

## الآية

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

قال تعالى: ﴿وَلَا تَمْشِ فِي الْأَرْضِ مَرَحًا إِنَّكَ لَنْ تَخْرِقَ الْأَرْضَ وَلَنْ تَبْلُغَ  
الْجِبَالَ طُولًا (37) كُلُّ ذَلِكَ كَانَ سَيِّئَهُ عِنْدَ رَبِّكَ مَكْرُوهًا (38) ذَلِكَ مِمَّا  
أَوْحَى إِلَيْكَ رَبُّكَ مِنَ الْحِكْمَةِ وَلَا تَجْعَلْ مَعَ اللَّهِ إِلَهًا آخَرَ فَتُلْقَى فِي جَهَنَّمَ  
مَلُومًا مَدْحُورًا (39)﴾

صدق الله العظيم

سورة الإسراء الآيات (37-38-39)

## Dedication



*This research thesis is dedicated to:*

*My parents, who continuously encouraged and  
supported me in countless ways,*

*My beloved brothers and sisters;*



## Acknowledgements

First and foremost, I must acknowledge my limitless thanks to Allah, the Ever Magnificent; the Ever-Thankful, for His helps and bless. I am totally sure that this work would have never become truth, without His guidance.

I owe a deep debt of gratitude to my supervisor **Prof Dr. Galal A. Ali Mohamed** for his time, encouragement, and expertise during all phases of the research for his exquisite attention to detail and for his demand for excellence. Thank you, **Prof Dr. Galal A. Ali Mohamed** now and always.

I am most grateful to Dr. Rashid A. Saeed and Mr. Mubark M. A. Elmubark for their time and willing help, particularly providing their high-quality know-how in information technology and computer programming that contributed to the development of the software applied in this study.

## Abstract

In this study the thickness of rigid pavement was determined using manual computations by applying two design approaches namely American Association of State Highway and Transportation Officials Method (AASHTO) and Portland cement Association Method (PCA). There are four types of rigid pavements; but this study focuses on Jointed Plan Concrete Pavement (JPCP) and Jointed Reinforced Concrete Pavement (JRCP).A computer program with Visual Basic software was developed, entitled GalalM-RP program, to determine the rigid pavement design thickness in accordance with PCA method. Al-Ilaifoun urban-rural highway was selected as a case study, the thickness of the rigid pavement was computed using manual method to verify the results obtained from GalalM-RP program. Comparison of the results showed that the difference between manual design and GalalM-RP software did not exceed 5%.The computer program GalalM-RP can be used reliably as design thickness program for rigid pavements with doweled joints and without concrete shoulders.

## تجريـد

في هذه الدراسة تم حساب سماك الرصف الخرساني بإستخدام الحسابات اليدوية من خلال تطبيق أسلوبين من أساليب التصميم مثل طريقة الجمعية الأمريكية للطرق والنقل AASHTO وطريقة جمعية الأسمنت البورتلاندي PCA . هناك أربعة أنواع من الأرصفة الخرسانية لكن هذه الدراسة ركزت على الرصف الخرساني المربوط والرصف الخرساني المربوط المسلح. تم تصميم برنامج حاسوب بإستخدام لغة الفيجول بيزيك (Visual Basic) وسمى GalalM-RP لحساب سماك الرصف الخرساني استنادا على طريقة تصميم جمعية الأسمنت البورتلاندي PCA لتصميم الطرق الخرسانية . تم اختيار طريق العيلفون (Al-Ilaifoun highway) كدراسة حالة. حسب سماك الرصف الخرساني بإستخدام الطريقة اليدوية للتحقق من النتائج التي تم الحصول عليها من برنامج GalalM-RP . أظهرت المقارنة بين النتائج أن الفرق بين التصميم اليدوي و GalalM-RP لم يتعدى ال 5% وشملت الإستنتاجات أن البرنامج الحاسوبي GalalM-RP يمكن إستخدامه بشكل موثوق به كبرنامج للتصميم الإنسائي للطرق الخرسانية التي تحتوي على الأوتاد (dowel) دون الكتوف الخرسانية ( without Concrete ) .(Shoulders

## TABLE OF CONTENTS

الآية	i	
<b>Dedication</b>	ii	
<b>Acknowledgment</b>	iii	
<b>Abstract in Arabic</b>	iv	
<b>Abstract in English</b>	v	
<b>Table of contents</b>	vi	
<b>Abbreviations and Definition of Terms</b>	x	
<b>List of Tables</b>	xiii	
<b>List of Figures</b>	xiv	
<b>CHAPTER1</b>	<b>INTRODUCTORY BACKGROUND</b>	
1.1	Introduction	1
1.2	Problem Statement and significance	3
1.3	The Design Methods and Procedures	4
1.4	Objectives and Scope of Research	5
1.5	Out Line of Thesis	5
<b>CHAPTER2</b>	<b>RIGID PAVEMENT TYPES AND DESIGN METHODOLOGIES</b>	
	<b>FOR JOINTED PLAIN AND JOINTED REINFORCED</b>	
	<b>CONCRETE PAVEMENTS</b>	
2.1	Introduction	6
2.2	Types of Concrete Pavements	8

