

Sudan University for Science & Technology
College of Graduate Studies & Scientific Research

Comparative Study of Flexible Pavement Design Methodologies

دراسة مقارنة بين طرق ومنهجيات تصميم الرصف المرن

**Thesis Submitted for Partial Fulfillment of M.Sc. Degree in Civil
Engineering (Highway and Transportation)**

Prepared by:

Selma Ahmed Mohamed Abdalla

Supervisor:

Prof. Galal Abdalla Ali

2011

السورة

قال تعالى:

(بسم الله الرحمن الرحيم ۞ الحمد لله رب العالمين ۞ الرحمن
الرحيم ۞ مالك يوم الدين ۞ اياك نعبد و اياك نستعين ۞ اهدنا
الصراط المستقيم ۞ صراط الذين انعمت عليهم ۞ خير الممضوب
عليهم ۞ ولا الضالين ۞ آمين)

سورة الفاتحة

Dedication

Dedicated to my parents and sisters for their
understanding and support that assisted me to
pursue my studies

Acknowledgements

I would like to express my deepest gratitude and thanks to my supervisor, Prof Galal Abdalla Ali who has provided me with numerous opportunities to perform research in the area of pavement design. I am gratefully indebted to him for the challenges he has placed upon me as well as his invaluable guidance throughout this research. I would like to express my thanks to National Highway Authority (NHA), Newtech Engineering Company and Ashraf& Salah consultant for providing data for design.

I would like also to thank Willbur Smith Engineering Associates and Engineer Abubaker .M. Khalafalla for the design data regarding Alain- Nahel Road in UAE

Thanks everyone.

Abstract

Road deterioration, potholes, ruts, crack, and undulations, set evidence on the importance of investigating the causes of these defects and then offering a solution to eliminate them. Poor pavement thickness design is one of the most important reasons affecting road deterioration and distress. The overall objective of this study is to develop a good knowledge of flexible pavement design methodologies, their use, application, data required for design, advantages and disadvantages and compare among them. Also to develop a good knowledge of the new design technology of flexible pavement structures based on mechanistic analysis and the common empirical parameters used by AASHTO Guide for Design of Pavement. The use of empirical methods has been established and widely recognized approach to thickness design; however, their disadvantages are becoming more prevalent with the increase in understanding of mechanistic-empirical design. The new 2002 AASHTO 'Guide for Design of Pavement Structures' is based on mechanistic -empirical procedures.

The research plan was to study and collect data for sample roads in Khartoum State (Alhuda Street) and national road (Atbara Heya Road) and in UAE (Al-ain Nahel Road) the data for design of these roads are subgrade strength (CBR and MR), traffic data, road location and climate conditions, The flexible pavement design methods applied were: TRM, AASHTO, AI, SPDM and Layers system.

Comparison between results had been made in term of total thickness of pavement. It was found for case study1 and 2 that AI method gave the smallest thickness, RN31 method gave the largest thickness, and SPDM and AASHTO gave in between ,for case study3 the method that gave the smallest thickness was RN31, while the method that gave the largest thickness was AASHTO. Medium values were by SPDM and AI methods

Method that gives results closer to the results of the program

-AASHTO method was closer in result to SPDM in case study1 Alhuda Street while AI was the closer one in case study2 Atbara Heya and RN31 was the closer one in case study 3 Alain Nahel road in term of total thickness. SPDM computer software program is effective and easy to be applied. Hence it is recommended to be used in pavement design.

مستخلص

تدهور وضع الطرق من الحفر والأخاديد ، والتشققات ، والتموجات ، توجب أهمية التحقيق في أسباب هذه العيوب ومن ثم تقديم حل للقضاء عليها. سوء تصميم سمك الرصف هي واحدة من أهم الأسباب التي تؤثر على تدهور الطرق . الهدف العام من هذه الدراسة هو تطوير معرفة جيدة بمنهجيات وطرق تصميم الرصف المرن ، استخداماتها وتطبيقها والبيانات اللازمة للتصميم ، وعيوب ومزايا كل طريقة والمقارنة بينهم. أيضا لتطوير المعرفة الجيدة لتكنولوجيا التصميم الجديدة في مجال الرصف المرن تعتمد على التحليل الميكانيكي والمعاملات التجريبية المشتركة التي يستخدمها دليل AASHTO لتصميم الرصف. استخدام الطرق التجريبية معترف به على نطاق واسع لتصميم سمك الرصف ، ولكن عيوبها أصبحت أكثر انتشارا مع الزيادة في فهم التحليل الميكانيكي التجريبي للتصميم. ويستند "دليل التصميم الانشائي الجديد للرصف AASHTO " لعام 2002 على إجراءات التحليل الميكانيكي التجريبي.

