RELIABILITY AND OPTIMIZATION ISSUES IN INDIAN PAVEMENT DESIGN GUIDELINES

ABHISHEK MITTAL

DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI
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RELIABILITY AND OPTIMIZATION ISSUES IN INDIAN PAVEMENT DESIGN GUIDELINES

by

Abhishek Mittal

Department of Civil Engineering

Submitted

In fulfilment of the requirements for the degree of Doctor of Philosophy

to the

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To my family and friends

CERTIFICATE

This is to certify that the thesis entitled **“RELIABILITY AND OPTIMIZATION ISSUES IN INDIAN PAVEMENT DESIGN GUIDELIENS”**, being submitted by **Mr. Abhishek Mittal**, to the **Indian Institute of Technology Delhi**, for the award of **‘Doctor of Philosophy’** in Department of Civil Engineering is a record of the bonafide research work carried out by him under my supervision and guidance. He has fulfilled the requirements for submission of this thesis, which to the best of my knowledge has reached the requisite standard.

The material contained in the thesis has not been submitted in part or full to any other University or Institute for the award of any other degree or diploma.

(Dr. Aravind K. Swamy)
Associate Professor
Department of Civil Engineering
Indian Institute of Technology Delhi
New Delhi-110016, India

Date:

New Delhi

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Abhishek Mittal

ABSTRACT

The design of pavements is usually done following a deterministic process by ignoring the uncertainties associated with the various input variables. The consequences of not considering these uncertainties in the pavement design process are quite serious and have been reported to be one of the main reasons for the failure of pavements. The application of reliability concepts for the probabilistic analysis of pavements provides a rational approach for incorporating and analyzing these uncertainties in the pavement design process. In this thesis, reliability concepts have been applied for designing safe and reliable pavements. Two different types of pavement structures have been analyzed in the thesis, viz. conventional granular pavements and cementitious stabilized pavements. Ready-made design charts have been proposed for varying combinations of subgrade CBR and design traffic levels, such that these can be readily used by the field engineers, thereby avoiding the involved mathematical complexity.

The conventional granular pavements have been analyzed as three-layered pavement structures with two distinct failure modes of fatigue and rutting. The estimation of critical strains for fatigue and rutting failures has been done through the use of Artificial Neural Networks (ANNs) based surrogate models. First Order Reliability Method (FORM) was employed for the reliability estimation of pavement sections. It has been concluded that the thicknesses given in the current Indian specifications (IRC:37 2018) don’t meet the specified reliability criteria for both fatigue and rutting reliability. Reliability based design charts based on the concept of Optimal Point have been proposed for the conventional granular pavements. These charts have been proposed for the traffic levels of 5 msa to 50 msa and CBR ranging from 5 % to 10 %. The reliability analysis was also carried out for the cementitious stabilized pavements.

Such pavements have been analyzed as five-layered structure. Ready-made charts have been proposed for such pavements for traffic levels of 30 msa to 50 msa. These charts are expected to help the field engineers in designing safe and reliable pavements considering the specified uncertainty in the input parameters.

System reliability concept was applied to the conventional granular pavements to consider the possible correlation between the two failure modes of fatigue and rutting. It has been estimated that the correlation coefficient between the two failure modes was between 0.3672 to 0.6344 for the proposed optimal sections for varying traffic and CBR values. Based on the rankings obtained from the sensitivity analysis of the input parameters, it was concluded that bituminous layer thickness is the most significant parameter affecting the reliability of both the conventional granular and cementitious stabilized pavement. This indicates that stringent quality control must be ensured during the construction of bituminous layer to ensure enhanced performance of the pavement.

