# DEVELOPMENT OF A CORRELATION BETWEEN DYNAMIC CONE PENETRATION INDEX (DCPI) AND CALIFORNIA BEARING RATIO (CBR) FOR TROPICAL SOIL CONDITIONS

Koruwage Lathika Iromi Ranasoma

(198350T)

Degree of Master of Science in Geotechnical Engineering

Department of Civil Engineering

University of Moratuwa
Sri Lanka

June 2024

# DEVELOPMENT OF A CORRELATION BETWEEN DYNAMIC CONE PENETRATION INDEX (DCPI) AND CALIFORNIA BEARING RATIO (CBR) FOR TROPICAL SOIL CONDITIONS

Koruwage Lathika Iromi Ranasoma
(198350T)

Thesis submitted in partial fulfillment of the requirements for the degree in
Master of Science in Geotechnical Engineering

Department of Civil Engineering

University of Moratuwa
Sri Lanka

June 2024

## DECLARATION OF THE CANDIDATE AND SUPERVISOR

I declare that this is my work. This thesis does not incorporate any material previously submitted for a Degree or Diploma in any other University or Institute of higher learning without acknowledgment. To the best of my knowledge and belief, it does not contain any material previously published or written by another person except where the acknowledgment is made in the text.

Also, I hereby grant to the University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: ***UOM Verified Signature*** Date: 06.06.2024

The above candidate has carried out this research for the Master's thesis under my supervision.

Name of the supervisor: Dr. K.H.S.M. Sampath

Signature of the supervisor: Date:

**Development of a correlation between Dynamic Cone Penetration Index (DCPI) and California Bearing Ratio (CBR) for tropical soil conditions**

**ABSTRACT**

As a design input for structurally designing a road pavement, for the assessment of subgrade strength in Mechanistic-Empirical (M-E) based designs, the design Level 2 could be utilized mainly as a feasible & preferred option because it is easily obtainable and less costly than Level 1, provided we have the necessary correlations established for material input characteristics, in this case, the subgrade strength. Level 2 needs to get empirical correlations which have to be found by undertaking/carrying out studies to establish correlations for the California Bearing Ratio (CBR). This research is aimed at developing a correlation for CBR vs Dynamic Cone Penetration Index (DCPI) with the consideration of the moisture-density variation of soil representing wet and dry seasons in Sri Lanka and being a tropical country, its application for the tropical environment as well.

The DCP test offers simplicity and effectiveness in assessing subgrade strength based on penetration depth per blow count. Therefore, establishing a correlation between DCPI and laboratory CBR emerges as the optimal approach for predicting subgrade strength in terms of CBR.

Soil data samples representing the Wet Zone and Dry Zone of Sri Lanka consisting of various types of locally found soils that are typically predominant in pavement construction were considered for this study. Seasonal variations are captured by analyzing soil strength data during the monsoon and inter-monsoon periods, effectively characterizing the wet and dry seasons.

These datasets are afterward analyzed using a multivariable regression analysis approach to form a relationship between CBR, DCP result, density, and moisture content.

CBR to DCPI relationship was determined for the inherent soil types consisting of GC, SC, SM & SM-SC separately for Zone 1 (Wet Zone) and Zone 3 (Dry Zone) of Sri Lanka and for both dry season and wet season of the zone so the soils physical properties in their natural state and controlled state are represented.

Derived equations followed the trend of already established correlation patterns and could be validated. Three (3) equations were developed for Zone 1 and six (6) equations for Zone 3 for single independent variable DCPI in predicting CBR in a power relationship. The relationship of CBR2 which is CBR under field conditions, vs DCPI was found to give higher $R^2$ than CBR1 which is CBR at optimum conditions, meaning that DCPI is stronger in predicting CBR cast under field conditions. CBR2 is the parameter to consider in pavement overly designs on existing road pavements while CBR1 is the parameter considered for new road pavements.

Further improvement to the CBR vs DCPI relationship was undertaken by incorporating Moisture, Density, and the Degree of Compaction (DOC) parameters, all taken as two independent variable combinations in three different cases. From this analysis, Forty-Three (43) Equations with different combinations resulted in achieving unique improved correlations with the influence of Moisture, Density, or DOC as the case may be.

