		Bitu	GB	Sub	
150.000L	254.8	203.9	44.9	2.26	401.0	198.6	73.1	1.70	439.7	263.3	71.1	1.46
150.060L	404.6	192.9	44.9	1.55	375.2	239.1	57.4	4.34	381.7	268.6	67.8	1.60
150.120L	384.9	162.1	48.0	1.06	329.0	169.9	55.8	1.32	268.8	246.2	62.9	2.02
150.180L	375.2	200.8	52.4	1.85	375.2	190.7	54.9	1.20	375.2	352.6	54.3	1.56
150.240L	377.4	169.2	47.4	1.21	448.3	210.9	56.9	0.84	295.6	241.7	61.1	1.61
150.005R	375.2	162.1	47.6	2.41	489.2	328.4	63.1	1.28	345.1	320.9	59.7	2.06
150.065R	393.5	139.5	44.8	1.50	375.2	322.7	57.4	3.66	268.4	240.9	53.0	3.53
150.125R	384.3	206.8	45.7	2.90	376.3	218.4	63.6	1.73	303.2	242.2	71.2	1.49
150.185R	260.2	227.7	52.6	1.22	423.6	274.7	70.0	1.83	426.8	346.0	82.2	1.73
150.245R	266.6	134.4	47.9	2.20	387.2	248.9	59.4	2.06	444.0	246.6	65.6	4.29
Maximum	404.6	227.7	52.6	2.90	489.2	328.4	73.1	4.34	444.0	352.6	71.2	4.29
Minimum	254.8	134.4	44.8	1.06	329.0	169.9	54.9	0.84	268.4	240.9	54.3	1.46
Average	347.7	179.9	47.6	1.82	398.0	240.2	61.2	2.00	354.9	276.9	64.9	2.14
Std. Dev	60.8	31.0	2.87	0.61	45.2	54.07	6.22	1.13	68.8	45.1	8.7	0.97
COV (%)	17.48	17.23	6.02		11.35	22.51	10.1		19.38	16.28	13.4	
A. Moduli	Bitu: 366.87MPa				GB: 232.33 MPa				Sub: 57.89 MPa			

Bitu- Bituminous Material; GB- Granular Base; Sub- Subgrade; Std. Dev- Standard Deviation
A. Moduli- Average Moduli of the Three Seasons; L-Left: Towards Bahoragora; R-Right: Towards Kharagpur

Table C-17 CASE Thick_4: Layer Moduli for Km 150.000 to 150.245 of NH-6 for the Deflection Data collected during the Year 2001-02 (MORTH Research Scheme R-81)

Thickness Details for the Stretch from Km 150.000 to 150.245 of NH-6

Location (Km)	Layer Thickness (mm)				Location	Layer Thickness (mm)			
	Surface		Base			Surface		Base	
	Over	BM	WBM	CS		Over	BM	WBM	CS
150.000L	75	95	170	536	150.125R	75	95	130	405
150.005R	75	95	130	415	150.180L	75	95	140	545
150.060L	75	95	130	405	150.185R	75	98	135	530
150.065R	75	95	170	405	150.240L	75	95	130	405
150.120L	75	95	130	405	150.245R	75	95	130	405

Statistical Details

Parameter	Overlay, mm	BM, mm	WBM, mm	CS, mm
Maximum	75.00	98.00	170.00	545.00
Minimum	75.00	95.00	130.00	405.00
Average	75.00	95.30	139.50	445.60
Std. Dev	00.00	0.95	16.41	63.75

Table C-18 Thickness Details for the Stretch from Km 150.000 to 150.245 of NH-6 (MORTH Research Scheme R-81)

CASE Thick_5: **Km 151.000 to 151.245 of NH-6 for the Deflection Data collected during the Year 2001-02**