सार

फुटपाथों का डिजाइन आमतौर पर विभिन्न इनपुट चर से जुड़ी अनिश्चितताओं की अनदेखी करके एक नियतात्मक प्रक्रिया का पालन करते हुए किया जाता है। फुटपाथ डिजाइन प्रक्रिया में इन अनिश्चितताओं पर विचार नहीं करने के परिणाम काफी गंभीर हैं और फुटपाथ की विफलता के मुख्य कारणों में से एक बताया गया है। फुटपाथ के संभाव्य विश्लेषण के लिए विश्वसनीयता अवधारणाओं का अनुप्रयोग फुटपाथ डिजाइन प्रक्रिया में इन अनिश्चितताओं को शामिल करने और उनका विश्लेषण करने के लिए एक तर्कसंगत दृष्टिकोण प्रदान करता है। इस थीसिस में सुरक्षित और विश्वसनीय फुटपाथों को डिजाइन करने के लिए विश्वसनीयता अवधारणाओं को लागू किया गया है। थीसिस में दो अलग-अलग प्रकार की फुटपाथ संरचनाओं का विश्लेषण किया गया है, अर्थात, पारंपरिक दानेदार फुटपाथ और सीमेंटयुक्त स्थिर फुटपाथ। सबग्रेड सीबीआर और डिज़ाइन ट्रैफ़िक स्तरों के अलग-अलग संयोजनों के लिए तैयार डिज़ाइन चार्ट प्रस्तावित किए गए हैं जिनहे फील्ड इंजीनियरों द्वारा आसानी से उपयोग किया जा सकता है, जिससे शामिल गणितीय जटिलता से बचा जा सकता है।

पारंपरिक दानेदार फुटपाथों का विश्लेषण तीन-परत फुटपाथ संरचनाओं के रूप में किया गया है, जिसमें थकान और रट के दो अलग-अलग विफलता प्रकार हैं। कृत्रिम तंत्रिका नेटवर्क (एएनएन) आधारित सरोगेट मॉडल के उपयोग के माध्यम से थकान और रट विफलताओं के लिए महत्वपूर्ण उपभेदों का आकलन किया गया है। फुटपाथ अनुभागों की विश्वसनीयता के आकलन के लिए प्रथम आदेश विश्वसनीयता विधि (FORM) को नियोजित किया गया था। यह निष्कर्ष निकाला गया है कि वर्तमान भारतीय विनिर्देशों (आईआरसी: 37 2018) में दी गई मोटाई थकान और रटिंग विश्वसनीयता दोनों के लिए निर्दिष्ट विश्वसनीयता मानदंडों को पूरा नहीं करती है। पारंपरिक दानेदार फुटपाथों के लिए इष्टतम बिंदु की अवधारणा पर आधारित विश्वसनीयता आधारित डिजाइन चार्ट प्रस्तावित किए गए हैं। ये चार्ट 5 एमएसए से 50 एमएसए और सीबीआर 5% से 10% तक के यातायात स्तरों के लिए प्रस्तावित किए गए हैं।

सीमेंटयुक्त स्थायी फुटपाथों के लिए विश्वसनीयता विश्लेषण भी किया गया है। इस तरह के फुटपाथों का विश्लेषण पांच-परत संरचना के रूप में किया गया है। ऐसे फुटपाथों के लिए 30 एमएसए से 50 एमएसए के यातायात स्तर के लिए तैयार चार्ट प्रस्तावित किए गए हैं। इन चार्टों से इनपुट मापदंडों में निर्दिष्ट अनिश्चितता को देखते हुए फील्ड इंजीनियरों को सुरक्षित और विश्वसनीय फुटपाथ डिजाइन करने में मदद मिलने की उम्मीद है।

थकान और रट के दो विफलता प्रकार के बीच संभावित सहसंबंध पर विचार करने के लिए पारंपरिक दानेदार फुटपाथों पर सिस्टम विश्वसनीयता अवधारणा लागू की गई है। यह अनुमान लगाया गया है कि अलग-अलग यातायात और सीबीआर मूल्यों के लिए प्रस्तावित इष्टतम वर्गों के लिए दो विफलता मोड के बीच सहसंबंध गुणांक 0.3672 से 0.6344 के बीच पाया गया। इनपुट मापदंडों के संवेदनशीलता विश्लेषण से प्राप्त रैंकिंग के आधार पर, यह निष्कर्ष निकाला गया कि बिटुमिनस परत की मोटाई पारंपरिक दानेदार और सीमेंटयुक्त स्थिर फुटपाथ दोनों की विश्वसनीयता को प्रभावित करने वाला सबसे महत्वपूर्ण मापदंड है। यह इंगित करता है कि फुटपाथ के बेहतर प्रदर्शन को सुनिश्चित करने के लिए बिटुमिनस परत के निर्माण के दौरान सख्त गुणवत्ता नियंत्रण सुनिश्चित किया जाना चाहिए।