2.3	Joints and Dowel Bars	11
2.4	Design Parameters and Methodologies for JPCP and JRCP	12
2.4.1	Portland Cement Association (PCA) Method	12
2.4.1.1	Design factors	13
2.4.1.2	Load Safety Factors	14
2.4.1.3	Design Methodology	15
2.4.2	AASHTO Method	16
2.4.2.1	Design Variables	16
2.4.2.2	Design Equations	17
2.4.2.3	Design Chart	17
2.5	Other Design Features	19
2.5.1	Joint spacing	19
2.5.1.1	Jointed Plain Concrete Pavement (JPCP)	19
2.5.1.2	Jointed Reinforced Concrete Pavement (JRCP)	20
2.5.2	JRCP Reinforcement	21

### **CHAPTER 3 CASE STUDY PROJECT**

3.1	Location and Characteristics of the Case-Study Road Project	22
3.2	ESAL for the Case Study	24
3.3	Upgrading of Al-Ilaifoun Road to Dual Highway	25
3.4	Pavement Structural Design Methodology	25

## **CHAPTER 4 DESIGN OF JOINTED AND JOINTED REINFORCED CONCRETE PAVEMENT**

4.1	Introduction	27
4.2	Load Stresses	27
4.3	Subgrade Resilient Modulus $M_R$ and Reaction Modulus $k$	28
4.4	Design Slab thickness for JPCP and JRCP	29
4.4.1	Portland Cement Association Design Method	29
4.4.2	AASHTO (1993) design method	35
4.4.3	Other design features	38

## **CHAPTER 5 APPLICATION OF SOFTWARE PROGRAM**

5.1	Introduction	44
5.2	Main Screen	45
5.3	Traffic Analysis Screen	46
5.4	Calculations of Pavement Thickness Screen	47

## **CHAPTER 6 RESULTS AND DISCUSSION**

6.1	Results	51
6.2	Discussions	61

## **CHAPTER 7 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS**

7.1	Summary	62
7.2	Conclusions	62
7.3	Recommendations	64

## **REFERENCES**

## **APPENDICES**

### **APPENDIX A      PCA DESIGN METHOD: TABLES AND CHARTS**

A.1	PCA Design Method: Tables	67
A.2	PCA Design Method: Figures	68

### **APPENDIX B      AASHTO DESIGN METHOD: TABLES AND CHARTS**

B.1	AASHTO Design Method: Tables	71
B.2	AASHTO Design Method: Figures	75

## **List of Abbreviations and Symbols**

**RPs** : Rigid (or Concrete) Pavements

**PCC** : Portland Cement Concrete

**JPCP** : Jointed Plain Concrete Pavement

**JRCP** : Jointed Reinforced Concrete Pavement

**CRCP**: Continuous Reinforced Concrete Pavement

**PCP** : Prestressed Concrete Pavement

**AASHTO**: American Association of State Highway and Transportation Officials

**PCA**: Portland Cement Association

**AI**: Asphalt Institute

**CBR**: California Bearing Ratio

**N<sub>A</sub>**: Number of Axles per Trucks Surveyed, say 100

**ADT**: Daily Traffic, veh. /day in both directions

**D**: Direction Split (the larger value is used in the design)

**P<sub>T</sub>**: % Trucks

**r**: Annual Traffic Growth Factor for Design Period n

**L**: The Lane Distribution Factor which varies with the volume of traffic and the number of lanes.

**w<sub>18</sub>** : The Number of 18-kip (80-kN) Single-axle load applications

**Z<sub>R</sub>** : Normal deviate for a given Reliability R

**S<sub>0</sub>**: Overall Standard Deviation

**D**: Slab Thickness in Inches

**ΔPSI** : Present serviceability index

**P<sub>t</sub>** : The Serviceability at time t

**S<sub>c</sub>** : Modulus of Rupture of Concrete

**C<sub>d</sub>** : Drainage Coefficient

**J**: Load Transfer Coefficient

**E<sub>c</sub>** : Elastic Modulus

**K** : Modulus of Subgrade Reaction

**ΔL**: the Joint Opening caused by Temperature Change and Drying Shrinkage of concrete

**α<sub>t</sub>**: The Coefficient of Thermal Expansion of Concrete, generally 5 to

$6 \times 10^{-6} /{ }^{\circ}\text{F}$  (9 to  $10.8 \times 10^{-6} /{ }^{\circ}\text{C}$ )