Location (Km)	Backcalculated Layer Moduli (MPa)											
	Monsoon			RMS (%)	Winter			RMS (%)	Summer			RMS (%)
	Bitu	GB	Sub		Bitu	GB	Sub		Bitu	GB	Sub	
151.000L	507.5	205.9	55.1	2.91	422.5	246.1	70.0	1.88	511.8	261.1	88.8	0.90
151.060L	501.3	201.6	46.6	3.64	358.0	246.6	57.4	1.68	477.4	366.7	76.2	2.26
151.120L	306.1	264.6	32.6	0.78	374.1	212.3	64.1	2.44	429.0	288.8	68.2	0.91
151.180L	424.0	236.0	75.4	0.98	375.2	204.3	57.4	1.37	383.8	232.5	82.5	1.39
151.240L	438.5	195.0	54.0	1.05	412.9	317.0	73.7	1.52	501.0	386.0	72.7	0.68
151.005R	369.1	199.7	51.5	1.46	346.2	201.7	57.3	2.46	374.2	210.7	70.0	1.12
151.065R	361.2	189.5	48.0	0.97	339.7	190.9	54.3	0.60	375.2	200.4	68.9	1.67
151.125R	408.2	265.3	47.2	0.69	324.7	271.7	57.6	1.24	257.1	201.7	70.0	1.41
151.185R	324.7	202.6	74.0	0.95	340.8	218.9	63.6	1.21	554.8	192.0	61.0	2.51
151.245R	387.6	200.0	56.7	2.36	375.2	270.3	63.3	1.66	443.0	218.9	82.0	5.23
Maximum	507.5	265.3	75.4	3.64	422.5	317.0	73.7	2.46	554.8	366.0	88.8	5.23
Minimum	306.1	195.0	32.6	0.69	324.7	190.9	54.3	0.60	257.1	192.0	61.0	0.68
Average	402.8	216.0	54.1	1.58	366.9	237.9	61.9	1.61	430.7	255.9	74.0	1.81
Std. Dev	67.5	28.57	12.8	1.03	31.8	39.8	6.3	0.57	86.8	70.2	8.3	1.34
COV (%)	16.75	13.22	23.6		8.66	16.72	10.2		20.15	27.43	11.2	
A. Moduli	Bitu: 400.13 MPa				GB: 236.00 MPa				Sub: 63.33 MPa			

Bitu- Bituminous Material; GB- Granular Base; Sub- Subgrade; Std. Dev- Standard Deviation
A. Moduli: - Average Moduli of the Three Seasons;; L-Left: Towards Bahoragora; R-Right: Towards Kharagpur

Table C-19 CASE Thick_5: Km 151.000 to 151.245 of NH-6 for the Deflection Data collected during the Year 2001-02 (MORTH Research Scheme R-81)

Thickness Details for the Stretch from Km 151.000 to 151.245 of NH-6

Location (Km)	Layer Thickness (mm)				Location	Layer Thickness (mm)			
	Surface		Base			Surface		Base	
	Over	BM	WBM	CS		Over	BM	WBM	CS
151.000L	75	95	135	355	151.125R	75	95	130	330
151.005R	75	95	130	340	151.180L	75	95	132	358
151.060L	75	96	136	410	151.185R	75	98	135	340
151.065R	75	95	135	405	151.240L	75	95	135	400
151.120L	75	95	130	340	151.245R	75	95	140	475

Statistical Details

Parameter	Overlay, mm	BM, mm	WBM, mm	CS, mm
Maximum	75.00	98.00	140.00	475.00
Minimum	75.00	95.00	130.00	330.00
Average	75.00	95.40	133.80	375.30
Std. Dev	0.00	0.97	3.26	46.11

BM: Bituminous Macadam, Over: Bituminous Overlay; WBM: Water Bound Macadam; CS: Crushed Stone
L: Left Side - Towards Bahoragora; R: Right Side - Towards Kharagpur

Table C-20 Thickness Details for the Stretch from Km 151.000 to 151.245 of NH-6 (MORTH Research Scheme R-81)

CASE Thick_7: **Km 152.000 to 152.245 of NH-6 for the Deflection Data collected during the Year 2001-02**