CONTENTS

CERTIFICATE

ACKNOWLEDGEMENTS i

ABSTRACT.. iii

LIST OF FIGURES.. xii

LIST OF TABLES... xiv

LIST OF NOTATIONS xviii

CHAPTER 1 - INTRODUCTION... 1

1.0 Preface... 1

1.1 Problem Definition.. 3

1.2 Pavement Design Concept.. 4

1.2.1 Empirical Design... 4

1.2.2 Mechanistic – Empirical (M-E) Design.............................. 5

1.3 Use of Surrogate Models for Pavement Analysis..................... 6

1.4 Need of the Study 9

1.5 Objectives of the Study... 11

1.6 Organisation of the Thesis 11

CHAPTER 2 - LITERATURE REVIEW 15

2.0 Introduction.. 15

2.1 Conventional Flexible Pavement Design............................... 17

2.1.1 Empirical Pavement Design Approach............................. 17

2.1.2 Mechanistic – Empirical (M-E) Pavement Design Approach................ 18

2.1.2.1 Fatigue Evaluation.. 20

2.1.2.2 Rutting Evaluation.. 20

2.2 Various Sources of Uncertainty in the Pavement Design Process............ 21

2.2.1 Uncertainty of Design Input Parameters 23
2.2.1.1 Layer Thicknesses 23
2.2.1.2 Layer Moduli 25
2.2.1.3 Poisson’s Ratio 26
2.2.1.4 Vehicle Damage Factor 28
2.2.1.5 Lateral Distribution Factor 28
2.2.1.6 Tyre Contact Pressure 28
2.2.1.7 Wheel Spacing 29
2.2.2 Model Uncertainty 29
2.2.3 Spatial Variability 30
2.2.4 Time Dependent Reliability 31
2.3 Reliability Considerations in the Existing Specifications 32
2.3.1 AASHTO 1993 32
2.3.2 MEPDG Guide 33
2.3.3 Indian Specifications (IRC:37 2018) 38
2.4 Reliability Analysis in Flexible Pavement Design 41
2.4.1 Surrogate Model Development for Flexible Pavement Analysis 42
2.4.2 Probabilistic Analysis of Flexible Pavements 43
2.4.3 Sensitivity Analysis in Flexible Pavement Design 48
2.5 Artificial Neural Networks (ANNs) 52
2.5.1 Application of Artificial Neural Networks (ANNs) in Pavement Engineering 54
2.6 Concluding Remarks 55
CHAPTER 3 – METHOD OF ANALYSIS ADOPTED IN THE STUDY 59
3.0 Introduction 59
3.1 Deterministic Approach to Pavement Design 59