From this research study, it came to light that a better reliable correlation existed for Lab CBR cast under field conditions to DCPI than Lab CBR cast at OMC & MDD. A set of representative equations were derived for inherent soil types under different conditions in subjective zones. By incorporating a second variable to take the effect of moisture, density & degree of Compaction, CBR cast at optimum conditions too produced acceptable correlations to give acceptable predictions from DCPI. The produced family of curves for the given governing conditions can be conveniently referred to in predicting the desired CBR simply from a DCP test as the design input in pavement designs and enhanced as a correlation equation for CBR in M-E pavement designs.

In this study, the sample data comprised a limited number of districts covering the zone, and hence it is suggested to include more data from many other districts for better reliability of the prediction models. This study should be extended to include the remaining zone which is the Intermediate zone as well.

## DEDICATION

I dedicate this thesis to my loving Amma, Mrs Olivia Ranasoma, and Thaththa, Mr. Hemakeerthi Ranasoma who together brought me up with great love & care. Then to the cherished memory of my dearly beloved Nanga, Dilani Ranasoma.

**K L I Ranasoma**

## ACKNOWLEDGEMENT

I would like to express my sincere and foremost gratitude to my research advisor Dr. K.H.S.M. Sampath, Senior Lecturer, Department of Civil Engineering, University of Moratuwa, for all his invaluable guidance and advice throughout my research work.

I also express my heartfelt appreciation to Prof. S.A.S Kulathilaka, Prof. L.I.N. de Silva, and Dr. (Mrs) A. S Ranathunga for their valuable suggestions and constructive feedback throughout this Post Graduate Degree Program in Geotechnical Engineering. Their contributions have immensely enriched my knowledge and understanding of the subject matter.

The main contribution to my research database is the road pavement test pit investigations carried out by Soils Laboratory of Central Laboratory, Research & Development division, RDA and I am very grateful to the Laboratory staff, Engineers, and the Director (R&D), of R&D division, RDA, for providing me with the resources and facilitating me to carry out this research study.

I thank all researchers whose works and research have been referred to in this thesis which helped greatly to put this study in shape. Finally, I thank my family and friends for their encouragement & constant support throughout the study.

**K L I Ranasoma**

TABLE OF CONTENTS

ACKNOWLEDGEMENT ........ 7

LIST OF FIGURES ........ 11

LIST OF TABLES ........ 15

LIST OF ABBREVIATIONS ........ 17

1 INTRODUCTION ........ 18

1.1 Introduction ........ 18

1.2 Mechanistic-Empirical Pavement Design ........ 18

1.3 Importance of Subgrade Strength in Pavement Design ........ 20

1.4 Methods of Obtaining Subgrade Strength ........ 20

1.5 Significance of the Research ........ 21

1.5.1 Observations/Research Gaps Prevailing correlations on DCPI and lab CBR 21

1.6 Problem Statement ........ 22

1.7 Objectives ........ 22

1.8 Scope of the study ........ 23

1.9 Organization of the Report ........ 25

2 LITERATURE REVIEW ........ 27

2.1 Background ........ 27

2.2 Prevailing Correlations between DCP and CBR ........ 27

2.2.1 Internationally carried out research ........ 28

2.2.2 Locally carried out research ........ 33

2.3 Test that can be used to evaluate the subgrade soil strength ........................... 35

2.3.1 Method of California Bearing Ratio (CBR) test for subgrade strength assessment ........................................................................................ 36

2.3.2 Dynamic Cone Penetrometer (DCP) test for subgrade strength assessment 37

2.3.3 Soil Classification Systems ........................................................................ 41

2.4 Summary of Literature Review ..................................................................... 41

3 METHODOLOGY ............................................................................................ 43

3.1 Introduction ..................................................................................................... 43

3.2 Study Area ....................................................................................................... 44