Location (Km)	Backcalculated Layer Moduli (MPa)											
	Monsoon			RMSE (%)	Winter			RMSE (%)	Summer			RMSE (%)
	Bitu	GB	Sub		Bitu	GB	Sub		Bitu	GB	Sub	
152.000L	372.0	199.1	47.8	4.14	423.6	240.0	62.9	1.86	451.6	371.9	88.1	5.78
152.060L	402.4	165.1	46.0	7.97	352.6	198.6	46.0	2.11	511.8	274.7	82.5	1.05
152.120L	383.8	160.8	40.1	1.02	406.5	190.7	52.8	1.20	405.3	201.3	57.4	1.66
152.180L	415.0	181.0	42.4	8.93	375.2	240.3	51.1	2.38	382.7	203.5	58.6	2.44
152.240L	410.7	181.0	59.1	1.00	461.2	250.5	70.0	1.70	478.4	240.0	83.5	1.67
152.005R	308.6	201.7	49.4	7.78	237.6	218.9	54.4	1.34	411.8	185.9	67.2	1.26
152.065R	423.6	205.2	44.7	7.46	381.7	200.4	51.7	0.85	361.2	223.3	55.0	2.25
152.125R	381.7	227.2	55.7	5.04	462.3	274.7	60.3	2.10	470.4	287.3	79.1	1.33
152.185R	350.5	186.3	44.9	6.06	375.2	190.7	44.9	2.32	430.1	273.9	76.0	1.55
152.245R	358.0	198.6	46.0	8.82	319.3	218.9	57.4	1.81	431.1	260.7	73.0	1.45
Maximum	423.6	227.2	59.1	8.93	462.3	274.7	70.0	2.38	511.8	371.9	88.1	5.78
Minimum	208.6	165.1	40.1	1.0	237.6	190.7	44.9	0.85	361.2	185.9	55.0	1.05
Average	380.6	190.6	47.6	5.8	379.5	222.4	55.2	1.77	433.4	252.3	72.0	2.04
Std. Dev	35.1	19.8	5.8	2.9	67.3	28.4	7.7	0.50	45.9	54.7	11.9	1.38
COV (%)	9.22	10.38	12.2		17.7	12.76	13.9		10.5	21.6	16.5	
A. Moduli	Bitu: 397.83 MPa				GB: 221.77 MPa				Sub: 58.27 MPa			

Bitu- Bituminous Material; GB- Granular Base; Sub- Subgrade; Std. Dev- Standard Deviation
A.Moduli- Average Moduli of the Three Seasons;; L-Left: Towards Baharagora; R-Right: Towards Kharagpur

Table C-21 CASE Thick_7: Km 152.000 to 152.245 of NH-6 for the Deflection Data collected during the Year 2001-02 (MORTH Research Scheme R-81)

Thickness Details for the Stretch from Km 152.000 to 152.245 of NH-6

Location (Km)	Layer Thickness (mm)				Location	Layer Thickness (mm)			
	Surface		Base			Surface		Base	
	Over	BM	WBM	CS		Over	BM	WBM	CS
152.000L	75	95	132	415	152.125R	75	95	127	390
152.005R	75	95	132	412	152.180L	75	95	130	400
152.060L	75	95	130	400	152.185R	75	98	130	420
152.065R	75	95	132	460	152.240L	75	95	130	415
152.120L	75	95	140	488	152.245R	75	95	130	448

Statistical Details

Parameter	Overlay, mm	BM, mm	WBM, mm	CS, mm
Maximum	75.00	98.00	131.30	488.00
Minimum	75.00	95.00	127.00	390.00
Average	75.00	95.30	140.00	424.80
Std. Dev	00.00	0.95	3.40	30.90

BM: Bituminous Macadam, Over: Bituminous Overlay; WBM: Water Bound Macadam; CS: Crushed Stone

Table C-22 Thickness Details for the Stretch from Km 152.000 to 152.245 of NH-6 (MORTH Research Scheme R-81)