3.1.1 Conventional Three-Layered Pavement Structure................................59

3.1.1.1 Pavement Structure Characterization and Material Properties.......60

3.1.1.2 Traffic and Environmental Conditions...64

3.1.1.3 Distress Mechanism 67

3.1.2 Stabilized Pavement Structure with Cementitious Base and Sub-base 69

3.1.2.1 Stabilized Pavement Structure Characterization and Material Properties...69

3.1.2.2 Distress Mechanism 71

3.2 Surrogate Modelling Approach..74

3.2.1 Sampling Plan or DOE 75

3.2.1.1 Sobol Sequence Sampling Plan..76

3.2.1.2 Artificial Neural Network (ANN)..77

3.3 Methods of Structural Reliability Analysis 78

3.3.1 First Order Reliability Method (FORM)..84

3.3.1.1 Hasofer – Lind Reliability Index 86

3.4 System Reliability...89

3.4.1 Different Approaches for the Estimation of Reliability Bounds 91

3.5 Sensitivity Analysis 95

3.5.1 Connection Weight Approach 96

3.5.2 Approach based on Direction Cosines 96

3.6 Concluding Remarks 97

CHAPTER 4 – RELIABILITY ANALYSIS FOR THREE-LAYERED FLEXIBLE PAVEMENT 99

4.0 Introduction...99

4.1 Need of the Study 101

4.2 Study Objectives...102

4.3 Methodology Adopted 102

4.4 Reliability Analysis for Three-Layered Pavement 103

4.4.1 Pavement Design Model 104

4.4.1.1 Statistical Modelling of Input Variables 105

4.4.1.2 Development of ANN based Surrogate Model for Prediction of Critical Pavement Responses 108

4.4.1.2.1 Generation of Data Points 108

4.4.1.2.2 Building the artificial neural network (ANN) architecture 111

4.4.1.2.3 Development of Model Equations from ANN 116

4.4.1.2.4 Performance Assessment of ANN Models 119

4.4.1.2.5 Error analysis of strain outputs from ANN compared with LEA 122

4.4.2 Component Reliability Estimation using FORM 125

4.4.2.1 Validation of the FORM model through Monte Carlo Simulation (MCS) 131

4.5 Development of Optimal Reliability Based Pavement Design Charts 133

4.5.1 Optimal Reliability Based Design Charts for Conventional Three-Layered Pavement Structure 136

4.6 Conclusions 141

CHAPTER 5 - RELIABILITY ANALYSIS FOR CEMENTITIOUS STABILIZED FLEXIBLE PAVEMENT 145

5.0 Introduction 145

5.1 Need of the Study 147

5.2 Study Objectives 147

5.3 Methodology Adopted 148

5.4 Reliability Analysis of Stabilized Pavement with Cementitious base and Sub-base 149

5.4.1 Pavement Design Model 149

5.4.1.1 Statistical Modelling of Input Variables 152

5.4.1.2 Development of ANN Based Surrogate Model for Prediction of Critical Pavement Responses 154

5.4.1.2.1 Generation of Data Points 155

5.4.1.2.2 Building the Artificial Neural Network (ANN) Architecture 157

5.4.1.2.3 Development of Model Equation from ANN 162

5.4.1.3 Performance Assessment of ANN Models 167

5.4.1.4 Error Analysis of Strain Outputs from ANN Compared with LEA 171

5.4.2 Component Reliability Estimation Using FORM 173

5.5 Development of Reliability Based Design Charts for Stabilized Pavements 178

5.6 Conclusions 183

CHAPTER 6 – SYSTEM RELIABILITY ANALYSIS FOR A THREE-LAYERED FLXIBLE PAVEMENT 185

6.0 Introduction 185

6.1 Need of the Study 186

6.2 Study Objectives 187

6.3 Methodology Adopted 188

6.4 System Reliability Analysis for a Three-Layered Pavement Structure 189

6.4.1 Development of ANN model for estimation of critical strains 189

6.4.2 Estimation of reliability index and correlation coefficients for pavement sections designed as per IRC:37-2018 for varying traffic levels and CBR values 191

