ANALYTICAL AND FIELD STUDIES OF SAFETY ON EGYPTIAN HIGHWAYS

By

KHALED ZAKY HUSSIEN SALEM

A THESIS

Submitted to the Faculty of Engineering at
Benha University in Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In

CIVIL ENGINEERING

Shoubra faculty of engineering, Benha University
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UNDER SUPERVISION OF

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ABSTRACT

The traffic accidents problem disturbs the majority of people all over the world because of the harmful effects they may have on them. These effects could be summarized in loss of life, health damage that may cause handicap and damage to their properties. Therefore, researches all over the world were conducted to study traffic accidents to explain their causes and reduce their harmful effects; this study tries to model the traffic accidents to explain their causes.

High speeds increase the probability of accidents occurrence and the severity of them, so traffic accidents that occur on rural roads are assumed to be more dangerous and have more victims, cost and damage than those on urban roads with relatively lower speeds. Therefore, this work concentrates on rural road traffic accidents as its specific field of study.

This research aims to evaluate the safety level on the Ring Road, This objective is achieved by identification of the road characteristics which have the major effects on the road safety, the Field Inspection Survey which include four main tasks; identification of locations of major pavement defects, inventory of defective joints on bridge sections; inventory of damaged traffic safety barriers and signs, and Pavement Condition Index (PCI) survey, all distress types were recorded in a special form. The field data were then coded into a computer program for computing the PCI values.

The structural assessment of the existing pavement was carried out based on the AASHTO Guide for Design of Pavement Structures. Comparison between the existing pavement structures against the required pavement strength to sustain the design ESAL. Structural overlays were recommended in pavement areas that lack capacity to withstand the design ESAL.

Accident traffic data, provided by the "General Authority of Roads, Bridges and Land Transport, GARBLT", are used to identify the black spots and segments at which road characteristics data are collected, the road characteristics data are processed to calibrate different types of traffic accident models.

Statistical analysis was then conducted to estimate Number of Accidents (NA) as a function of surface indicators. Also, a statistical based model was developed to predict the NA and PCI from the road characteristics of the Ring Road. Research results can be used to assist decision makers to develop the road network to be more safe and minimize the accidents rate.

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Nomenclature

Symbols	Nomenclature
EPDO-R	Equivalent Property Damage Only-Rate
SI	Severity Index
F	Number of Fatal Accidents
J	Number Injury Accidents
PDO	Number of Property Damage Only Accidents
Nt	Total Number of Accidents
FMVSS	Federal Motor Vehicle Safety Standard
ADT	Average Daily Traffic
ROR	Run-Off-Road
OD	Opposite-Direction
IFI	International Friction Index
IRI	International Roughness Index
AC	Asphalt Content
PCI	Pavement Condition Index
FOD	Foreign Object Damage
NDT	Non Destructive Testing
FAA	Federal Aviation Administration
Mn/DOT	Mn Department of Transportation
VIV	Video Inspection Vehicle
PCC	Portland Cement Concrete
FHWA	National Transportation Safety Board and the Federal Highway Administration
MDSHA	Maryland State Highway Administration
FN	Friction Number
GARBLT	General Authority of Roads, Bridges Land Transport
ARS	Average Rectified Slope
EASL	Equivalent Single Axle Loads
D_D	Direction Distribution Factor
D_L	Lane Distribution Factor

AADT	Average Annual Daily Traffic
GF	Growth Factor
SN	Structure Number
P_i	Initial Serviceability
P_t	Terminal Serviceability
D_{OL}	Overlay Thickness
a_{OL}	Structural Coefficient for the Overlay
NA	Number of Accidents
G	Longitudinal Profile Grade
RC	Horizontal Curve Radius
TH	Thickness of Asphalt Layers
La	Number of Lanes
PT	Percent of Truck

CHAPTER 1

INTRODUCTION

1.1 General

Traffic accident problem disturbs the majority of people all over the world, because of the bad effects it has on them. The effects of road accidents include loss of life, health damage and damage of properties. Therefore, the research all over the world tries to explain accident causes to enable people to mitigate their harmful effects.

In Egypt, It should be noted that the rural road accidents forms about 12% of total traffic accidents in Egypt as estimated for the financial year 2007/2008 for the rural road accidents only. The analysis of rural roads traffic accident shows that for each accident that occurs there are about 0.8 dead persons and 3 injured persons. This study tries to model the traffic accidents occurrence on Egyptian roads in order to identify their causes and the priority of maintenance and the most convenient times to them on the selected roads.

This work concentrates on rural road accidents as they cause the major loss to the community. These effects result from the fact that rural roads are characterized by relatively long segments and sections, and have high speeds traffic compared to urban roads. Therefore, any error in safety measures, geometric features, or conflict between different road users, such as pedestrians, vehicles drivers etc., happening on rural roads could probably results in serious accidents.

1.2 Problem Definition

Inferior safety level on rural roads is a very serious and dangerous problem in Egypt. Accident statistics issued by the different governmental administrations in Egypt highlight this fact. Although traffic accident problem is serious and gnaws the Egyptian economy, modeling and valuating of accidents based on accurate scientific methodology, which could reduce the hazards of this problem by determining its causes and the most suitable solutions, is not available.

1.3 Research Objectives

The main objectives of this research are as follows:

1. Identification of the road characteristics which have the major effects on the road safety.
2. Field Evaluation of a road surface (Ring Road) by visual inspection using the program PAVER 5.2 to calculate the “PCI” for this road.
3. Evaluation of the safety factors irrigated on this road where the presence of islands and barriers separating traffic trends and the presence of signs indicative planning and traffic signs.
4. Identifying the most prevalent defects on the surface of the road in fact.
5. Using the results of field study of the work to conduct a statistical analysis using “SPSS 16” program to link accident rates with some other variables and extract some conclusions and important guidelines to limit the increase of the road accidents.
6. Determining priorities of maintenance on the selected road.

1.4 Thesis Organization

The thesis is organized in six main chapters. In Chapter (1), problem definition, main research objectives and thesis organization are introduced. Intensive literature review on the previous studies on accidents causes are discussed in Chapter (2). These causes include driver characteristics, roadway characteristics that affects accidents occurrence through roadway geometry, safety features. Moreover, it discusses how to determine pavement condition and evaluation; it also illustrates distress types, and classification and the main factors affecting pavement performance that has been discussed in some previous researches.

Chapter (3) aims to investigate the field inspection survey carried out to evaluate the current condition of pavement and record damaged traffic safety barriers, signs, and bridge joints of the Regional Ring Road.

Chapter (4) presents the evaluation of the current structural capacity of pavement in embankment areas along the Ring Road. Objective of this chapter is to evaluate the current structural capacity of pavement to sustain the traffic loads and to recommend any necessary actions to rehabilitate the existing pavement. All field samples and laboratory tests were conducted by GARBLT main laboratory. A total of twenty cores and three open pits were taken from the Ring Road.

Chapter 5 shows the analysis of traffic accident modeling data. It displays statistics for the road characteristics variables and their relations to the traffic accidents, it also demonstrate the relation between the road characteristics and the pavement condition index of the road surface.

Finally, summary, conclusions and recommendations for future work are presented in Chapter (6).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Traffic accidents have very harmful effects on the community, which is represented by person loss of life, health, property damage, physiological effects, etc. Traffic accident also affects the economy of the country due to temporary or permanent loss of the victims' output. Therefore, reducing accidents is the goal of many studies, which are performed at many research centers all over the world. This research calibrates the accident models and evaluates different types of accidents. Starting with reviewing previous studies, this chapter demonstrates traffic accident definition, black spot (or hazard location) definition and its identification method. It also demonstrates the factors affecting traffic accidents, the safety counter measures, traffic accident modeling methods. Moreover, examples on some of these methods are provided. In addition, accident valuation method and results of its application in some countries are illustrated in the following subsections.

2.2 Traffic Accident Definition

Garib (2001) said that traffic accident is an expression used to describe a certain failure in the performance of one or more of the driving component, the driver, the vehicle, and the roadway. Therefore, this failure results in death, injury, and/or property damage.

The unit of measuring the loss due to a fatal or an injury accident is defined by number of property damage only accident using relative cost between fatal or injury and property damage accidents. It means fatal or injury accidents are converted to times of property damage accident using the ratio of fatal, or injury accident cost to property damage accident cost. Accident rate used as a measure of traffic accident is given in Equation (2-1), (Behairy, 1989).

$$AR=\frac{\text{No of Accident}\times 1{,}000{,}000}{\text{ADT}\times 365\times N_Y\times L} \qquad (2\text{-}1)$$

Where,

AR: Accident rate, the unit is accident per million-vehicle kilometer

NY: Number of years.

L : Length of the section.

2.3 Identification of Black Spot (Hazard Location)

Black spot is an accident location at which a value of selected classification measure at that location is greater than the reference value of the same measure. The reference value is usually average of the measure values at locations grouped owing to any specified criteria, (Behairy, 1989).

The location is defined as a black spot if the selected value, as accident rate, is greater than the reference value, as critical accident rate that is statistically derived value. Therefore, accidents taken place at this location are not occurred by chance. Another definition of black spot, segment, etc. is provided in Table (2-1), (Institute of Highway Engineers, 1978).

Most of the time, the value of accident rate is defined by Equivalent Property Damage Only-Rate (EPDO-R) at certain location. This value is calculated by multiplying severity index with average accident rate for all accident types. The previous value is used as a selected value in determining the location of black spots. The next paragraph gives the formulas used to calculate the EPDO-R using severity index and average accident rate. EPDO-R is calculated, at each road section and for certain duration using formula in Equation (2-1), (Behairy, 1989).

Severity index (SI) is defined as a measure for the equivalence of traffic accident. It is equal to the numerical value which is used to convert the average value of different traffic accident types into property damage only accident rate. This value is calculated from the formula which driven by Behairy, (Behairy, 1989).

$$SI=\frac{N(F+IA)+M(IB+IC)+PDO}{N_t} \qquad (2\text{-}2)$$

Where,

SI: Severity index.

F: Number of fatal accidents.