خطة البحث والدراسة جمع البيانات لعينة من الطرق في ولاية الخرطوم (شارع الهدى) وطريق قومي (عطبرة هيا) وطريق (العين- ناهل) بدولة الامارات, البيانات لتصميم هذه الطرق هي قوام التربة التحتية (CBR و MR) ، بيانات حركة المرور ، موقع الطريق والظروف المناخية .

طرق تصميم الرصف المرن التي طبقت : TRL ، AASHTO ، AI ، SPDM ونظام الطبقات. المقارنة بين النتائج في المدى الكلي لسمك الرصف. وجد أنه في حالة الدراسة 1 و 2 AI أعطى أصغر سمك و RN31 أعطى أكبر سمك ، SPDM و AASHTO ، أعطت القيم المتوسطة . في حالة الدراسة (3 RN31 أعطى أصغر سمك ، في حين أن AASHTO أعطى أكبر سمك. AI و SPDM أعطت القيم المتوسطة

الطريقة التي اعطت نتائج أقرب إلى نتائج البرنامج SPDM في المدى الكلي لسمك الرصف هي AASHTO في حالة شارع الهدى بينما كان الاقرب في حالة طريق عطبرة هيا هي AI و RN31 كان الاقرب في حالة طريق العين- ناهل

برنامج الكمبيوتر SPDM فعال وسهل التطبيق. وبالتالي فمن المستحسن استخدامه في تصميم الرصف.

Table of Contents

-Dedication.....	II
-Acknowledgements.....	III
- Abstract	IV
- Arabic Abstract	V
- Table Of Contents	VI
- List of Tables	IX
- List of Figures	X
-Abbreviations	XII
-CHAPTER ONE	INTRODUCTION
-1.1 General introduction.....	1
-1.2 Pavement definitions.	2
-1.3 Background.....	5
-1.4 Pavement design factor.....	10
-1.5 Objectives.....	12
-1.6 Report Contents	14
-CHAPTER TOW	LITERATURE REVIEW
2.1 General.....	15
2.2Design Parameters.....	15
2.3Flexible Pavement Design.....	19
2.3.1Empirical Design.....	19
2.3.1.1(CBR) Method.....	21
2.3.1.2 Road Note Method (RN31)	22
2.3.1.3 AASHTO Empirical Design Method.....	24

2.3.1.4 Asphalt Institute Method (AI)	29
2.3.2 Mechanistic-Empirical design.....	37
2.3.2.1 Theoretical Analytical Methods.....	38
2.3.2.1.1 Elastic layer analysis.....	39
2.3.2.1.2 Finite Element procedures.....	38
2.3.2.2 SPDM Method.....	43
2.3.2.3 The 2002 Mechanistic-Empirical Design Procedure.....	46
2.3.3 Difference between mechanistic-empirical over empirical methods.....	54
2.4 MEPDG Programme.....	54
2.5 SPDM Programme.....	57
-CHAPTER THREE MATERIALS and METHODS (CASES of STUDY)	
3.1 Study and Structural Design Comparison of ALHUDA Street	70
3.1.1 Road Note Method (RN31)	71
3.1.2 Asphalt Institute Method (AI)	72
3.1.3 AASHTO Method.....	63
3.1.4 Elastic layer method	76
3.1.5 (SPDM) Program.....	77
3.2 Study and Structural Design Comparison of HEAYA ATBARA ROAD.....	78
3.2.1 AASHTO Method.....	80
3.2.2 Asphalt Institute Method (AI)	84
3.2.3 Elastic layer method.....	88
3.2.4 SPDM Method.....	89
3.3 Study and Structural Design Comparison of AL-AIN_NAHEL ROAD	90
3.3.1 RN(31) Method.....	90

3. 3.2 Asphalt Institute Method (AI).....	91
3. 3.3 Elastic layer method.....	93
3. 3.4 SPDM Method.....	93

-CHAPTER FOUR

RESULTS

4.1 Table of Results for Structural Design of ALHUDA STREET.....	95
4.2 Table of Results for Structural Design of HEAYA ATBRA ROAD.....	99
4.3 Table of Results for Structural Design of AL-AIN_NAHEL ROAD (UAE).	102

-CHAPTER FIVE

ANALYSIS and DISCUSSION

5.1 Analysis of Results.....	105
4.5.1 Analysis of Results for Structural Design of ALHUDA STREET	106
4.5.2 Analysis of Results For Structural Design of HEAYA ATBRA ROAD.....	108
4.5.3 Analysis of Results For Structural Design of AL-AIN_NAHEL ROAD (UAE)....	110
5.2 Conclusions.....	112
5.2 .1 Summary.....	112
5.2 .2 Recommendations.....	113
5.2 .3Future studies.....	114