6.4.3 Estimation of reliability bounds and system reliability for pavement sections designed as per IRC:37-2018 195

6.4.4 Proposed Optimal Pavement Cross-sections and Correlation Coefficient Estimation for the Optimal Sections..200

6.4.5 Estimation of System Failure Probability and Reliability Bounds for the Proposed Optimal Pavement Sections..204

6.5 Cost Comparison between IRC:37-2018 sections and proposed optimal sections..207

6.6 Conclusions..209

CHAPTER 7 – SENSITIVITY ANALYSIS FOR PAVEMENT DESIGN........211

7.0 Introduction..211

7.1 Need of the Study..212

7.2 Study Objectives..213

7.3 Methodology Adopted..213

7.4 Sensitivity Analysis for Conventional Three-Layered Asphalt Pavement Structure..214

7.4.1 Connection Weight Approach..214

7.4.2 Sensitivity Based on Estimation of Direction Cosines..219

7.4.3 Comparison of Rankings Obtained by the Two Methods..222

7.5 Sensitivity Analysis for Stabilized Five-Layered Asphalt Pavement Structure..223

7.5.1 Sensitivity Analysis Based on Connection Weight Approach..223

7.5.2 Sensitivity Analysis Based on Direction Cosines by FORM..234

7.6 Conclusions..238

CHAPTER 8 – SUMMARY AND CONCLUSIONS..241

8.0 Introduction..241

8.1 Important Conclusions from the Thesis..241

8.1.1 Reliability Analysis for Conventional Three-Layered Pavement........242

8.1.2 Reliability Analysis for Stabilized Five-Layered Pavement................243

8.1.3 System Reliability Analysis for Three-Layered Pavement 244
8.1.4 Sensitivity Analysis for Pavement Design 245
8.2 Further Scope 246
REFERNCES 248
Appendix A...270
Appendix B...281
Appendix C...283
Appendix D...294
Author's Curriculum Vitae..297

LIST OF FIGURES

Fig. 1.1 : Different fields of application for surrogate models 7

Fig. 1.2 : A schematization of different levels of representation of physical systems 7

Fig. 2.1 : Typical three-layer neural network 53

Fig. 3.1 : Schematic diagram of a typical three-layered pavement structure 61

Fig. 3.2 : Schematic diagram of a typical five-layered pavement structure 70

Fig. 3.3 : Comparison of LHS and Sobol sampling for three parameters 77

Fig. 3.4 : Artificial Neuron 78

Fig. 3.5 : Densities of $\boldsymbol{R}$ and $\boldsymbol{S}$ for first form of $\boldsymbol{Pf}$ 81

Fig. 3.6 : Densities of $\boldsymbol{R}$ and $\boldsymbol{S}$ for alternate form of $\boldsymbol{Pf}$ 81

Fig. 3.7 : Probability density for margin of safety 83

Fig. 3.8 : Illustration of transformation from basic variable space (left) to U-space (right) and first-order reliability estimate 87

Fig. 4.1 : Schematic diagram of a typical three-layered pavement structure indicating locations for strain computations 99

Fig. 4.2 : Flowchart depicting the methodology adopted in the present study ... 103

Fig. 4.3 : Histogram plot of the generated data points based on Sobol sampling 110

Fig. 4.4 : Neural network architecture adopted 113

Fig. 4.5 : Comparison of ANN predicted strain values with IITPAVE computed strain values 115

Fig. 4.6 : Variation of RMSE values with number of hidden neurons 121

Fig. 4.7 : Reliability values for design traffic of 5 msa 127

Fig. 4.8 : Reliability values for design traffic of 10 msa 128

Fig. 4.9 : Reliability values for design traffic of 20 msa 128

Fig. 4.10 : Reliability values for design traffic of 30 msa 129

Fig. 4.11 : Reliability values for design traffic of 40 msa 129

Fig. 4.12 : Reliability values for design traffic of 50 msa 130

Fig. 4.13 : Typical M-E pavement design chart indicating optimal point 134

Fig. 4.14 : Optimal design curve for 5 msa traffic and 5 % CBR 137

Fig. 4.15 : Reliability based optimal pavement design chart for traffic of 5 msa . 139