IA: Number of class A injury accidents.

IB: Number of class B injury accidents.

IC: Number of class C injury accidents.

PDO: Number of property damage only accidents.

N and M: Two constants weigh the different classes of accidents according to the cost of each class.

Nt: Total no. of accidents.

Behairy (1989) stated that the previous formula cannot be used in Egypt, because the injury accidents in Egypt are not divided into classes. Therefore, the formula, which is used in Egypt, is:

$$SI=\frac{a \times F + b \times J + PDO}{N_t} \tag{2-3}$$

Where,

F: Number of fatal accidents.

J: Number injury accidents.

PDO: Number of property damage only accidents.

a and b : Two constants weigh the different classes of accidents according to the cost of each class.

Where,

a: (average cost of fatal accident)/ (average cost of property damage only accident).

b: (average cost of injury accident)/ (average cost of property damage only accident).

Nt: Total number of accidents.

Table (2-1): Criteria used for identifying black spots, (Institute of Highway Engineers1978)

Criteria	Elements	1970 Definition	1973-78 Definition	Current Definition
Black Spot	Accident	All Types	As 1970	
	Unit	1/10th kilometer o.s. Grid Square for all roads		
	Time	Any 12-month period ending in the current year. Printout monthly		
	Reaction	4 or over		
Black Site	Accident	All Types	As 1970	Section of any class of road
	Unit	Section of class M, A& B roads within 3/10th Kilometer o.s. grid lines, either Basting or Northing according to road alignment.	As 1970	
	Time	12 Months of any period	Previous 3 calendar Years	
	Reaction	4 or over	12 or over	
Black Mile	Accident	All Types	All Types	
	Unit	1 mile length of road	1 mile length of road	
	Time	Calendar year	Calendar year	
	Reaction	The twenty 1-mile lengths of road having the highest accident record	12 months (Dec – Nov of following year). The 21 miles lengths of road having the highest accident record	

2.4 Variables Affecting Accident Frequently and Severity

Traffic safety is a function of good management, consistent geometric design, roadway illumination, for giving roadside features, timely maintenance, uniform enforcement, understandable traffic control measure, and reasonable traffic operation, (Garib, 2001). Moreover, driver is considered one of the most important factors.

The factors affecting the road traffic safety are Driver, Vehicle, Roadway characteristics, and weather condition. Moreover, the traffic volume effect on accident occurrence depends on drivers' behavior and reaction, vehicle response and roadway features. In Egypt, these factors are responsible for accident occurrence by the percentages of 74%, 17% and 4% for driver, vehicle and road characteristics factors respectively. These ratios are calculated from the available accident database used in this work. The following subsections discuss some reasons for these variables sharing in traffic accidents.

2.4.1 Driver

Driver ability to control the vehicle is the most effective measure of controlling occurrence of accident probability to occur. His ability is affected by roadway and vehicle’s condition, making activities like talking in phone, eating, etc. The more the driver attention is distracted the more the increase of accident occurrence probability. Moreover, driver performance may be affected by mental and physical limitations, (Garib, 2001). There are also other factors affecting driver behavior such as age, sex, attitudes, alcohol and drugs. Also, Fatalities rates are influenced by driver’s age and sex as shown in Figure (2-1).

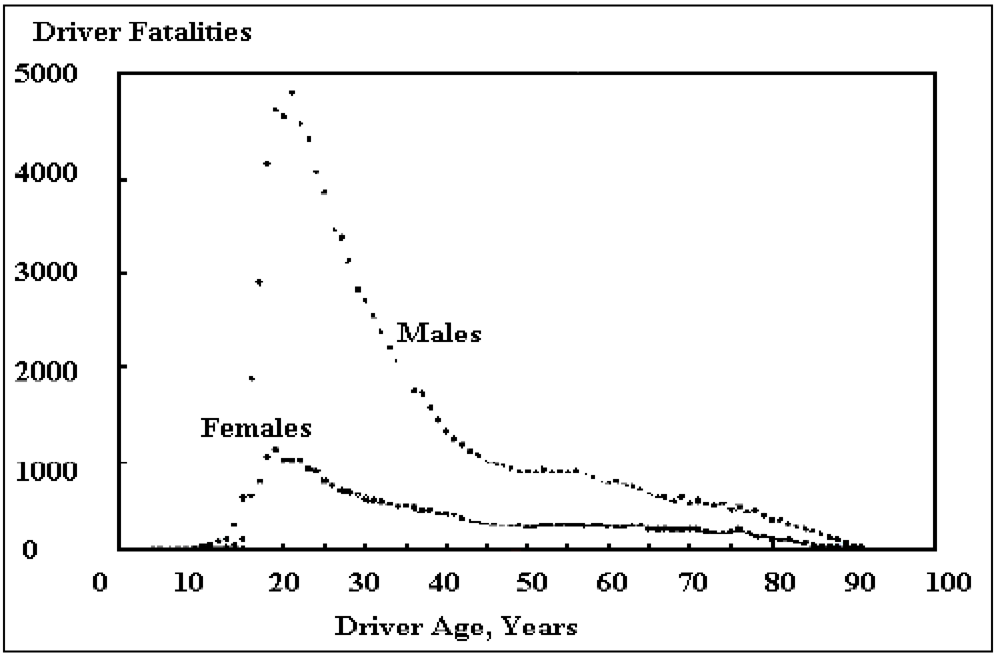


Figure (2-1): No. of driver fatalities versus sex and age, (Garib, 2001).

It is noticed from the curve that driver sex affects the accident occurrence frequencies on the rural roads. Also, male makes traffic accidents more than female does all over the age scale of driver. Moreover age affects on accident occurrence as the driver fatalities in the age of the 15-30 years old is greater than all the fatalities occurrence all over other ages scale.

2.4.2 Vehicle

Vehicles motion on roads must be in balance with the speed moving by (Garib, 2001). Bad maintenance may affect the required moving balance by reducing the vehicle parts needed quality. Many faults in the vehicle can cause accidents like braking red light, turning flasher, quality of vehicle doors locking, tires, brakes, windshield, etc, (Garib, 2001). These are main factors, of which any defect in one or more of them may cause an accident occurrence. Table (2-2) gives the responsibility of the vehicle mass in the accident severity.

Table (2-2): Drivers' fatalities in cars of mass m_i in crashes with cars of mass m_j, (Garib, 2001).

	Car j							
Car i	Mass.kg	m1	m2	m3	m4	m5	m6	Total
	500-900 m1	34	79	156	352	582	578	1781
	900-1100 m2	33	86	165	396	679	693	2052
	1100-1300 m2	36	74	171	443	684	698	2106
	1300-1500 m2	47	79	226	604	1088	1132	3176
	1500-1800 m2	34	95	189	558	1071	1253	3200
	1800-2400 m2	35	70	139	415	753	878	2290
	Total	219	483	1064	2768	4857	5232	14605

Responsibility of vehicle maintenance is clear in Table (2-3) which describes the accident reduction ratio if some parts of the vehicle are well maintained. These ratios follow the FMVSS (Federal Motor Vehicle Safety Standard).

Table (2-3): Fatality reduction estimated by Kahane for various federal motor vehicle safety standards (FMVSS), (Garib, 2001).

Description	FMVSS	Occupants protected	Fatalities prevented	
			Protected Occupant	Average Over all Occupants
Energy absorbing column Column displacement	203 204	Driver	6.6%	4.4
Instrument panels	201	Front Passengers	7%	1.7%
Side structure	214	All	17%	1.7%
Door locks	206	All	1.5%	1.5%
Roof crush resistance	216	All	0.43%	0.43%
Windows glazing	212	All	0.39%	0.39%
Head restraints	202	Driver and Right Front Passengers	0.36%	0. 33%
Braking improvements	105	All	0. 9%	0. 9%

2.4.3 Roadway Characteristics

Many factors could affect safety in highway characteristics. These factors are influenced by good road design and continuous maintenance. The better the road design and road maintenance, the lesser the road characteristics responsibility in the accident occurrence. The following subsections explain what is mentioned in this paragraph.

2.4.3.1 Effect of Lane Width, Shoulder Width and Shoulder Type

From more than 50 parameters, which affect safety, three parameters only have greater effects. These factors are determined through review of 30 studies. The results of these studies estimated relation between roadway and safety for two-lane roadway that have ADT 3000 or less as follows (Garib, 2001):

1. Increase of lane/shoulder width beyond 11 ft (3.35m) may not be effective in further reduction in accident rates
2. Studies indicate that rates of runoff road accidents are higher for low ADT group specially, with sharp curves, and poor road sides.
3. Decrease in accident rates is achieved in case of controlling the other factors by 6-20% in Run-Off-Road (ROR), and Opposite-Direction (OD) if shoulder is widened from 1 (0.30m) to 9 ft (2.74m).

This means that lane width, shoulder width and shoulder type have high effect on safety on rural roads. The following model is calibrated in a study performed in Kentucky and Ohio states which is used for forecasting the accident rate in the roadway under the condition of two lane two-way highways roads only, (Garib, 2001).

$$AR = (C_1) \times (C_2)L \times (C_3)S \times (C_4)L.S \times (C_5)P \times (C_6)L.P \qquad (2\text{-}4)$$

Where,

AR: no of ROR and OD accident,

L: Lane width in feet,

S: Shoulder width in feet (including stabilized components),

P: Width in feet of stabilized component of shoulder ($0 \leq P \geq S$),

P: 0 for unstabilized shoulder and P = S for full stabilized, and

Ci's: Constants.

The values of the constants are:

C1 = 4.1501

C2 = 0.8901

C3 = 0.9562

C4 = 1.0026

C5 = 0.9403

C6 = 1.0040

Values calibrated using data from Kentucky and Ohio.

2.4.3.2 Intersection Sight Distance

Driver who approaches an intersection should have an unobstructed view for the intersection. Moreover, sufficient unobstructed view of the intersection allows the vehicle a sufficient distance to perform the complete stop for avoiding collision with approaching vehicles or other road users at the intersection. David et al. (1975) studies the relationships between accident rates and various intersection geometrics. The results show a significant accident rate differences between obstructed and unobstructed intersections, (Garib, 2001).