**ε**: The Drying Shrinkage Coefficient of Concrete, approximately

$0.5 \text{ to } 2.5 \times 10^{-4}$

**L**: is the Joint Spacing or Slab Length

**ΔT**: is the Temperature Range, which is the Temperature at placement minus the lowest mean monthly temperature

**C**: is the Adjustment Factor due to slab-subbase Friction, 0.65 for stabilized base and 0.8 for granular subbase.

**A<sub>s</sub>**: is the Area of Steel required per unit width

**f<sub>s</sub>** : is the Allowable Stress in Steel.

**$f_a$** : Average Friction Coefficient between Slab and Foundation usually taken as 1.5

**$\gamma_c$** : is the Unit Weight of the Concrete

**$h$** : is the Thickness of the Slab

**$m$** : Number of Axle Load Groups

**$\mu$** : The Allowable Bond Stress

**$F_i$**  : Equivalent Axle Load Factor (EALF) for each axle load group.

**$n_i$**  : Number of passes of the  $i$ th-axle load group during the design period

## List of Tables

Table 3- 1: Traffic Analyses for Pavement Design.....	24
Table 4 -1: Average Daily Traffic Volumes (Current ADT <sub>current</sub> ).....	30
Table 4 -2: Axle Load Distributions for Al-Ilaifoun Road .....	31
Table 4 -3: Equivalent Stresses for Slabs without Concrete Shoulders .....	33
Table 4 -4: Erosion Factors for Slabs with Doweled Joints and no Concrete Shoulders .....	34
Table 6 -1: Manual Solution Against GalalM-RP program.....	58
Table 6 -2: Comparison thickness design between AASHTO and PCA design method.....	61
Table A -1: Effect of Untreated Subbase on $k$ Values.....	67
Table A- 2: Recommended Dowel Size and Length.....	67
Table B -1: Recommended Load Transfer Coefficient for Various Pavement Types and Design Conditions .....	71
Table B -2: Recommended Value of Drainage Coefficient, $C_d$ , for Rigid Pavement .....	71
Table B- 3: Suggested Levels of Reliability for Various Functional Classifications.....	72
Table B- 4: Yield Strength and Allowable Stress for Steel.....	72
Table B -5: Weights and Dimensions of Welded Wire Fabric .....	73
Table B -6: Weights and Dimensions of Welded Wire Fabric .....	74

## List of Figures

Figure 2-1: Rigid Pavement Rigidity and Typical Thickness.....	7
Figure 2-2: Four types of concrete pavements (1 ft = 0 .305 m).....	9
Figure 2-3: Dowel Bars.....	12
Figure 2-4: Joint Opening .....	20
Figure 3-1: Al-Ilaifoun highway segment showing the survey Stations 1, 2 and 3.....	22
Figure 3-2: Al-Ilaifoun Highway Upgrading Under Construction.....	25
Figure 4- 1: Design chart for rigid pavements based on mean values .....	36
Figure 4- 2: Schematic illustration of wire reinforcement .....	39
Figure 4- 3: Diameter, spacing, and length of the tie bars for JPCP .....	41
Figure 5- 1: Main Screen .....	45
Figure 5- 2: Traffic Analysis Screen .....	46
Figure 5- 3: Calculations of Pavement Thickness Screen.....	48
Figure 5-4: Display Result Screen.....	49
Figure 6- 1: GalalM-RP Results of PCA Traffic Analysis.....	51
Figure 6- 2: GalalM-RP calculation of pavement thickness 9in.....	52
Figure 6- 3: GalalM-RP calculation of pavement thickness 9.5in.....	53
Figure 6-4: GalalM-RP calculation of pavement thickness 10in.....	54
Figure 6-5: Manual Calculation by Design Worksheet PCA: 9in .....	55
Figure 6- 6: Manual Calculation by Design Worksheet PCA: 9.5in.....	56
Figure 6- 7: Manual Calculation by Design Worksheet PCA: 10in .....	57

Figure 6- 8: Fatigue Percent Manual Solutions against Fatigue Percent GalalM-RP .....	58
Figure 6-9: Damage percent manual solution against damage percent GalalM-RP .....	59
Figure 6- 10: Graphical presentation for thickness pavement design using manual solution.....	59
Figure 6- 11: Graphical presentation for thickness pavement design using GalalM-RP .....	60
Figure 6- 12: Manual solution VS GalalM-RP Software Program.....	60
Figure 6- 13: Typical Thickness Design.....	62
Figure A- 1: Effect of various thicknesses of granular subbase on $k$ values...	67
Figure A-2: Stress ratio factors versus allowable load repetitions both with and without concrete shoulders. ....	68
Figure A-3: Erosion factors versus allowable load repetitions without concrete shoulders.....	70
Figure B- 1: Chart for $k$ as a function of bedrock depth.....	75
Figure B- 2: Chart for estimating composite $k_{\infty}$ .....	76