Fig. 4.16 : Reliability based optimal pavement design chart for traffic 10 msa ... 139
Fig. 4.17 : Reliability based optimal pavement design chart for traffic 20 msa ... 140
Fig. 4.18 : Reliability based optimal pavement design chart for traffic 30 msa ... 140
Fig. 4.19 : Reliability based optimal pavement design chart for traffic 40 msa ... 141
Fig. 4.20 : Reliability based optimal pavement design chart for traffic 50 msa ... 141
Fig. 5.1 : Flowchart depicting the methodology adopted in the present study ... 149
Fig. 5.2 : A typical five layer pavement structure as per IRC:37-2018 indicating critical locations of strain points ... 150
Fig. 5.3 : Histogram plot of the generated data points based on Sobol sampling ... 157
Fig. 5.4 : A view of the neural network architecture adopted ... 160
Fig. 5.5 : Comparison of ANN predicted strain values with IITPAVE computed strain values ... 161
Fig. 5.6 : Variation of RMSE values with number of hidden neurons ... 169
Fig. 5.7 : Reliability values for design traffic of 30 msa ... 176
Fig. 5.8 : Reliability values for design traffic of 40 msa ... 176
Fig. 5.9 : Reliability values for design traffic of 50 msa ... 177
Fig. 5.10 : Design thickness for 30 msa traffic (Set-1) ... 180
Fig. 5.11 : Design thickness for 40 msa traffic (Set-1) ... 180
Fig. 5.12 : Design thickness for 50 msa traffic (Set-1) ... 181
Fig. 5.13 : Design thickness for 30 msa traffic (Set – 2) ... 181
Fig. 5.14 : Design thickness for 40 msa traffic (Set – 2) ... 182
Fig. 5.15 : Design thickness for 50 msa traffic (Set – 2) ... 182
Fig. 6.1 : Flowchart depicting the methodology adopted in the present study ... 189
Fig. 7.1 : Direction cosine values for fatigue failure ... 221
Fig. 7.2 : Direction cosine values for rutting failure ... 221
Fig. 7.3 : Direction cosine values for bituminous fatigue failure ... 236
Fig. 7.4 : Direction cosine values for rutting failure ... 237
Fig. 7.5 : Direction cosine values for cementitious fatigue failure ... 237

LIST OF TABLES

Table 2.1 : Layer thickness variability 24
Table 2.2 : Layer Moduli Variability 27
Table 2.3 : Variability of regression coefficients of transfer functions 30
Table 3.1 : Values of Resilient Modulus (MPa) of Bituminous Mixes 64
Table 4.1 : Summary of modulus and thickness values as per IRC:37-2018 107
Table 4.2 : Ranges of input parameters used for sampling point generation 109
Table 4.3 : Correlations coefficients among input parameters 111
Table 4.4 : Summary of values of coefficient of determination ($\boldsymbol{R2}$) obtained during development of ANN model 115
Table 4.5 : RMSE values for ANN models with varying hidden neurons 120
Table 4.6 : Values of Nash-Sutcliffe Efficiency Coefficient (NS) 122
Table 4.7 : Error analysis for critical horizontal tensile strain 124
Table 4.8 : Error analysis for critical vertical compressive strain 124
Table 4.9 : COVs of parameters adopted 126
Table 4.10 : Error analysis of fatigue reliability 132
Table 4.11 : Error analysis of rutting reliability 132
Table 4.12 : Thickness data for 5 msa traffic and 5 % CBR 137
Table 4.13 : Optimal pavement thickness data 138
Table 5.1 : Modulus and thickness values for the uniform section as per IRC:37 (2018) 153
Table 5.2 : Range of input parameters for sampling point generation 156
Table 5.3 : Pairwise correlation coefficients among input parameters 158
Table 5.4 : Summary of values of coefficient of determination (R- square) obtained during development of ANN model 162
Table 5.5 : RMSE values for ANN models with varying hidden neurons 168
Table 5.6 : Values of Nash-Sutcliffe Efficiency Coefficient (NS) 170
Table 5.7 : Data chosen for validation of ANN model 172
Table 5.8 : Error analysis for critical strains 173
Table 5.9 : COVs of parameters adopted 175
Table 5.10 : Thickness of bituminous layer (for >= 90 % reliability for cementitious fatigue failure) 179

Table 5.11 : Thickness of cementitious sub-base layer (for >= 90 % for cementitious fatigue failure)........179

Table 6.1 : Summary of modulus and thickness values used to calculate reliability indices as per IRC:37-2018 recommendations........193

Table 6.2 : Summary of reliability index and correlation coefficient as per current IRC:37-2018 recommendations........195

Table 6.3 : System failure probability and reliability bounds for IRC:37-2018 sections (Design Traffic = 5 msa) (× 10^{-2})........196

Table 6.4 : System failure probability and reliability bounds for IRC:37-2018 sections (Design Traffic = 10 msa) (× 10^{-2})........197

Table 6.5 : System failure probability and reliability bounds for IRC:37-2018 sections (Design Traffic = 20 msa) (× 10^{-2})........197

Table 6.6 : System failure probability and reliability bounds for IRC:37-2018 sections (Design Traffic = 30 msa) (× 10^{-2})........198