2.4.3.3 Effective of Pavement / Shoulder Drop-off on Highway Safety

Drop-offs are defined as, “unstabilized shoulders frequently are hazardous because the elevation of the shoulder at the pavement edge tends to become one half to several inches lower the pavement", (Garib, 2001).

The previous review leads to the following conclusions:

1. Height of drop-off: This is the most important element. The greater the height, more hazardous would be the situation.
2. Lane width: Greater lane widths are safer, as this increases the probability of re-mounting on the lane after traversal on the shoulder.

2.4.3.4 Effect of Pavement Condition

Pavement surface distresses are one of the factors that may affect highway safety. The presence of distresses in rural road section would be unusual to the drivers more than other road type section. This may cause interruption to the driver, which could lead to deterioration of safety level. The distress may include the following points.

1. Alligator cracks, which make unusual view of the pavement surface
2. Rutting distress make the control of the steering wheel needs more effort from the driver.
3. Pothole distress affects the driver comfort by sudden impact on the wheel in case of vehicle wheel passing on it.
4. Bleeding distress makes the friction resistance of the pavement surface condition lower than the required for the vehicle control.

Table (2-4) summarizes the pavement factors and parameters in terms of safety.

Another effect on accident is stated by Maurer (2001), which is the skid resistance; where accident occurs in places that have bad road condition or poor road design, predominantly occur in connection with a wet road surface, At wet road condition, a clear increase of accident spots in sections with a bad skid resistance is occurred as presented in Figure (2-2) and Figure (2-3).

Table (2-4): Safety effects of traffic control features, (Garib2001)

Class of factors	Safety Attributes or Indicators	Sensitivity to Driver
Surface texture or friction	1. Macro texture and micro texture characteristics, such as International Friction Index (IFI). 2. Skid resistance or skid number measure. 3. Vehicle tire type standards.	Low
Pavement roughness or riding quality	1. Riding Comfort rating or roughness such as International roughness Index (IRI). 2. Roughness Vs speed relationship.	High
Pavement surfaces distresses	1. Severity and extent of surface distresses such as ruts, faults, potholes, cracks, spalls, etc. 2. Distress Index.	Medium
Pavement geometric design and location	1. Width of lanes and shoulders, median, and pedestrian paths; paved or gravel shoulders. 2. Cross slopes of pavement surfaces.	Medium
Visibility of pavement surface features	1. Pavement surface color and reflectivity. 2. Lane marking and signing. 3. Visibility at night and bad weather conditions.	High
Paving materials and pavement mix design	1. Types of pavement. 2. Texture and color of paving materials. 3. Mineralogy and anti-skid properties.	Low
Road safety measures and facilities	1. Safety warning signs. 2. Safety protection facilities.	High
Environmental and weather condition	1. Place and time of accident occurrence. 2. Roadside obstacles and safety facilities. 3. Precipitation (fog, rain, snow) and wind, etc.	Very High

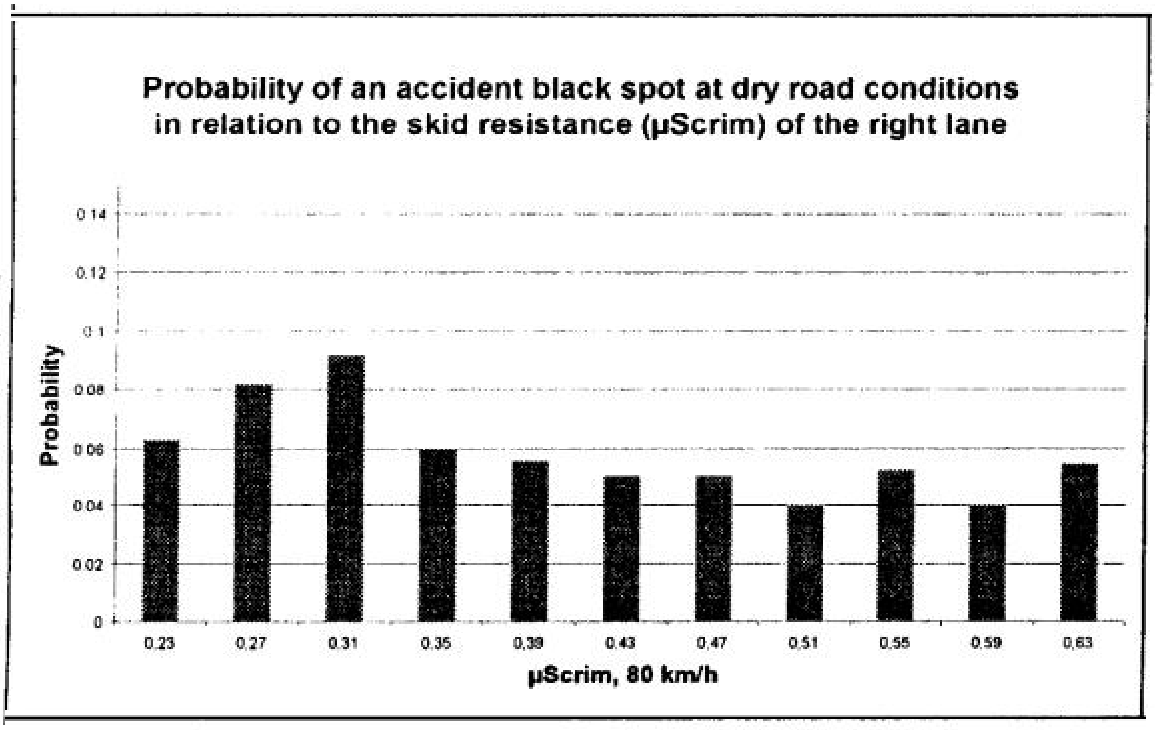


Figure (2-2): Probability of an accident black spot at dry road condition in relation to the skid resistance of right lane, (Maurer, 2001).

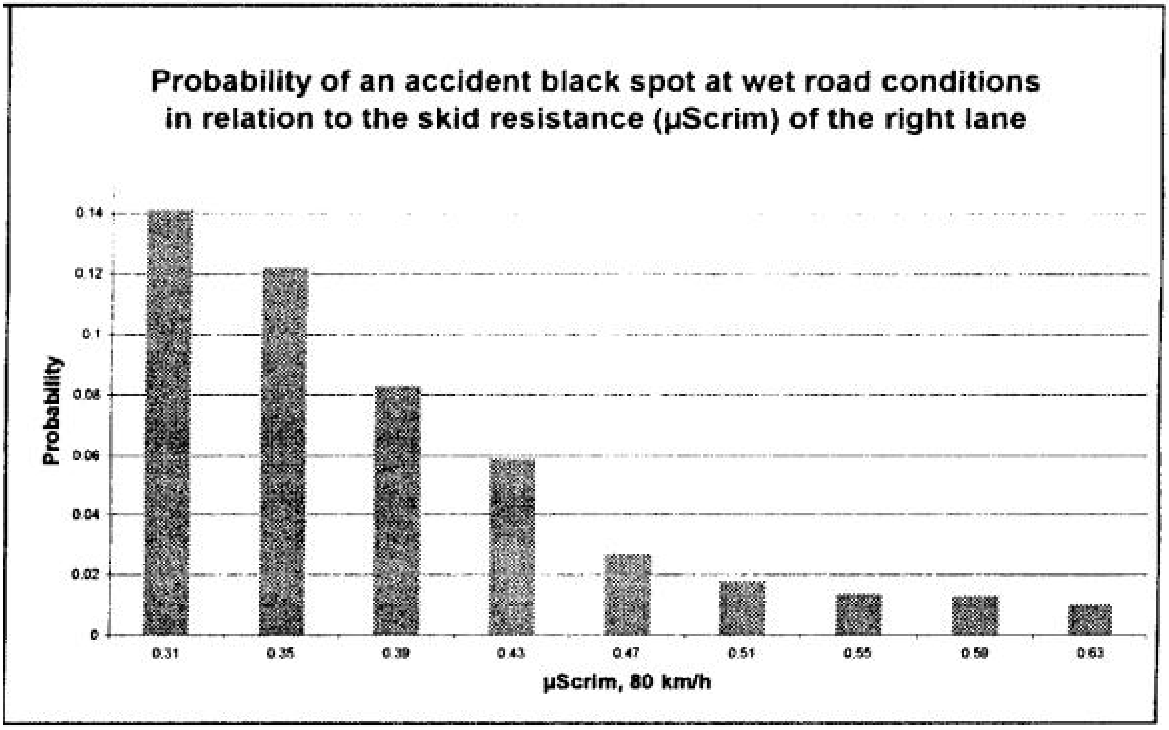


Figure (2-3): Probability of an accident black spot at wet road condition in relation to the skid resistance of right lane, (Maurer, 2001).

2.4.3.5 Horizontal Alignment Variables

Equation (2-5) shows the degree of the road curve in degrees per hundred feet. It is an important variable because horizontal and vertical alignments correlate positively with accidents but are not consistently significant. Horizontal alignment is computed from the following formula, (Vogt and Bared, 1998).

$$DEG\ (i) = \frac{180{,}000}{\pi \times \mathrm{rad}\ (i)} \tag{2-5}$$

Where,

rad: the road curve radius measured in feet.

2.4.3.6 Vertical Alignment Variables

Vertical alignment variable is subject to some of the same considerations as horizontal alignment variable. The basic variable associated with each vertical curve is V (i), (Vogt and Bared, 1998).

$$V(i) = \frac{\text{Absolute Value of Change of Grade at j-th Vertical Curve}}{\text{Length l(i) of j-th Vertical Curve in hundered of feets}} \tag{2-6}$$

Where,

V(i): The measuring unit is percent per hundred feet.

Change of grade: $\Delta g(j) = g(j) - g(j+1)$.

l(i): The length of the curve in hundreds of feet.

g(j) and g(j+1) : Longitudinal road grades as shown in Figure (2-4).