List of Tables

Table 2.1: Traffic Classes According to RN31 Method	23
Table 2.2: Soil Classes According to Road Note	23
Table 2.3: (a_3, a_2, a_1) Layers Coefficients	26
Table 2.4: (m_2, m_3) Drainage Coefficients.....	26
Table 2.5 : %Truck in the Design Lane.....	31
Table 2.6: (M_R %) Design Ratio of Resilient Modulus.....	32
Table 2.7: Minimum Thicknesses for Pavement Layers.....	36
Table 2.8: Axle Loads Converted Coefficients According to SPDM Method.....	45
Table 3.1: Thickness design of pavement layers (Atbara Heya road) due to consultant....	79
Table 3.2: Values of Resilient Modulus of Subgrade(Atbara Heya road).....	81
Table 3.3: The Values of D_3 according to AASHTO method (Atbara Heya road).....	83
Table 3.4: M_R Values in Ascending Order for Cumulative design Curve (Atbara Heya road).....	85
Table 3.5: Design Ratio of Resilient Modulus.....	86
Table 4.1: Results of Design Methods for Alhuda street.....	95
Table 4.2 : Results of Design Methods for Atbara Heya Road.....	99
Table 4.3: Results of Design Methods for Alain Nahel road	102

List of Figures

Fig 1.1: Flexible Pavement Cross section.....	3
Fig 1.2: Rigid Pavement Cross section.....	4
Fig 1.3: Load Distribution for a Typical Flexible Pavement and a Typical Rigid Pavement..	5
Fig 1.4: Fatigue Cracks in Flexible Pavement.....	18
Fig 2.1: CBR Design Chart.....	21
Fig 2.2: AASHTO Nomographs for Pavement Design.....	28
Fig 2.3: Asphalt Institute Chart of full depth design	33
Fig 2.4: Chart of Emulsified Asphalt Mix Type.....	34
Fig 2.5: Chart of untreated aggregate base 8.0 in	34
Fig 2.6: Layered System Consist of (n) Layer Subjected Crucial Load.....	41
Fig 2.8: Design Process for Asphalt Pavement according to MEPDG	49
Fig 2.9: Operating Windows ofMEPDG2002.....	51,52,53
Fig 3.1 :CBR Values Distribution of Heya Atbara Road.....	81
Fig 3.1: MR Cumulative Design Curve.....	85
Fig 4.1: AI, SPDM&EM Design Results.....	96
Fig 4.2: AI, SPDM&EM Design Results.....	97
Fig 4.3: AI, AASHTO&TRL Design Results.....	98
Fig 4.4: AI, EM&SPDM Design Results.....	101
Fig 4.5: AI, AASHTO&TRL Design Results.....	101
Fig 4.6: AI&EM Design Results.....	103

Fig (4.7): AI&SPDM Design Results	104
Fig (4.8): AI, AASHTO&RN31 Design Results	104

Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
AI	Asphalt Institute
AADT	Average Annual Daily Traffic
BS	British Standard
CMSAPP	Calibrated Mechanism Structural Analysis of The Pavement
CBR	California Bearing Ratio
HMA	Hot Mix Asphalt
HRB	Highway Research Board
HCADT	Heavy Commercial Average Annual Daily Traffic
FWD	Falling Weight Deflectometer
FE	Finite Element Method
IRI	International Roughness Index
S mix	Asphalt Mix Stiffness Modulus
S bit	Bitumen stiffness modulus of original asphalt for analyzing low temperature cracking
SF	Soil Factor
LL	Liquid Limit
LTPP	Long Term Pavement Performance
ORN	Overseas Road Note
TRL	Transportation Research Laboratory
G.E	Granular Equivalent Thickness
GI	Group Index

RN31	Road Note 31
R -value	Resistance Value
R	Reliability in AASHTO Design Guide
S	Soil Strength
S _o	Overall Standard Deviation in AASHTO Design Guide
SN	Structural Number
SPDM	Shell Pavement Design Method
M-E	Mechanistic -Empirical
MEPDG	Mechanistic Empirical Pavement Design Guide
M.D.D	Maximum Dry Density
MR	Resilient Modulus
MAAT	Mean Annual Air Temperature
MNROAD	Minnesota/Road
NCHRP 1-37A	National Cooperative Highway Research Program
ESWL	Equivalent Single Wheel Load
ESAS	Equivalent Single Axes
ESAL	Equivalent Single Axial Load
E ₁	Elastic Modulus of Layer1 or HMA Layer
E ₂	Elastic modulus of Layer2 or Base Course
E ₃	Elastic Modulus of Layer3 which may be Subbase or Subgrade
E _p	Effective Modulus of all Pavement Layers above the Subgrade
E	Elastic Modulus

E t	Tensile Strain
E _c	Compressive Strain
EMS	Emulsified Asphalt
PCC	Portland Cement Concrete
PDMAP	Probabilistic Distress Model for Asphalt Pavement
PSI	Present Serviceability Index
W18	Number of Equivalent 18-kip Single Axial Load
WASHO	Western Association of State Highway Officials
WSDOT	Washington (State) Departments of Transportation
ZR	Normal Deviate for Given Reliability R