Table 6.7 : System failure probability and reliability bounds for IRC:37-2018 sections (Design Traffic = 40 msa) (× 10^{-2})........198

Table 6.8 : System failure probability and reliability bounds for IRC:37-2018 sections (Design Traffic = 50 msa) (× 10^{-2})........199

Table 6.9 : Modulus and thickness values used to obtain optimal pavement structure from system reliability considerations........202

Table 6.10 : Values of Reliability index (β) and correlation coefficient (ρ) for the proposed optimal sections........203

Table 6.11 : System failure probability and reliability bounds for proposed optimal section (Design Traffic = 5 msa) (× 10^{-2})........204

Table 6.12 : System failure probability and reliability bounds for proposed optimal section (Design Traffic = 10 msa) (× 10^{-2})........204

Table 6.13 : System failure probability and reliability bounds for proposed optimal section (Design Traffic = 20 msa) (× 10^{-2})........205

Table 6.14 : System failure probability and reliability bounds for proposed optimal section (Design Traffic = 30 msa) (× 10^{-2})........205

Table 6.15 : System failure probability and reliability bounds for proposed optimal section (Design Traffic = 40 msa) (× 10^{-2})........205

Table 6.16 : System failure probability and reliability bounds for proposed optimal section (Design Traffic = 50 msa) ($\times 10^{-2}$) 206
Table 6.17 : Cost comparison of proposed optimal sections versus IRC:27-2018 sections 208
Table 7.1 : Input – Hidden layer connection weights 215
Table 7.2 : Hidden - Output layer connection weights 215
Table 7.3 : Product of Connection weights for output 1 $\boldsymbol{\varepsilon t(c)}$ 216
Table 7.4 : Product of Connection weights for output 2 $\boldsymbol{\varepsilon t(m)}$ 216
Table 7.5 : Product of Connection weights for output 3 $\boldsymbol{\varepsilon z(c)}$ 217
Table 7.6 : Product of Connection weights for output 4 $\boldsymbol{\varepsilon z(m)}$ 217
Table 7.7 : Computed values of $\boldsymbol{Sj}$ 218
Table 7.8 : Ranking of ANN variables for critical strains based on connection weight approach 218
Table 7.9 : Sensitivity analysis for fatigue using direction cosines ($\boldsymbol{\alpha}$) 220
Table 7.10 : Sensitivity analysis for rutting using direction cosines ($\boldsymbol{\alpha}$) 220
Table 7.11 : Ranking of parameters based on Direction cosines 222
Table 7.12 : Input – Hidden layer connection weights 225
Table 7.13 : Hidden - Output layer connection weights 226
Table 7.14 : Product of Connection weights for output 1 $\boldsymbol{\varepsilon tbit(c)}$ 227
Table 7.15 : Product of Connection weights for output 2 $\boldsymbol{\varepsilon tbit(m)}$ 228
Table 7.16 : Product of Connection weights for output 3 $\boldsymbol{\varepsilon z(c)}$ 229
Table 7.17 : Product of Connection weights for output 4 $\boldsymbol{\varepsilon z(m)}$ 230
Table 7.18 : Product of Connection weights for output 5 $\boldsymbol{\varepsilon tcem(c)}$ 231
Table 7.19 : Product of Connection weights for output 6 $\boldsymbol{\varepsilon tcem(m)}$ 232
Table 7.20 : Computed values of $\boldsymbol{Sj}$ 233
Table 7.21 : Ranking of inputs based on connection weight approach 234
Table 7.22 : Sensitivity analysis for bituminous fatigue using direction cosines ($\boldsymbol{\alpha}$) 235
Table 7.23 : Sensitivity analysis for rutting using direction cosines ($\boldsymbol{\alpha}$) 235
Table 7.24 : Sensitivity analysis for cementitious fatigue using direction cosines ($\boldsymbol{\alpha}$) 236
Table 7.25 : Ranking of parameters based on Direction cosines 238