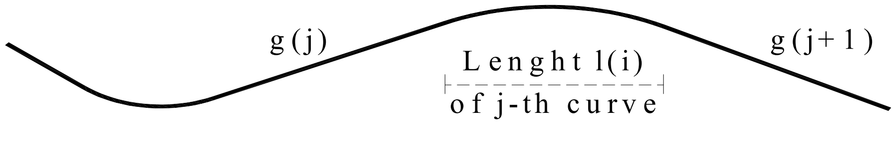


Figure (2-4): Vertical curve.

2.4.3.7 Traffic Control Devices

Traffic control devices include three major categories, which are signs, marking, and traffic signal. Effective traffic control devices must be visible, recognizable, understandable, and necessary. Failure to meet any one of these criteria makes the device to be unsatisfactory no matter how much money is spent to be installed, (Garib, 2001).

They are essential tool to manage given traffic activity to make the roadway safer. Garib, 2001 stated that “Accident reduction factors have been sought so that they would provide traffic engineer with the basics of making choice and decision about which traffic control devices are most effective and when they should be used". Because of difficulty in carrying out good experimental designs, the conclusions resulting from previous studies can be accepted even with its limitation. It is useful to review at least their findings. Therefore, Table (2-5) provides the safety and cost benefits associated with some traffic control devises.

Sign physical conditions affect the sign message, which is delivered to drivers. Therefore, it affects safety level. In addition, Highway section should also give the driver adequate limitations of pavement edge especially at night. Moreover, pavement edges and between lanes marking give limitation to drivers about the width required to drive on, especially in night and reduced sight times. Also, between directions marking make the direction limits for drives clear. The condition of the marking, which affects the function of the marking and then highway safety, is illustrated in Table (2-5)

2.4.3.8 Safety Features (Barriers)

Roadside and median barriers are a longitudinal system used to shield vehicles from hazards on the roadside. They are used also to prevent out of control vehicles from crossing the median, and go to the opposite direction, (Garib, 2001). At Egyptian rural roads, barriers may have additional function, which is preventing the road users from crossing the road section except from certain safe entrance and exit. Position, type, and condition of the barriers affect the safety level of the highway section.

Table (2-5): Safety effects of traffic control devices, (Garib, 2001).

Item	$ Spent (Millions)	% Reduction in Accident Fatality Rates	% Reduction in Accident Injury Rates	% Reduction in Accident Fatality Rates and Injury Combined	Benefit cost Ratio
Traffic Signs	14.4	29	14	14	7.3
Markings and delineation	36.3	9	5	5	0.8
Lighting	14.3	41	16	17	12.1
Upgraded Traffic Signals	97.4	39	21	21	3.2
New Traffic Signal	151.7	52	22	22	4
Upgraded railroad Flashing Lights	19.6	87	36	46	2
New railroad Flashing Lights	60.3	85	76	78	1.6
New railroad Flashing Lights and gates	147.7	91	83	84	1.5
New railroad gates	55.8	91	74	78	21

2.4.3.9 Other Road Characteristics

Institute of highway engineer summarizes the roadway characteristics data which affects accident occurrence as road data which includes geometry (curvature, width, and junctions), surface (type, and texture), physical aids (lighting, signs, and marking), and the road speed limit. Adjacent land use may also be a critical factor especially in urban areas. Evaluating the accident rates depends on identification of changes in road and environment features, (Institute of Highway Engineers 1978).

2.4.4 Traffic Characteristics

The traffic characteristics effect is measured by the exposure variable, which is given by Equation (2-7). In addition, it should be noted that this equation calculates the exposure at segments, (Vogt and Bared, 1998).

$$\text{EXPO} = \frac{\text{ADT} \times 365 \times (\text{N}_\text{Y}) \times \text{Seg\_1ng}}{10^6} \qquad (2\text{-}7)$$

Where,

EXPO: Exposure variable measuring unit is millions of vehicle-miles (MVM) during time period NY.

Seg_lng: Variable which represents segment length in miles from true begging and true end (250 feet removed if the segment begins or ends at an intersection).

NY: Number of years in time period.

Institute of Highway Engineers summarizes the traffic characteristics data for three items: traffic data which includes traffic flow, composition (by class of road user, including pedestrian flow), and speed. Traffic data is used to measure the exposure in dangerous accident situation. This data type should also be related to time and location.

2.5 Pavement Condition and Evaluation

In USA there are three methods for determining pavement condition: Visual rating, Non Destructive Testing (NDT). The Visual rating method is most commonly used. All agencies are gathering information on their pavements based on a visual survey. However, the extent to which they gather the data varies. The NDT method is generally used for project level information to enhance visual ratings. NDT enables an agency to identify problems, examine their extent, and solve them effectively. A few agencies also use NDT data for network as well as project level evaluation. Destructive testing is primarily used to support design analysis in identifying pavement makeup, reasons the pavement failed, and solutions for improving the pavement. This includes pavement coring, boring, and test pits, along with evaluation, (TPMSGR, 1994).

Data on pavement conditions are essential to make valid decision about pavement maintenance; collection of this data requires that pavements be inspected, (Darwish, 1993). To complete the inventory of network, the managing agency needs to perform an evaluation of the present condition of different pavement sections. This evaluation will then serve as one of the main inputs in the decision that will determine the M&R activities to be carried out, it is therefore a crucial of any PMS .Without accurate data outputs would not be reliable, (Shahin, 1994). A primary component of pavement management is pavement condition evaluation. Figure (2-5) present the major pavement condition indicators for Highway pavement. These indicators include roughness, skid resistance, structure integrity and capacity, and the potential for damage from foreign objects. Figure (2-5) shows how the various distresses types in asphalt pavements relate to the various pavement condition indicators.

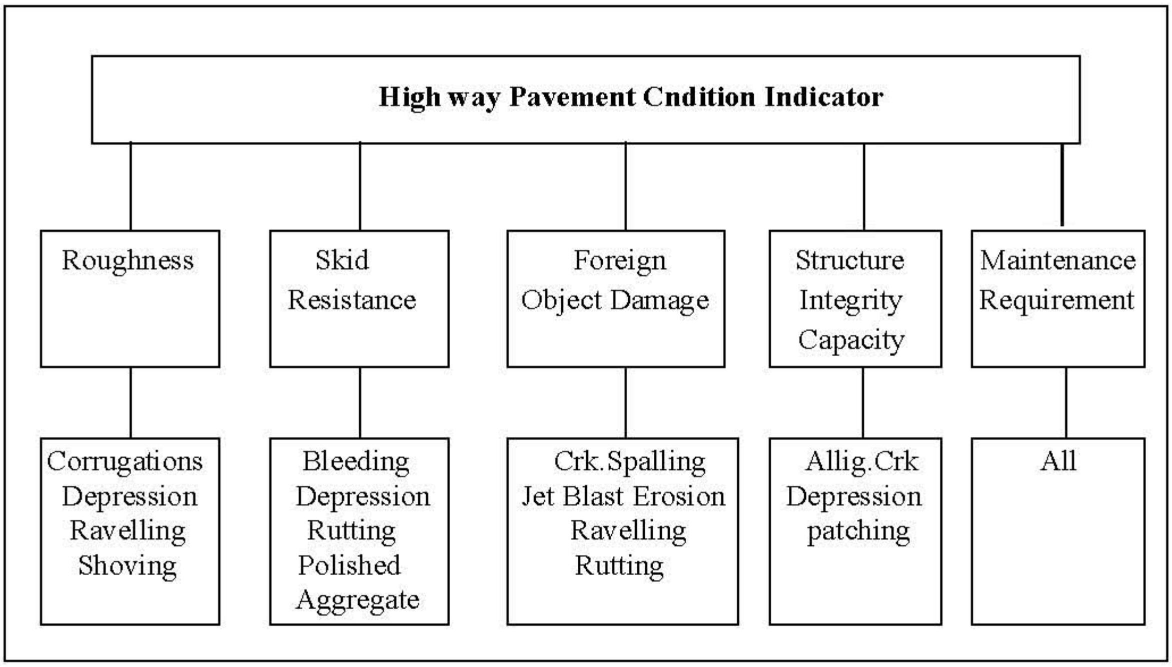


Figure (2-5): Relation between pavement condition indicators and distress types for asphalt pavement.

Many pavement engineers think that distress survey should be performed before a direct measurement of the condition indicators. (Shahin, 1994), describes pavement distress measurement and use procedures that were developed for the U.S. Air force and published by the federal Aviation Administration (FAA) (Shahin, 1982). Although the data collected are usually similar, for each agency's system, the method of collection, the processing of the data, and the frequency of collection differ (Shahin and Kone, 1979).

The evaluation surveys is done to determine the structure adequacy of a pavement and to establish reasons why the pavement condition is as its (El-gioshy, 1997). Structural evaluation involves examination of the collected distress, deflection, materials, soils, and drainage information for the following purposes:

1. Assessment of the current structural condition of the pavement that is, how much structural damage has been done to the pavement.
2. Assessment of the remaining structural life of the pavement that is how many more loadings it can support before failure.

The result of a structural evaluation are also used in dividing a project into structurally uniform sections, identifying areas requiring localized repair, selection one or more appropriate alternatives for structural improvement, and developing preliminary designs for these alternatives. Structural evaluation of asphalt pavement may be accomplished using condition data only, deflection measurements only, condition plus deflection data only or traffic data only. As a general rule, an asphalt pavement is considered to require a structural improvement when 50 percent of the wheel path area (equivalent to 10 percent of the total area) has medium to high severity alligator cracking.

A critical rutting level of one half inch is often cited as indicative of a need for structural improvement. However, rutting may have causes related not only to the load bearing capacity of the pavement layers, but rather the stability of the mix, so the cause of rutting should be examined before deciding whether or not a structural improvement is the appropriate remedy.

Structural evaluation of concrete pavements may be accomplished using condition data only, condition plus deflection data only, or traffic data only. this approach involves determining an “effective slab thickness’’ which is less than or equal to the actual slab thickness, depending on the types, extents, and severities of load related distress present.