3.2.1 Wet Zone (Zone 1) ......................................................................................... 44

3.2.2 Dry Zone (Zone 3) .......................................................................................... 46

3.3 The Test pit Data collection & Laboratory Testing ..................................... 48

3.3.1 Determination of the Particle size distribution .......................................... 50

3.3.2 Determination of Moisture content of soils ............................................... 50

3.3.3 Determination of Consistency limits (Atterberg Limits) of soils ............... 51

3.3.4 Determination of Modified Proctor Compaction ....................................... 52

3.3.5 Determination of California Bearing Ratio ................................................ 53

3.3.6 Determination of Field Density ................................................................. 53

3.3.7 Determination of DCPI ................................................................................ 54

3.4 Data Analysis ................................................................................................... 56

4 DATA ANALYSIS AND RESULTS ..................................................................... 58

4.1 Database and its Categorization .................................................................... 58

4.2 Test Properties of Data Samples for the Zones ............................................. 59

4.2.1 Summary of Test Results of Data Samples for Zone 1 ................................ 59

4.2.2 Summary of Test Results of Data Samples for Zone 3 ................................ 60

4.3 Distribution of Moisture Variation of the Data Samples ................................ 60

4.3.1 Distribution of Moisture Variation of the Data Samples for Zone 1 ........... 61

4.3.2 Distribution of Moisture Variation of the Data Samples for Zone 3 ........... 62

4.4 Development of Relationship between DCPI and CBR ................................. 63

4.4.1 Formulation of Non-Linear Power Relationships - Zone 1 ......................... 64

4.4.2 Formulation of Non-Linear Power Relationships - Zone 3 ......................... 68

4.4.3 Formulation of Non-Linear Power Relationships – Summary of Z1 &Z3 . 73

4.5 Further analysis using Multiple Regression using Excel to incorporate Moisture and Density effects for the relationship between DCPI and CBR ............................... 74

4.5.1 Incorporate moisture and density parameters for the correlations obtained between DCPI & CBR – Zone 1 ................................................................... 79

4.5.1.1 Case 1: CBR 1, CBR 2 correlated with DCPI, including moisture-density parameters under laboratory compacted OMC, MDD conditions – Zone 1 79

4.5.1.2 Case 2: CBR2 correlated with DCPI, including moisture density parameters under laboratory compacted FMC, FDD conditions – Zone 1 .......... 89

4.5.1.3 Case 3: CBR 1, CBR 2 correlated with DCPI & DOC – Zone 1 ....... 96

4.5.2 Incorporate moisture and density parameters for the correlations obtained between DCPI & CBR – Zone 3 ................................................................. 104

4.5.2.1 Case 1: CBR 1, CBR 2 correlated with DCPI, including moisture-density parameters under laboratory compacted OMC, MDD conditions– Zone 3 104

4.5.2.2 Case 2: CBR2 correlated with DCPI, including moisture density parameters under laboratory compacted FMC, FDD conditions– Zone 3 ......... 119

4.5.2.3 Case 3: CBR 1, CBR 2 correlated with DCPI & DOC– Zone 3 ...... 131

4.6 Predicting the CBR% using DCP with the available correlations ................ 141

4.6.1 Comparison of models obtained with available correlations for different soil types 141

4.6.1.1 Soil type GC ........................................................................ 142

4.6.1.2 Soil type SC ........................................................................ 143

4.6.1.3 Soil type SM ........................................................................ 144

4.6.1.4 Soil type SM-SC ................................................................... 145

4.6.2 Comparison of Lab CBR to DCPI correlations already established with the Predicted Relationships ........................................................................ 147

5 DISCUSSION ........................................................................................ 149

6 CONCLUSIONS AND RECOMMENDATIONS ............................................ 155

## LIST OF FIGURES

Figure 1-1: Climatic Zones of Sri Lanka ........................................................ 24

Figure 2-1: Source: extracts from Al-Refeai & Al-Suhaibani (1997) ............................ 31

Figure 2-2: Schematic Diagram of a CBR Apparatus.................................................... 37

Figure 2-3: Dynamic Cone Penetrometer Apparatus ..................................................... 39

Figure 2-4: DCP Test data plot, Source: ORN 31 .......................................................... 40