CASE Thick_8: **Km 153.000 to 153.245 on NH-6 for the Deflection Data collected during the Year 2001-02**

Location (Km)	Backcalculated Layer Moduli (MPa)											
	Monsoon			RMS	Winter			RMS	Summer			RMS
	Bitu	GB	Sub	(%)	Bitu	GB	Sub	(%)	Bitu	GB	Sub	(%)
153.000L	375.2	155.1	50.0	0.62	447.3	171.8	61.3	8.69	432.2	279.6	78.0	0.75
153.060L	419.3	183.2	53.1	2.07	475.2	183.7	65.9	9.72	527.9	225.9	79.5	0.65
153.120L	375.2	209.2	53.3	1.42	478.4	230.7	68.5	2.53	640.8	303.3	74.1	1.26
153.180L	382.0	179.3	51.6	1.68	389.2	236.0	65.2	2.36	410.7	247.0	65.5	1.39
153.240L	334.4	175.3	55.3	1.86	339.7	229.8	59.5	2.79	362.3	207.4	64.1	2.13
153.005R	384.9	156.8	43.3	2.40	448.3	186.8	59.0	1.85	452.6	210.5	62.7	1.95
153.065R	427.9	189.0	50.8	1.40	419.3	252.3	63.8	1.38	475.2	212.3	69.9	1.65
153.125R	368.8	191.6	48.9	1.42	398.9	276.1	69.8	1.75	576.7	246.6	75.9	1.09
153.185R	386.0	200.0	51.3	1.15	448.3	222.4	55.0	1.02	402.1	223.3	64.7	0.72
153.245R	364.5	213.6	51.2	1.05	469.8	244.8	57.6	1.32	489.2	251.9	66.5	0.58
Maximum	427.9	213.6	55.3	2.40	448.3	276.1	69.8	9.72	640.8	303.3	79.5	2.13
Minimum	334.4	155.1	43.3	0.62	339.7	171.8	55.0	1.02	362.3	207.4	62.7	0.58
Average	381.8	185.3	50.9	1.51	431.4	223.4	62.6	3.34	476.9	240.8	70.1	1.22
Std. Dev	26.6	19.7	3.2	0.52	44.5	33.2	4.9	3.15	85.2	31.6	6.28	0.56
COV	6.96	10.6	6.28		10.3	14.8	7.8		17.8	13.1	8.95	
A. Moduli	Bitu: 430.03 MPa				GB: 216.50 MPa				Sub: 61.20 MPa			

Bitu- Bituminous Material; GB- Granular Base; Sub- Subgrade; Std. Dev- Standard Deviation
A. Moduli- Average Moduli of the Three Seasons; L-Left: Towards Bahoragora; R-Right: Towards Kharagpur

Table C-23 CASE Thick_8: Km 153.000 to 153.245 on NH-6 for the Deflection Data collected during the Year 2001-02 (MORTH Research Scheme R-81)

Thickness Details for the Stretch from Km 153.000 to 153.245 of NH-6

Location (Km)	Layer Thickness (mm)				Location	Layer Thickness (mm)			
	Surface		Base			Surface		Base	
	Over	BM	WBM	CS		Over	BM	WBM	CS
153.000L	75	95	130	428	153.125R	75	95	134	310
153.005R	75	95	135	440	153.180L	75	95	130	305
153.060L	75	95	130	300	153.185R	75	98	130	335
153.065R	75	95	127	290	153.240L	75	95	130	328
153.120L	75	95	134	405	153.245R	75	95	130	315

Statistical Details

Parameter	Overlay, mm	BM, mm	WBM, mm	CS, mm
Maximum	75	98.00	135.00	440.00
Minimum	75	95.00	127.00	290.00
Average	75	95.30	131.00	345.60
Std. Dev	00	0.95	2.49	56.45

Table C-24 Thickness Details for the Stretch from Km 153.000 to 153.245 of NH-6 (MORTH Research Scheme R-81)