2.5.1 Require for Pavement Condition Data

Pavement condition data has been used in the past to improve maintenance rehabilitation and reconstruction programs, the data were used determine the projects requiring maintenance and the type of the maintenance and rehabilitation required to correct the observed deficiencies (Darwish, 1993). At present, three specific applications for pavement data can be identified:

1. To establish priories : data such as ride distress and deflections are used to setup projects most in need of maintenance are used.

2. To establish maintenance and rehabilitation strategies: data such as type, extent, severity, of distress are used to develop an action plan of a year to year basis, i.e. which strategy (repair, surface treatments, overlays ……etc) is most appropriate for a given pavement condition.

3. To project pavement performance: data such as ride skid resistance distress, or combined rating are projected into the future to assist in preparing along range budget (Darwish, 1993).

It is important to note that the evaluation survey is more comprehensive than the condition survey and is carried out in greater detail than simple determination of pavement condition (El-gioshy, 1997). Mn department of transportation (Mn/DOT) currently collects pavement condition data using a pathway Services, Video Inspection Vehicle (VIV) as shown in Figure (2-6). there are five laser mounted across the front bumper, one in each wheel path, one in the center, and two outside each wheel path as indicated in Figure (2-7). There are also four digital cameras mounted on top of the van as present in Figure (2-8). The lasers measure the pavement's longitudinal profile, used to calculate roughness as well as rutting and faulting.

They take a measurement approximately every 1/8 -inch as the van travels down the pavement at highway speed. The cameras are used to capture the pavement distress (cracking, patching … etc) and help assess the overall condition of the pavement.

Figure (2-6): MN/DOT's pathway service, Inc. video inspection vehicle (VIV)

Figure (2-7): Close-up of lasers used to measure roughness, rutting & faulting.

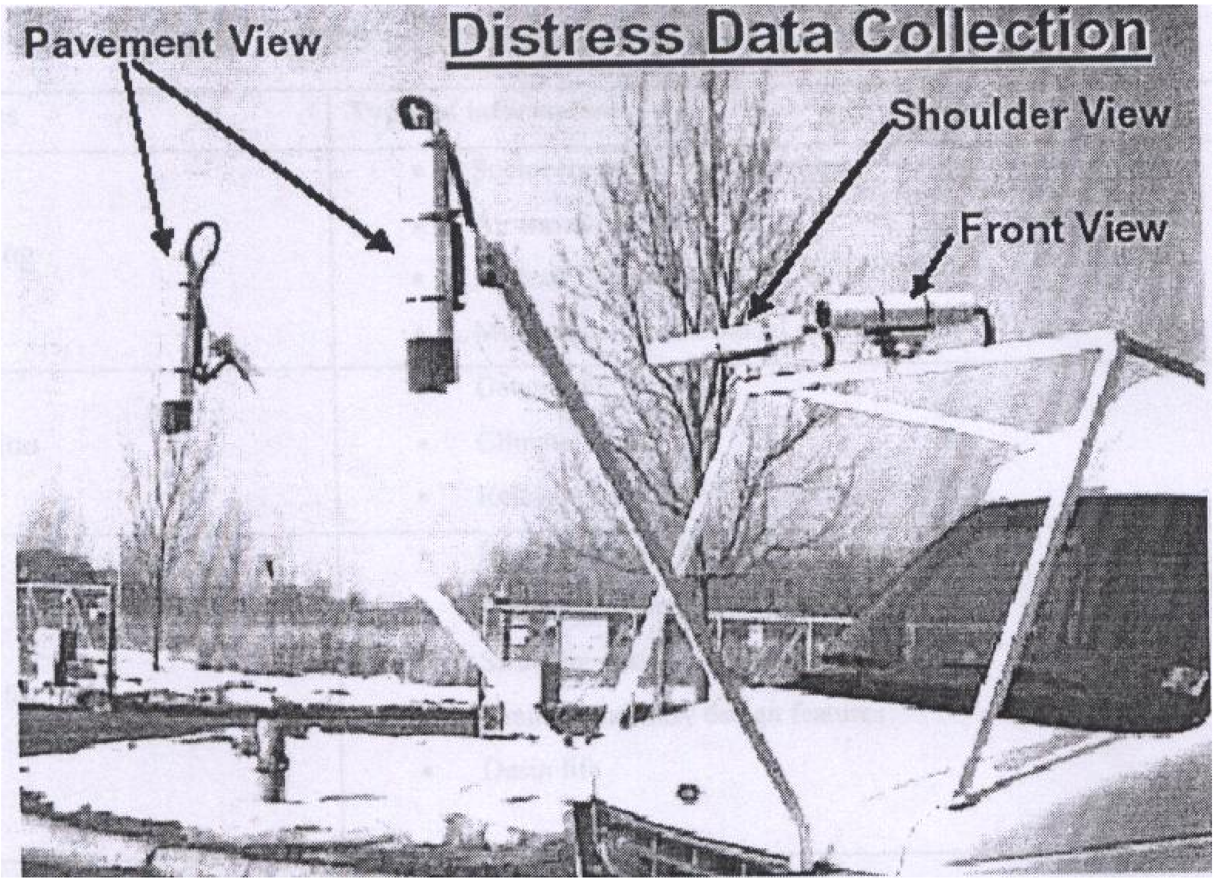


Figure (2-8): Close-up of cameras used to record pavement distresses.

2.5.2 Data Collection

Not all pavements need a pavement condition inspection every year, but an inspection producer should be developed to assist in determining which segment should be reinspected during the next year.

A recommended Pavement condition inspection policy helps to identify those pavement management segments which need reinspection and minimize the overall inspection effort required of the agency, (TPMSGR, 1994). The frequency at which collect pavement condition data depends up on how they need current data, budget restriction and availability of trained personnel. Some pavement management systems require annual inspection of pavement condition while others conduct pavement condition inventories once every two years still others use three year cycle (Darwish, 1993). Pavement which has been recently constructed or overlaid will be in excellent condition and need not to be inspected immediately.

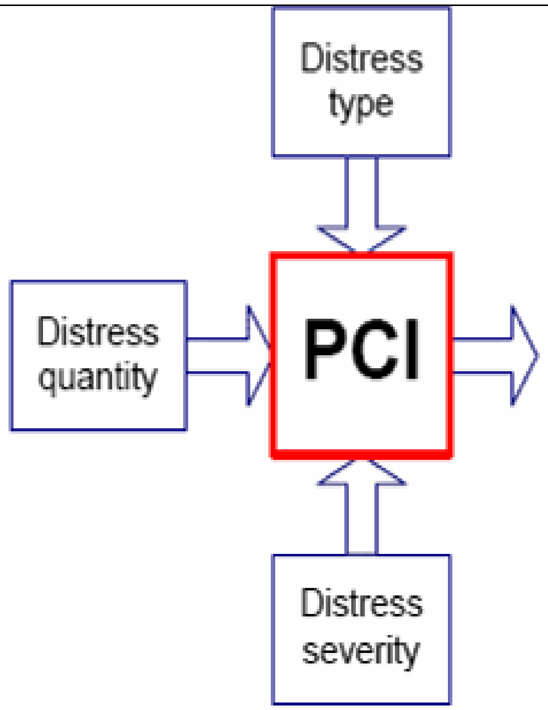
A two year inspection intervals after construction is normal, pavements which have had a surface treatment applied will initially look very good however after short period of time the cracks may appears.

A two year inspection interval is also suggested for this pavement, other pavement segments should be scheduled for inspection based on their rate of deterioration, (TPMSGR, 1994), and the scope of pavement management should be understood before developing and using such information. All pavements need to be divided into homogenous sections and assigned a section number. These section numbers are used as indices for assessing, storing, updating, and retrieving purposes (Alexander, 1998).

2.5.3 Pavement Condition Survey

A pavement condition survey is a visual inspection procedure for determining the present surface condition. The condition survey consists of inspecting a portion of the pavement surface for the various types of distresses, determining the severity of each distress, and measuring the density of each distress. The condition survey provides estimated density and severity of each distress type from which the PCI can be determined.

The PCI is numerical indictor based on a scale of 0 to 100 and is determined by measuring pavement surface distress that reflect the surface condition of the pavement. Pavement condition ratings (from excellent to fail) are assigned to different levels of numerical PCI values. These ratings and their respective PCI value definitions are shown in Figure (2-9) (U.S. Army Corps of Engineers, 2004).



PCI		Condition
86	100	Excellent
71	85	Very Good
56	70	Good
41	55	Fair
26	40	Poor
10	25	Very Poor
0	10	Failed

Figure (2-9): Pavement condition index numerical value versus condition rating.

The distresses types, distresses severities, methods of survey, and PCI calculation are described in references (Shahin, 1994) and (Shahin, 1982) Structural Condition Index (SCI), also known as PCI_{STR}, is the PCI obtained from considering only those distresses caused by structural deficiencies (MIL-HDBK, 1987). Because the PCI includes deducts due to non-structural deficiencies, it is difficult to judge the required overlay thickness based on a low PCI alone. In fact if most deficiencies are non-Structural, the minimum recommended overlay thickness is typically adequate (e.g. 2 inches for flexible pavements, and 6 inches for rigid ones) the minimum acceptable value for SCI is 35 This corresponds to having 60% of the concrete slabs shattered with medium severity, or 50% of the slabs with high severity cracks (MIL-HDBK, 1987).

Navy and Army have used a minimum SCI value of 50, below which slab replacement is recommended (Alexander, 1994). A Foreign object Damage (FOD) Index can be determined using the PCI survey data which is one of the primary factors for determining the serviceability of pavement area the Foreign object Damage Index is determined from the PCI calculated by considering only the distresses/severity levels capable of producing FOD the FOD Index = ($100\text{-}PCI_{FOD}$) Tables (2-6) show the distresses producing FOD (AFCESA, 2004).