Figure 2-5: DCP Test Operation ........................................................................... 40

Figure 3-1: Flow chart of the methodology applied to carry out the study .................... 43

Figure 3-2: Selected road sections for the study in the Wet Zone of Sri Lanka .............45

Figure 3-3: Selected road sections for the study in the Dry Zone of Sri Lanka .............47

Figure 3-4: Test pit excavation & summary of data collection......................................48

Figure 3-5: Test session in the Soil Laboratory of RDA Central Laboratory.................50

Figure 3-6: Compaction curve ........................................................................................52

Figure 3-7: Field Density test .........................................................................................54

Figure 3-8: No of Blows Vs Cumulative Penetration Graph (sample)...........................55

Figure 4-1: Fitness of data points for D-GC to the obtained model for CBR2...............66

Figure 4-2: Fitness of data points for D-SC to the obtained model for CBR2 ...............67

Figure 4-3: Fitness of data points for D-SM to the obtained model for CBR2...............67

Figure 4-4: Fitness of data points for W-GC to the obtained model for CBR1..............69

Figure 4-5: Fitness of data points for D-GC to the obtained model for CBR2...............70

Figure 4-6: Fitness of data points for W-GC to the obtained model for CBR2..............71

Figure 4-7: Fitness of data points for D-SC to the obtained model for CBR2 ...............71

Figure 4-8: Fitness of data points for W-SC to the obtained model for CBR2...............72

Figure 4-9: Fitness of data points for D-SM to the obtained model for CBR2...............72

Figure 4-10: Fitness of data points for W-SM-SC to the obtained model for CBR2 ......73

Figure 4-11: Chart for CBR 1 vs DCPI, with MDD for W_GC.....................................81

Figure 4-12: Chart for CBR 1 vs DCPI, with MDD for W_SM....................................83

Figure 4-13: Chart for CBR 1 vs DCPI, with OMC for D_GC .....................................84

Figure 4-14: Chart for CBR 2 vs DCPI, with MDD for D_GC.....................................84

Figure 4-15: Chart for CBR 2 vs DCPI, with OMC for D_SC......................................85

Figure 4-16: Chart for CBR 2 vs DCPI, with MDD for D_SC......................................86

Figure 4-17: Chart for CBR 2 vs DCPI, with MDD for W_SC......................................87

Figure 4-18: Chart for CBR 2 vs DCPI, with OMC for D_SM......................................88

Figure 4-19: Chart for CBR 2 vs DCPI, with MDD for D_SM......................................88

Figure 4-20: Chart for CBR 2 vs DCPI, with FMC for D_GC.......................................91

Figure 4-21: Chart for CBR 2 vs DCPI, with FDD for D_GC .......................................92

Figure 4-22: Chart for CBR 2 vs DCPI, with FMC for D_SC .......................................93

Figure 4-23: Chart for CBR 2 vs DCPI, with FDD for D_SC ........................................93

Figure 4-24: Chart for CBR 2 vs DCPI, with FDD for W_SC .......................................94

Figure 4-25: Chart for CBR 2 vs DCPI, with FDD for D_SM .......................................95

Figure 4-26: Chart for CBR 1 vs DCPI, with DOC for D_GC.......................................98

Figure 4-27: Chart for CBR 1 vs DCPI, with DOC for D_SC .......................................99

Figure 4-28: Chart for CBR 2 vs DCPI, with DOC for D_GC.....................................100

Figure 4-29: Chart for CBR 2 vs DCPI, with DOC for D_SC .....................................101

Figure 4-30: Chart for CBR 2 vs DCPI, with DOC for W_SC.....................................102

Figure 4-31: Chart for CBR 2 vs DCPI, with DOC for D_SM.....................................103

Figure 4-32: Chart for CBR 1 vs DCPI, with OMC for D_GC ....................................106

Figure 4-33: Chart for CBR 1 vs DCPI, with MDD for D_GC....................................107

Figure 4-34: Chart for CBR 1 vs DCPI, with MDD for W_GC ...................................108