Table A.1 : Data points generated using Sobol Sampling for conventional three-layer pavement structure 270
Table B.1 : Weights for the ANN (5-11-4) model for conventional three-layer pavement structure 281
Table B.2 : Bias for the ANN (5-11-4) model for conventional three-layer pavement structure 282
Table C.1 : Data points generated using Sobol Sampling for cementitious five-layer pavement structure 283
Table D.1 : Weights for the ANN (9-11-6) model for cementitious five-layer pavement structure 294
Table D.2 : Weights for the ANN (9-11-6) model for cementitious five-layer pavement structure 295
Table D.3 : Bias for the ANN (9-11-6) model for cementitious five-layer pavement structure 296

LIST OF NOTATIONS

ε_t	Horizontal tensile strain at the bottom of bituminous layer (in microtrains)
ε_z	Vertical compressive strain on the top of subgrade (in microstrains)
$\varepsilon_{t_{cem}}$	Horizontal tensile strain at the bottom of cementitious layer (in microstrains)
ε_{tbitc}	Bituminous tensile strain, underneath single tyre (in microstrains)
ε_{tbitm}	Bituminous tensile strain, between dual tyres (in microstrains)
ε_{zc}	Vertical compressive strain, underneath single tyre (in microstrains)
ε_{zm}	Vertical compressive strain, between dual tyres (in microstrains)
ε_{tcemc}	Cementitious tensile strain, underneath single tyre (in microstrains)
$\varepsilon_{t_{cemm}}$	Cementitious tensile strain, between dual tyres (in microstrains)
N_f	Fatigue life of the pavement
N_r	Rutting life of the pavement
N_A	Actual number of axle load repetitions
N_{allow}	Allowable number of axle load repetitions
N_{cem}	Cementitious fatigue life of the pavement
N_{bit}	Bituminous fatigue life
$\mathrm{N_D}$	Design traffic
R	Reliability
R_f	Fatigue reliability
R_r	Rutting reliability
R_{ps}	Overall reliability of the pavement system
P_f	Probability of failure
P_{ff}	Probability of failure of pavement due to fatigue

	consideration
P_{fr}	Probability of failure of pavement due to rutting consideration
P_{fps}	Probability of failure of the pavement system
$P(\bullet)$	Probability
β	Reliability index
β_i	Reliability index for i^{th} failure mode
β_j	Reliability index for j^{th} failure mode
$\Phi(\bullet)$	Cumulative distribution function of the standard normal random variable
$\Phi_2(\bullet)$	Cumulative distribution function of two dimensional standard normal distribution
$\varphi_2(\bullet)$	Probability density function of two dimensional standard normal distribution
σ	Standard deviation
w_{ij}	Weights between nodes i and j
$g(X)$	Performance or limit state function
ρ	Correlation coefficient
ρ_{ij}	Correlation coefficient between i^{th} and j^{th} failure modes
α	Direction cosine vector or the representative alpha
S_0	Overall standard deviation
S_0^2	Overall variance
S_N^2	Variance in traffic prediction
S_W^2	Variance in prediction of pavement performance
h_i	Thickness of the i-th layer from top (in mm)
E_i	Resilient modulus of the i-th layer from top (in MPa)
k_1, k_2, k_3, k_4, k_5	Regression coefficients
$M_{RSubgrade}$	Resilient modulus of subgrade soil
$M_{RGranular}$	Resilient modulus of granular layer
W_s	Standard axle load
W_i	Median value of axle load for the i-th axle group
V_i	Traffic volume for the i-th axle group

N_{design}	Cumulative number of standard axle for design
A	Initial commercial traffic in the year of completion of construction
D	Lateral Distribution Factor
F	Vehicle Damage Factor
n	Design life, in years
r	Annual growth rate of commercial traffic
P	Number of commercial vehicles per day as per last count
x	Number of years between last count and year of completion of construction
RF	Reliability factor for cementitious materials for fatigue failure
$N_{fi_{cem}}$	Fatigue life of cementitious material for i-th axle load class
$\sigma_{t_{cem}}$	Tensile stress at the bottom of cementitious layer for given axle load class
M_{Rup}	28-day flexural strength of cementitious base
N_C	Capacity
N_D	Demand
$f_R(r)$	Probability density function of R at R = r
$f_S(s)$	Probability density function of S at S = s