The PCI calculation producer involves dividing a pavement into features which are defined as areas of pavement of like cross section subjected to similar traffic. Then each feature is divided into sample units facilitate the inspection process. Sample unit for asphalt concrete (AC) pavement are approximately 500 sq. m (5000 sq. ft), and sample units for Portland cement concrete (PCC) pavements contains approximately 20 slabs. A statistical sampling technique is often used to determine the required number of sample unites to be surveyed to provide a specified confidence level in the result of the survey, as many sample units as possible where surveyed, generally 100 percent after the sample units are inspected the mean PCI of all the sample units within a feature is calculated and the feature is rated as to its condition: excellent, very good, good, fair, poor, very poor, and failed as illustrated in Figure (2-9).

Inspection of the entire pavement is not considered necessary, visual inspection is conducted on selected number of samples of each pavement section; each pavement section is divided into sample of manageable size (Alexander, 1998).

Table (2-6): Distress list for asphalt pavements.

Distress Type	**Severity Levels** **(L=Low, M=Medium, H=High)**
Alligator cracking	L, M, H
Bleeding	n/a
Block Cracking	L, M, H
Corrugations	L,M,H
Depression	L,M,H
Jet Blast Erosion	n/a
Joint Reflection Cracking	L,M,H
Longitudinal and Transversal Cracking	L,M,H
Oil Spillage	n/a
Patching	L,M,H
Polished Aggregate	n/a
Ravelling and Weathering	L,M,H
Shoving	L,M,H
Rutting	L,M,H
Slippage Cracking	n/a
Swelling	L, M, H

2.5.4 Distress Types, and classification

A PCI survey is performed by measuring the amount and severity of certain defined distresses observed within a sample unit, there are fifteen different types of distress in rigid pavement and sixteen for flexible pavement (SEl-gioshy, 2001). Table (2-7) lists the asphalt pavement distress types considered in the PCI method, and also indentifies the related causes (load, climate/durability, other) as assigned by the Micro PAVER pavement maintenance management software. Load-related distresses exist where the pavement has been over- stressed by loads applied to its surface. Climate/durability-related distresses arise due to exposure to climatic conditions. Other related distresses are causes by actions not related to load or climate, such as oil spillage.

Although each distress is assigned only one cause by the Micro PAVER software, the appearance and rate at which the distress occurs may be influenced by other causes. As an example, while Alligator cracking is used by Truck load its occurrence may be exacerbated by environmental factors.

For instance, after prolonged wet weather, or during a spring thaw, the base coarse and subgrade materials maybe significantly weaker than during dry weather. As a result, the occurrence of alligator cracking maybe accelerated due to the fact that the asphalt concrete is flexing more under each Truck load due to weak support condition (Champaign, 1977).

To obtain a reliable PCI for given pavement section units within that section. An adequate number of randomly chosen sample units were selected for surveying based on the total number of sample units contained in the section. The advisory circular recommends inspecting a specific number of sample units that will result in confidence level in the data of 95 percent. It is necessary to survey /inspect all samples (FAA, 1982).

Visual distress data are an excellent source of pavement condition information and are used in many ways by airfield pavement engineers, planners and maintenance personnel. Pavement distress data are used to evaluate pavement performance and are a basic input to pavement management systems. The key to a useful pavement condition evaluation lies in the objectivity allowed and reliability of the survey procedures (line and Schiavino, 2004).

Table (2-7): Distress types and their associated distress mechanism.

Asphalt Pavement	
Distress	**Mechanism**
Alligator Cracking	Load
Bleeding	Other
Block Cracking	Climate
Corrugation	Other
Depression	Other
Jet Blast	Other
Joint Reflection Cracking	Climate
Longitudinal and Transverse Cracking	Climate
Oil Spillage	Other
Patching	Other
Polished Aggregate	Other
Weathering Ravelling	Climate
Rutting	Load
Shoving	Other
Slippage Cracking	Other
Swelling	Other

2.5.5 Factors Affecting Pavement Performance

Performance surveys are conducted to find the cause and effect of pavement distresses (Asphalt Institute, 1994). Many factors affecting pavement performance by causing a lot of distresses. These factors can be summarized as follow:

1. Traffic load on pavement surface.
2. Soil characteristics.
3. Quality control level.
4. Strength of pavement section.
5. Environmental factors.

2.6 Skid Collection Data

The frictional properties of pavement surfaces play an important role in highway safety. Pavement surfaces must ensure an adequate level of friction at the tire pavement interface to provide safe operation of vehicles. Vehicles control safety is highly dependent on pavement surfaces characteristics. When pavement is dry, the friction generated between the tire and the pavement is normally high, during inclement weather; water can create a critical situation by increasing potential for hydroplaning or skidding particularly when the skid resistance of the pavement is low. Without adequate skid and hydroplaning resistance, the diver may not be able to retain directional control and stopping ability on wet pavement (Shahin, 1994).

The scope of this particular discussion to descript in detail the mechanics of skidding and methods of measuring skid resistance. However, it must recognize that this becomes an integral part of any evaluation system. Skidding refers to sliding motion with locked wheels and is generally evaluated as skid number called the coefficient of friction (Yoder and Witeszak, 1975).

2.6.1 Factors Affecting Skid Resistance and Hydroplaning

According to the National Transportation Safety Board and the Federal Highway Administration (FHWA) reports, approximately 13.5% of fatal accidents and 25% of all accident occur when pavement are wet. According to The Maryland State Highway Administration (MDSHA) Traffic & Safety Analysis Division reports, 18 % of fatal accidents 24.3 % of all accident occur when pavement are wet. The following factors affect the friction levels on a wet pavement surface (Stephanos, 2002):

1. Pavement factors (surface characteristics “micro-texture and macro-texture”, drainage).
2. Age of the pavement Surface.
3. Seasonal Variation.
4. Traffic Intensity.
5. Vehicle factors (speed, tire pressure, wheel load, and tire tread).

2.6.2 Pavement Surface Characteristics

Pavement Surface Characteristics are important for both the safety and comfort of drivers. Pavement surface should provide adequate friction and maintain a good level of ride quality to ensure satisfaction of the driving public. The combination of good friction and low levels of Roughness, and low levels of noise are important in the design of a pavement wearing Surface. The surface texture of a pavement – wearing surface is one of the primary contributors to tire pavement frictions. Both macrotexture and microtexture affect the friction Characteristics of pavement surfaces. Macro-texture is of primary important at high speed to remove excess water. Studies have shown that the deterioration of skid resistance with speed as macro texture increases. Micro-texture is important at all speeds to penetrate the remaining water film of on a pavement surface and to provide ‘dry’ contact with the vehicle tire (Stephanos, 2002) and (Flintsch, 2003).

2.6.3 Drainage

Drainage is another significant characteristic of the pavement surface. A good drainage system provides channels for the water to escape, allowing contact between the tire and the pavement. The effectiveness of the drainage system can be evaluated by measuring the friction factor immediately after applying water to the surface and at intervals afterward, to determine the increase in the friction (Shahin, 1994).

2.6.4 Age of Surface

Almost all new pavement surfaces have high skid resistance. Pavement surfaces will attain their peak skid resistance condition after a few weeks of traffic action. Under traffic action, skid resistance will deteriorate and gradually reach an 'equilibrium' level. Only small deviations in skid resistance are experienced while traffic levels are constant and no structural deteriorate is evident. It will take about two years to reach equilibrium (FAA, 1971)

2.6.5 Seasonal Variation

There are distinct seasonal patterns in skid resistance levels. Summer months have the lowest level of skid resistance. A variation of approximately 30% of skid resistance has been observed between a minimum in summer to a peak during the winter.

2.6.6 Traffic Intensity

Polishing of Aggregates relates to traffic intensity, commercial vehicles contribute to most of the polishing. The geometry of the pavement also contributes to polishing, Polishing relates to traffic volumes as shown in the chart in Figure (2-10) where high volume areas require a higher design friction Number (FN).

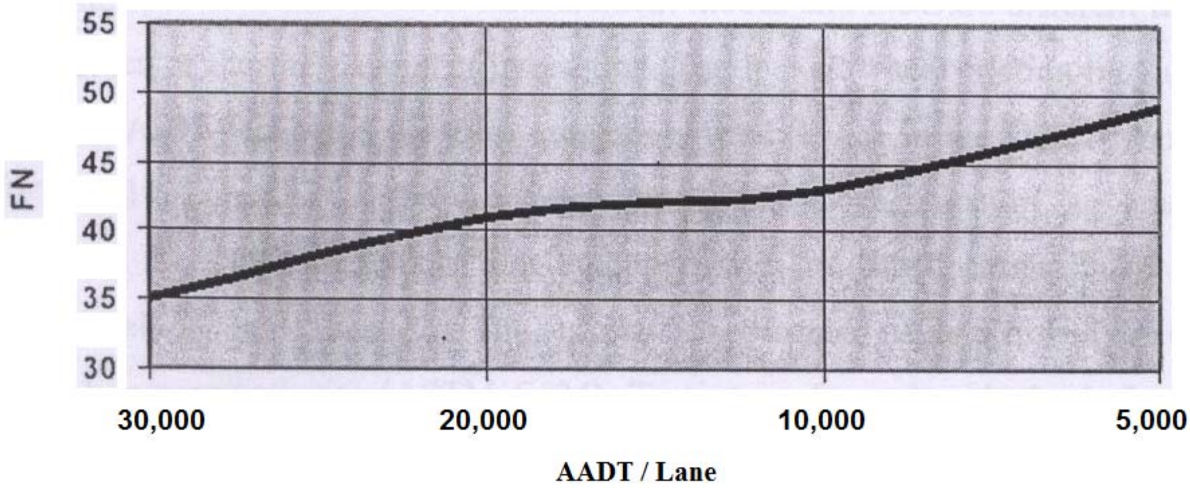


Figure (2-10): Friction number versus AADT for pavement with similar surfaces.

2.6.7 Vehicle Factors

2.6.7.1 Speed

In general, the friction coefficient decrease with increase in speed, it has been determined that on dry pavement, the friction factor changes very little with change of speed, however, on wet pavement the decrease is significant (Shahin, 1994).

2.6.7.2 Tire Pressure

Experimental have shown that for a given wheel load an increase in tire pressure will cause a decrease in friction coefficient, this can be attribute to the increase area of contact al low inflation pressure the heat created by skidding or deceleration is distributed over a large area and then produce high friction coefficient (Shahin, 1994).