Figure 4-35: Chart for CBR 1 vs DCPI, with OMC for W_SM-SC.............................109

Figure 4-36: Chart for CBR 1 vs DCPI, with MDD for W_SM-SC.............................109

Figure 4-37: Chart for CBR 2 vs DCPI, with OMC for D_GC ....................................110

Figure 4-38: Chart for CBR 2 vs DCPI, with MDD for D_GC....................................110

Figure 4-39: Chart for CBR 2 vs DCPI, with OMC for W_GC ...................................111

Figure 4-40: Chart for CBR 2 vs DCPI, with MDD for W_GC .................................. 112

Figure 4-41: Chart for CBR 2 vs DCPI, with OMC for D_SC .................................. 113

Figure 4-42: Chart for CBR 2 vs DCPI, with MDD for D_SC .................................. 113

Figure 4-43: Chart for CBR 2 vs DCPI, with OMC for W_SC .................................. 114

Figure 4-44: Chart for CBR 2 vs DCPI, with MDD for W_SC .................................. 115

Figure 4-45: Chart for CBR 2 vs DCPI, with OMC for D_SM-SC .............................. 116

Figure 4-46: Chart for CBR 2 vs DCPI, with MDD for D_SM-SC .............................. 116

Figure 4-47: Chart for CBR 2 vs DCPI, with OMC for W_SM-SC .............................. 117

Figure 4-48: Chart for CBR 2 vs DCPI, with MDD for W_SM-SC .............................. 118

Figure 4-49: Chart for CBR 2 vs DCPI, with FMC for D_GC .................................. 121

Figure 4-50: Chart for CBR 2 vs DCPI, with FDD for D_GC .................................. 122

Figure 4-51: Chart for CBR 2 vs DCPI, with FMC for W_GC .................................. 123

Figure 4-52: Chart for CBR 2 vs DCPI, with FDD for W_GC .................................. 123

Figure 4-53: Chart for CBR 2 vs DCPI, with FMC for D_SC .................................. 124

Figure 4-54: Chart for CBR 2 vs DCPI, with FDD for D_SC .................................. 125

Figure 4-55: Chart for CBR 2 vs DCPI, with FMC for W_SC .................................. 126

Figure 4-56: Chart for CBR 2 vs DCPI, with FDD for W_SC .................................. 126

Figure 4-57: Chart for CBR 2 vs DCPI, with FMC for D_SM-SC .............................. 127

Figure 4-58: Chart for CBR 2 vs DCPI, with FDD for D_SM-SC .............................. 128

Figure 4-59: Chart for CBR 2 vs DCPI, with FMC for W_SM-SC .............................. 129

Figure 4-60: Chart for CBR 2 vs DCPI, with FDD for W_SM-SC .............................. 129

Figure 4-61: Chart for CBR 1 vs DCPI, with DOC for D_GC .................................. 132

Figure 4-62: Chart for CBR 1 vs DCPI, with DOC for W_GC .................................. 133

Figure 4-63: Chart for CBR 1 vs DCPI, with DOC for W_SM-SC ............................. 134

Figure 4-64: Chart for CBR 2 vs DCPI, with DOC for D_GC ..................................... 135

Figure 4-65: Chart for CBR 2 vs DCPI, with DOC for W_GC .................................... 136

Figure 4-66: Chart for CBR 2 vs DCPI, with DOC for D_SC ..................................... 137

Figure 4-67: Chart for CBR 2 vs DCPI, with DOC for W_SC ..................................... 138

Figure 4-68: Chart for CBR 2 vs DCPI, with DOC for D_SM-SC .............................. 139

Figure 4-69: Chart for CBR 2 vs DCPI, with DOC for W_SM-SC ............................. 140

Figure 4-70: Comparison of CBR Vs DCPI Established Prediction models - GC ........ 142

Figure 4-71: Comparison of CBR Vs DCPI Established Prediction models – SC ........ 144

Figure 4-72: Comparison of CBR Vs DCPI Established Prediction models - SM ........ 145

Figure 4-73: Comparison of CBR Vs DCPI Established Prediction models – SM-SC . 146

