

**UNIVERSITI TEKNOLOGI MARA**

**FATIGUE DAMAGE RATIOS  
AND RUTTING DAMAGE RATIOS  
FOR OVERLOADED HEAVY  
VEHICLES**

**OSAMA MAHMOUD YASSEN AL-HUSYNI**

Thesis submitted in fulfillment  
of the requirements for the degree of  
**Doctor of Philosophy**

**Malaysia Institute of Transport**

February 2016

## ABSTRACT

It is impossible for any country to have a rapid economic growth without a good and efficient transportation system. However, there are several problems affecting the transportation systems. One of the most important and common problem currently is the overloading of heavy vehicles and trucks. Road pavements performance, infrastructure performance, and safety are severely reduced by heavy vehicles overloading. Several studies carried out in Malaysia, United States of America, Colombia, Australia, France, Portugal, South Africa, China, Thailand, Pakistan, and Taiwan confirmed that overloading is a series problem around the world. This study aims to investigate the effects of overloaded heavy vehicles on flexible pavements in Malaysia, by developing models describing the degradation of flexible pavement fatigue and rutting lives under different axle loadings, axle configurations and tire pressures. The study also aims to determine fatigue and rutting damage ratios for each heavy vehicle types based on their actual weights for usage in flexible pavements design. Secondary data were collected from Weight-In-Motion stations, Falling Weight Deflectometer, Coring, Dynamic Cone Penetration and Ground Penetration Radar. The secondary data were used to form plenty of finite element models to form the deterioration models and damage ratios. Apart from the development of fatigue and rutting damage models and ratios, several other conclusions were derived. The study found that fatigue and rutting damage ratios increased rapidly due to overloading. Furthermore, it was found that the damage caused by single axle with two wheels is the largest, then the single axle with four wheels followed by tandem axle and then the tri-axle configuration. It was also found that tire pressure has a high effect of fatigue and rutting damages and thus regulations should include tire pressure limitation. Twenty four models were developed in this study to calculate fatigue damage ratios and rutting damage ratios for flexible pavement in Malaysia. Furthermore, Single trailer trucks with four axles, single unit trucks with two axles, and buses were identified to be causing most of the fatigue damage, while rutting is mainly caused by the same types of vehicles and single trailer trucks with six axles. The study also found that an average value of 4.23 for fatigue damage and 6.20 for rutting damage could be multiplied with heavy vehicles traffic volume to represent their effects and to be used for flexible pavements design in Malaysia.

# TABLE OF CONTENTS

	<b>Page</b>
<b>CONFIRMATION BY PANEL OF EXAMINERS</b>	<b>ii</b>
<b>AUTHOR'S DECLARATION</b>	<b>iii</b>
<b>ABSTRACT</b>	<b>iv</b>
<b>ACKNOWLEDGMENTS</b>	<b>v</b>
<b>TABLE OF CONTENTS</b>	<b>vi</b>
<b>LIST OF FIGURES</b>	<b>xiv</b>
<b>LIST OF ABBREVIATIONS</b>	<b>xxvii</b>

<b>CHAPTER ONE: INTRODUCTION</b>	<b>1</b>
1.1 Background Of The Study	1
1.2 Problem Statement	4
1.3 Objectives	6
1.4 Scope And Limitations	6
1.5 Significance Of The Study	7
1.6 Thesis Organization	8
<b>CHAPTER TWO: LITERATURE REVIEW</b>	<b>9</b>
2.1 Introduction	9
2.2 Pavement Structure	11
2.2.1 Flexible Pavement	12
2.2.2 Rigid Pavement	14
2.2.3 Composite Pavement	15
2.2.4 Pavement Damages	16
2.2.4.1 Fatigue Cracking	17
2.2.4.2 Rutting	19
2.2.5 Fem Method For Prediction Of Pavement Damages	20
2.3 Heavy Vehicles Loading	22
2.3.1 Axle Load And Traffic Loading In Pavement Design	22

2.3.2	Axle Load Limits	22
2.3.3	Overloading In Malaysia	24
2.3.4	Overloading In China	25
2.3.5	Overloading In South Africa	26
2.3.6	Overloading In Thailand	27
2.3.7	Overloading In Pakistan	27
2.3.8	Overloading In Taiwan	29
2.3.9	Effects Of Overloading To Pavements	30
2.3.10	Effects Of Overloading To Road Safety	35
2.3.11	Load Equivalency Factor Concept	37
2.3.11.1	Load Equivalency Factor Based On Asshto Method	37
2.3.11.2	Deficiencies Of Load Equivalency Factor Based On Aashto	40
2.4	Finite Element Analysis Of Flexible Pavement	41
2.4.1	Introduction For Pavement Analysis Models	43
2.4.2	Elastic Modulus Determination	44
2.4.3	Finite Element Method	45
2.4.4	Tire-Pavement Contact Area	46
2.4.5	Tire Pressure	47
2.4.6	Primary Response Parameters	48
2.4.7	Load Equivalency Factors	49
2.4.7.1	Load Equivalency Factors Based On Fatigue Criteria	50
2.4.7.2	Load Equivalency Factors Based On Rutting Criteria	50
2.5	Research Gap	51
2.6	Summary	56
<b>CHAPTER THREE: RESEARCH METHODOLOGY</b>		<b>58</b>
3.1	Introduction	58
3.2	Stage Three - Load Survey	61
3.2.1	Load Survey Stations	64
3.3	Stage Three - Falling Weight Deflectometer Data	64
3.3.1	Pavement Cross-Sections	67
3.4	Stage Four - Finite Element Modelling	69
3.5	Stage Four - Finite Element Modelling Using Plaxis	73
3.5.1	Specifying General Settings Of The Model	74

3.5.2	Creating A Geometry Model	76
3.5.3	Selecting Boundary Condition	78
3.5.4	Inserting Material Specifications	78
3.5.5	Mesh Generation	79
3.5.6	Performing Analysis	80
3.5.7	Viewing Output Results	80
3.6	Stage Five - Data Analysis	81
3.7	Summary	82
<b>CHAPTER FOUR: DAMAGE RATIO MODELS</b>		<b>84</b>
4.1	Introduction	84
4.2	Fatigue Damage Ratio Models	84
4.2.1	Fatigue Damage Model For Single Axle With Two Wheels And 500 kPa Tire Pressure	85
4.2.2	Fatigue Damage Model For Single Axle With Two Wheels And 700 kPa Tire Pressure	91
4.2.3	Fatigue Damage Model For Single Axle With Two Wheels And 900 kPa Tire Pressure	97
4.2.4	Fatigue Damage Model For Single Axle With Four Wheels And 500 kPa Tire Pressure	103
4.2.5	Fatigue Damage Model For Single Axle With Four Wheels And 700 kPa Tire Pressure	109
4.2.6	Fatigue Damage Model For Single Axle With Four Wheels And 900 kPa Tire Pressure	116
4.2.7	Fatigue Damage Model For Tandem Axle With Eight Wheels And 500 kPa Tire Pressure	122
4.2.8	Fatigue Damage Model For Tandem Axle With Eight Wheels And 700 kPa Tire Pressure	128
4.2.9	Fatigue Damage Model For Tandem Axle With Eight Wheels And 900 kPa Tire Pressure	133
4.2.10	Fatigue Damage Model For Tri-Axle With Twelve Wheels And 500 kPa Tire Pressure	139
4.2.11	Fatigue Damage Model For Tri-Axle With Twelve Wheels And 700 kPa Tire Pressure	145