2.6.7.3 Wheel Load

Studying using varying wheel loads has shown that the friction coefficient increases as the wheel load decreases. One of the explanations is that the increase in wheel load causes a decrease in the tire contact area per unit load and there for a decrease in the friction coefficient.

2.6.7.4 Tire Tread

Tread design has a significant effect on the braking effectiveness. Tire groves provides channels through which water at the tire pavement interface can be displayed at high speed or in the presence of thick water films there not enough time for the water to be displayed and hydroplaning may occur.

CHAPTER 3

FIELD INSPECTION SURVEY

3.1 Introduction

The field inspection survey carried out to evaluate the current condition of pavement and record damaged traffic safety barriers, signs, and bridge joints of the entire Ring Road.

Assessment of the existing pavement of the Ring Road is based on visual inspection survey, core samples and test pits, and truck traffic volumes. The main objective of the Visual Inspection Survey is to identify the type, quantity and severity of existing pavement surface defects. The Pavement Condition Index (PCI) procedure was adopted to evaluate the existing pavement of the road. In addition to the Field Inspection Survey for pavement surface, we performed an inventory survey to record locations of defective joints on bridge sections, broken traffic safety barriers and signs, and major pavement defects.

The PCI field survey data was coded to computer, processed and analyzed to provide valuable information about the current condition of pavement. Core samples and test pits were taken at the Ring Road to provide in-situ inspection of the pavement material and verification of the asphalt and subjacent layers. The core samples and test pits were performed by GARBLT main laboratories.

This research presents all the details of the PCI survey and the inventory of broken joints, traffic safety barriers and signs. For each one of the field works, there is a description of the methodology and the findings. The research contains some appendices with the actual recorded data. It must be stressed that this research provides full details of the current condition of the various features of the Ring Road.

3.2 Brief Construction History of the Ring Road

As per the original Ring Road Consultant website, the final selected alignment was executed between 1985 and 2001. The Ring Road was constructed in the early 1990's as a 4-lane divided highway (i.e., 2 lanes per direction) and 15-m dirt median. The dirt median was then converted into traffic lanes in response to the significant increase in traffic volumes. In year 2000, the Ring Road stretch from Ismailia Desert Road (km 47.7) and Alex Agricultural Road (km 67.7) was widened to 4-lanes per directions. The road cross section became divided 8-lane with New Jersey concrete barrier in the median.

Starting from year 2002, the widening of the Ring Road continued from Cairo/Alex Agricultural Road (km 67.7) to Cairo/Alex Desert Road (km 91.5). Widening the Ring Road (i.e., construct new traffic lanes) was limited to locations with available median width. No widening was carried out for bridges. Number of lanes varies among the long bridges. For example, El Moneeb Bridge was constructed as 8-lane divided highway whereas the bridge from Mariutiya Canal N to Cairo/Alex Desert Road was constructed as 6-lane divided highway.

3.3 Methodology

3.3.1. Ring Road km Definition and Conventions

The Ring Road has a total length of 99.7 km. The km 0.0 is set at the beginning of the main carriageway, above Mansouriya Canal. The end of the Ring Road is established at the end of the main carriageway, where the El-Wahat Link merges with 6th of October Road (km 99.7). As the Ring Road has the approximate shape of a loop, the use of cardinal directions (N, S, NE, SW, etc.) is not practical. In order to differentiate between the two carriageways, we adopted the following convention:

1. Outer Direction – is the carriageway in the increasing km direction (counter-clockwise).
2. Inner Direction – is the carriageway in the decreasing km direction (clockwise).

3.3.2. Lane Numbering

The lane numbering convention used for the Ring Road is shown in Figure (3-1). The numbering of lanes starts from the outer shoulder for each direction of the Ring Road.

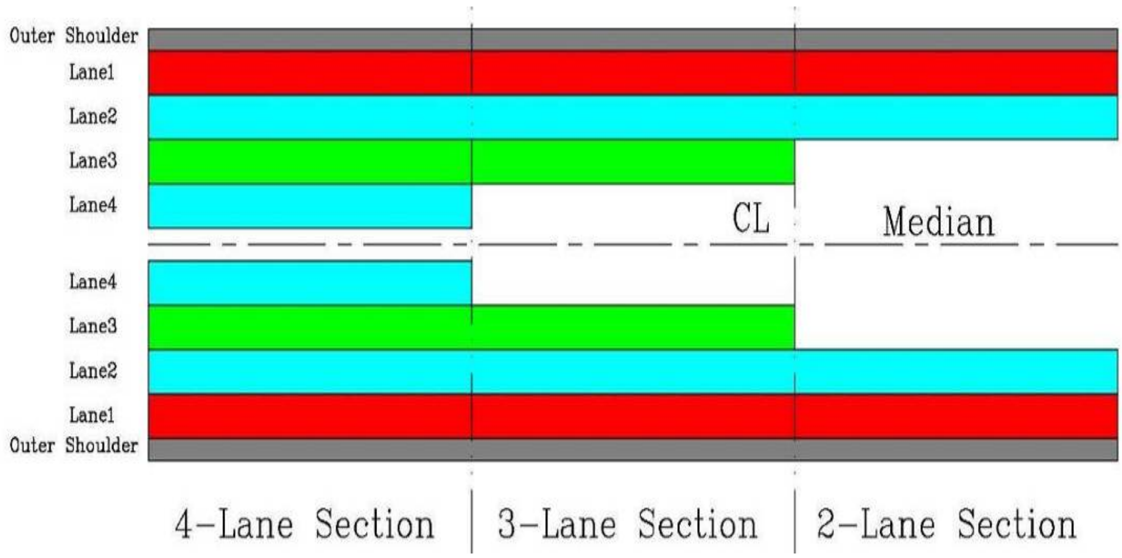


Figure (3-1): Lane numbering convention.

3.3.3. Field Inspection Survey

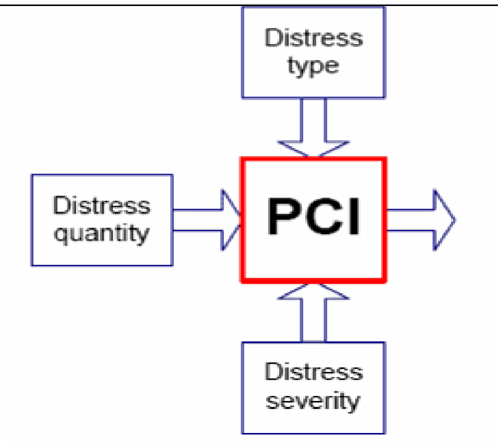
The proposed visual inspection survey included four main tasks as follow:

1. Pavement Condition Index (PCI) survey.
2. Identification of locations of major pavement defects.
3. Inventory of defective joints on bridge sections.
4. Inventory of damaged traffic safety barriers and signs.

3.3.4. Pavement condition index (PCI) survey

The Pavement Condition Index (PCI) is a numerical rating of the pavement surface condition. The PCI value results from a condition survey and depends on the distress type, severity, and quantity as shown in Table (3-1). PCI values range from 0 (worst condition, failed) to 100 (best condition, excellent).

Table (3-1): Ranges of PCI.



PCI		Condition	Maintenance Action
86	100	Excellent	Routine maintenance
71	85	Very Good	
56	70	Good	Repair maintenance
41	55	Fair	Pavement Rehabilitation
26	40	Poor	
10	25	Very Poor	Pavement Reconstruction
0	10	Fail	

As per the approved Action Plan, the Ring Road (99.7 km) was divided into sections, each one two-km long. Each section was further divided into sample units of 200-m long. One sample unit was then randomly selected to be included in the PCI survey. This procedure is considered an unbiased estimate for the PCI of the respective roadway section. The procedure of the PCI survey can be summarized as follows:

1. Divide the Ring Road into sections of equal length (2 km).
2. Divide pavement section into sample units (200 m) and randomly select sample units for inspection;
3. Identify and record pavement distress in the sample unit.

Table (3-2) shows the proposed locations of PCI sample units. Locations of sample units were all randomly generated in Excel software. PCI field inspection survey was conducted at the randomly selected locations shown in Table (3-2). In portions where the carriageway has four lanes, two PCI values were determined one for lanes 1 and 2, and the other for lanes 3 and 4. For two- and three-lane sections, one PCI value was determined.

Table (3-2): Locations of PCI sample units

Section From (km)	Section To (km)	Location of PCI survey sample unit (km)	Section From (km)	Section To (km)	Location of PCI survey sample unit (km)
0	2	0.6	50	52	50.5
2	4	2.8	52	54	52.1
4	6	5.6	54	56	55.2
6	8	7.5	56	58	56.4
8	10	8.3	58	60	59.6
10	12	11.1	60	62	61.5
12	14	12.9	62	64	63.8
14	16	15.5	64	66	65.2
16	18	16.8	66	68	66.9
18	20	18.6	68	70	69.6
20	22	21.1	70	72	71.5
22	24	23.7	72	74	73.6
24	26	24.9	74	76	74.3
26	28	26.1	76	78	77.0
28	30	28.1	78	80	78.9
30	32	30.2	80	82	80.6
32	34	32.3	82	84	83.5
34	36	34.1	84	86	85.0
36	38	37.4	86	88	87.8
38	40	38.5	88	90	88.9
40	42	41.7	90	92	90.4
42	44	43.1	92	94	92.2
44	46	45.6	94	96	95.7
46	48	47.7	96	98	96.1
48	50	48.3	98	100	98.9

3.3.5. PCI Field Form

The field form used for collecting field data for PCI survey is included in the Appendix (A). One form was filled out for each sample unit. For each defect detected on the pavement, we recorded the location, distress type and quantity (units) in the appropriate column.

3.3.6. Identification of Major Pavement Defects

We made several round-trips on the entire Ring Road to identify locations of major pavement defects. We recorded location, took pictures and wrote the description of all identified major pavement defects.