Figure 4-74: Comparison between existing models and newly developed models ....... 148

## LIST OF TABLES

Table 1-1: ME Pavement Design Guide Input Data ....................................................... 19

Table 1-2: Hierarchical Input Data Scheme of MEPD .................................................. 19

Table 1-3: Methods of obtaining Subgrade Strength ...................................................... 20

Table 2-1: Correlations between DCPI and CBR from literature ................................... 28

Table 2-2: Summary of test results, Muhammed, Jemal (2018) ..................................... 29

Table 2-3: Summary of test results, Al-Refeai & Al-Suhaibani (1997) .......................... 30

Table 2-4: Summary of Index properties & compaction test results, Al-Refeai & Al-Suhaibani (1997) ........................................................................................................ 31

Table 4-1: Data categorization ........ 58

Table 4-2: Summary with applicable ranges of engineering properties of soils for Z1 - D ........ 59

Table 4-3: Summary with applicable ranges of engineering properties of soils for Z1 - W ........ 59

Table 4-4: Summary with applicable ranges of engineering properties of soils for Z3 - D ........ 60

Table 4-5: Summary with applicable ranges of engineering properties of soils for Z3 - W ........ 60

Table 4-6: Moisture Content variation for GC, Z1 ........ 61

Table 4-7: Moisture Content variation for SC, Z1 ........ 61

Table 4-8: Moisture Content variation for SM, Z1 ........ 61

Table 4-9: Moisture Content variation for GC, Z3 ........ 62

Table 4-10: Moisture Content variation for SC, Z3 ........ 62

Table 4-11: Moisture Content variation for SM-SC, Z3 ........ 63

Table 4-12: Summary of model statistics for CBR vs DCPI in Zone 1 ........ 65

Table 4-13: Summary of model statistics for CBR vs DCPI in Zone 3 ........ 68

Table 4-14: Summary of Equations created for CBR vs DCPI ........ 73

Table 4-15: Variables for multiple regression analysis ........ 75

Table 4-16: Number of data samples with the applicable data range for each parameter - Z1 & Z2 ........ 75

Table 4-17: Summary of model statistics for CBR vs DCPI/ OMC/ MDD in Zone 1 ... 80

Table 4-18: Selected Prediction models for CBR vs DCPI/ OMC/ MDD in Zone 1 ...... 89

Table 4-19: Summary of model statistics for CBR vs DCPI/ FMC/ FDD in Zone 1 ...... 90

Table 4-20: Selected Prediction models for CBR2 vs DCPI/ FMC/ FDD in Zone 1 ......96

Table 4-21: Summary of model statistics for CBR vs DCPI/ DOC in Zone 1 ................96

Table 4-22: Selected Prediction models for CBR vs DCPI/ DOC in Zone 1 ................103

Table 4-23: Summary of model statistics for CBR vs DCPI/ OMC/ MDD in Zone 3 . 104

Table 4-24: Selected Prediction models for CBR vs DCPI/ DOC in Zone 1 ................118

Table 4-25: Summary of model statistics for CBR vs DCPI/ FMC/ FDD in Zone 3 ... 119

Table 4-26: Selected Prediction models for CBR2 vs DCPI/ FMC/ FDD in Zone 3 ... 130

Table 4-27: Summary of model statistics for CBR vs DCPI/ DOC in Zone 3 .............131

Table 4-28: Selected Prediction models for CBR vs DCPI/ DOC in Zone 3 ...............140

## LIST OF ABBREVIATIONS

| | |
|---|---|
| CBR | California Bearing Ratio |
| DCP/DCPI | Dynamic Cone Penetration Index (mm per blow) |
| DOC | Degree of Compaction |
| FMC/NMC | Field Moisture Content / Natural Moisture Content |
| LL | Liquid Limit |
| MDD | Maximum Dry Density |
| OMC | Optimum Moisture Content |
| ORN 31 | TRL Overseas Road Note 31 |
| PL | Plastic Limit |
| PI | Plasticity Index |
| RDA | Road Development Authority |
| SSCM | Standard Specification for Construction and Maintenance of |