3.3.7. Inventory of Defective Joints on Bridges

The Ring Road has a total of 121 bridges with a total length of about 20 km. We recorded the locations of defective bridge joints.

3.3.8. Inventory of Damaged Traffic Safety Barriers and Signs

We carried out an inventory of damaged traffic safety barriers and signs and included in the Appendix (B).

3.4 Finding of the Field Inspection Survey

3.4.1. Common and Major Pavement Defects

The most common observed pavement distress types were found to be Corrugation, Depression, and Polished Aggregate. Raveling and Shoving were also observed in some areas. Bleeding, Rutting, Potholes, and Longitudinal Cracks were not frequently observed on the Ring Road. The amount and severity of observed pavement distress varies by location and lane as explained in the next sub-sections. The identified major pavement defects are summarized in Table (3-3).

There are 24 locations that have major pavement defects. Most of the major defectives are corrugation, shoving and depression. About half of the major defective pavement spots are located between km 40 and km 70. Examples of the recorded major defective pavement locations are shown in Figures (3-2) to Figure (3-7).

Table (3-3): List of major pavement defects

Location (km)	Outer carriageway	Inner carriageway	Nearby interchange
7.1	Shoving		El Moneeb
23.0	Depression and Corrugation		Ain Sokhna
23.5	Pothole		Ain Sokhna
26.1	Depression and shoving		Qattamiya
27.7	Shoving		Qattamiya
29.5		Corrugation	Qattamiya
31.9		Corrugation	Qattamiya
33.6	Bumps		Nasr City
34.2		Depression and pothole	Nasr City
38.8	Corrugation		Suez Road
41.9	Rutting		Suez Road
43.9	Corrugation		Highestep Road
44.5	Pothole		Highestep Road
45.6	Raveling		Highestep Road
46.3	Corrugation and raveling		Ismailia Desert Rd
48.3	Corrugation	Shoving	Ismailia Desert Rd
49.4		Bleeding	Ismailia Desert Rd
50.6	Shoving		Moasaset El-Zakaa
55.9	Shoving		El Marg
60.9	Corrugation		Ismailia Agric. Rd
67.2	Corrugation		Alex Agric. Rd
69.7		Shoving	Warak Bridge No. 2
69.9		Transverse crack	Warak Bridge No. 2
76.7		Corrugation, raveling, depression	Warak Bridge No. 1

Figure (3-2): Shoving, outer carriageway, (km 7.1).

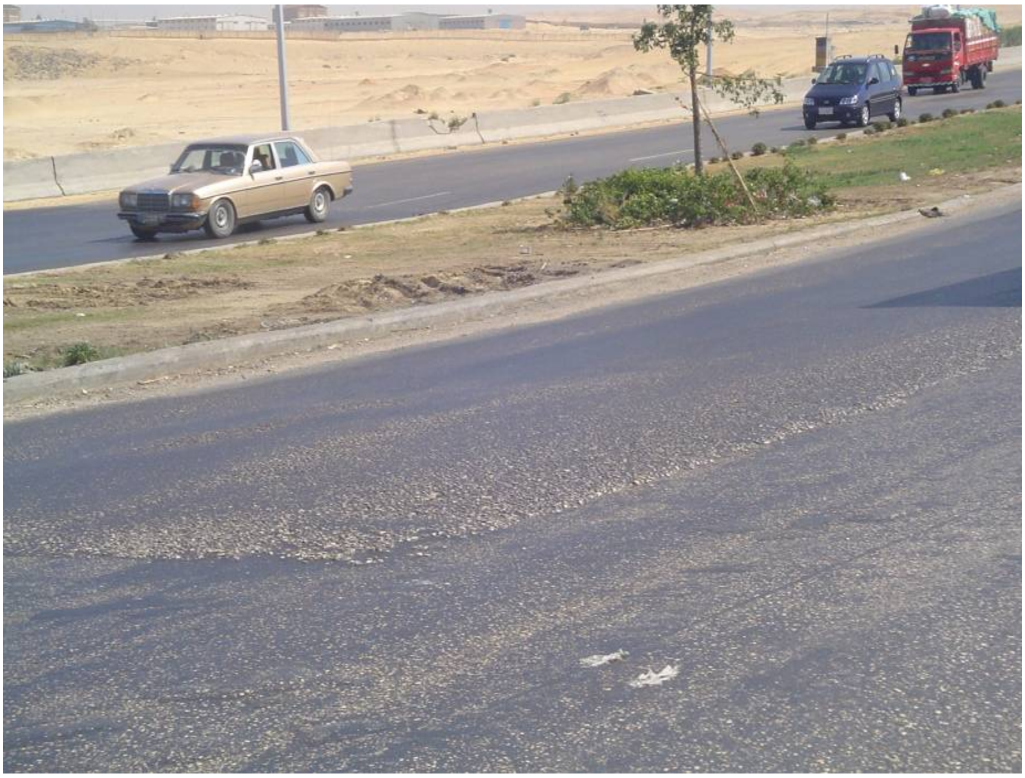


Figure (3-3): Depression and corrugation, outer carriageway, (km 23).

Figure (3-4): Pothole, outer carriageway, (km 23.5).

Figure (3-5): Rutting, outer carriageway, (km 41.9).

Figure (3-6): Bleeding, inner carriageway, (km 49.4).

Figure (3-7): Transverse crack, inner carriageway, (km 69.9).

3.4.2. Defective Joints on Bridge Sections

The bridge deck joint is an important element in the functioning of bridge structures. Bridge joints are provided to allow all movements due to temperature, braking forces, etc., between bridge decks and abutments, without affecting the functionality or performance of the joints. When joints fail to work properly, they can create problems out of proportion to their size. Selection of a good joint for use can create less bridge maintenance problems.

Joints can be broadly grouped into two categories: open and closed. Open joints (e.g., finger or tooth joints) see Figure (3-8) allow water and debris to pass through the deck joint this deck drainage often causes various problems, including corrosion of the bridge superstructure and substructure elements near the joint. Closed, or sealed, see Figure (3-9) joints offer corrosion protection to the underlying bridge superstructures by eliminating drainage through the deck joint.

3.4.2.1. Causes of problems at bridge joints

The general causes of problems at bridge joints vary between joints located at the bridge approach and other expansion joints located on the bridge spans.

The main causes of the differential settlement at bridge approach slabs are:

1. Settlement of the natural soil under the embankment.
2. Compression of the embankment fills material due to inadequate fill compaction.
3. A poor drainage behind the bridge abutment and related erosion of the embankment fill.

The main causes of damage of bridge expansion joints are:

1. Severe truck loading of bridges than was envisaging during their design due to increased traffic and higher axle loads.
2. Lack of quality during construction of joints.
3. Other causes include inadequate fatigue design of joints.
4. Fabrication defects.

Figure (3-8): Bridge finger joint.

Figure (3-9) Closed 'sealed' bridge joint.

3.4.2.2. Locations of Defective Bridge Joints along the Ring Road

Table (3-4) includes the locations of defective bridge joints. There are a total of 16 damaged joints on the Ring Road. The severity of damage varies among the recorded joints. Some of the damaged joints enforce the traffic to slow down. Examples of the recorded defective joints are shows in Figure (3-10) and Figure (3-11).

Table (3-4): List of defective bridge joints

Ring Road Station (km)	Outer Carriageway	Inner Carriageway	Nearby Interchange
7.2	√		El Moneeb
14.7		√	Autostrade
51.6	√		Moasaset El-Zakaa
51.9		√	Moasaset El-Zakaa
59.5	√		Ismailia Agriculture Road
59.8	√		Ismailia Agriculture Road
67.3		√	Alex. Agriculture Road
70.5		√	Warak Bridge No. 2
70.9		√	Warak Bridge No. 2
72.3	√		Warak Al-Arab
72.7		√	Warak Al-Arab
76.9	√		26th of July
77.1	√		26th of July
90.6		√	Cairo/Alex Desert Rd.
91.5	√		Cairo/Alex Desert Rd.
92.4		√	Cairo/Alex Desert Rd.

Figure (3-10): Damaged bridge joint, outer carriageway, (km 7.2).

Figure (3-11): Damaged bridge joint, inner carriageway, (km 67.3).

3.4.3. Damaged Traffic Safety Barriers and Signs

Locations of damaged traffic safety barriers and signs were recorded during the Road Inventory. A full list of the recorded damaged traffic safety barriers, bridge rails, and signs is included in the Appendix (B).

There is a total of 580 m of damaged concrete New Jersey barriers, of which 165 m are located in the Ring Road median. There is a total of 145 m of damaged metal W-beam guard rails. There is a total of 80 m of damaged bridge rail, mostly located at km 90. Examples of the damaged traffic safety barriers and signs are included in Figures (3-12) to Figure (3-16).

Figure (3-12): Damaged traffic sign, outer carriageway, (km 2.0).

Figure (3-13): Damaged W-beam traffic guardrail, outer carriageway, (km 88.5).

Figure (3-14): Damaged median concrete barrier, (km 88.5).

Figure (3-15): Damaged bridge rail, inner carriageway, (km 90.9).

Figure (3-16): Damaged bridge rail, outer carriageway, (km 91.5).

3.4.4. PCI Calculations

The PCI survey data was coded to computer, processed and analyzed to provide with valuable information about the current condition of pavement, as well as to define the areas of priority maintenance activates. The calculated PCI values along the Ring Road are summarized in Table (3-5), Note that two PCI values were surveyed and calculated only for the 4-lane cross section. The overall distributions of pavement condition along the Ring Road are depicted in Figures (3-17) to (3-19) for directions, inner carriageway, and outer carriageway, respectively. The Ring Road pavement condition can be classified as 10% excellent, 66% very good, and 24% good.

Figures (3-20) to (3-22) show the distribution of PCI values along the Ring Road for the Outer carriageway, Inner carriageway, and both directions combined, respectively. All sampled sections have at least a rating of good PCI except sample unit from km 22 to km 24, outer carriageway, Near to Ain-Sokhna Road. The new Link (from Cairo/Alex Desert Road to 6th of Oct. entrance road) has a relatively high PCI values.

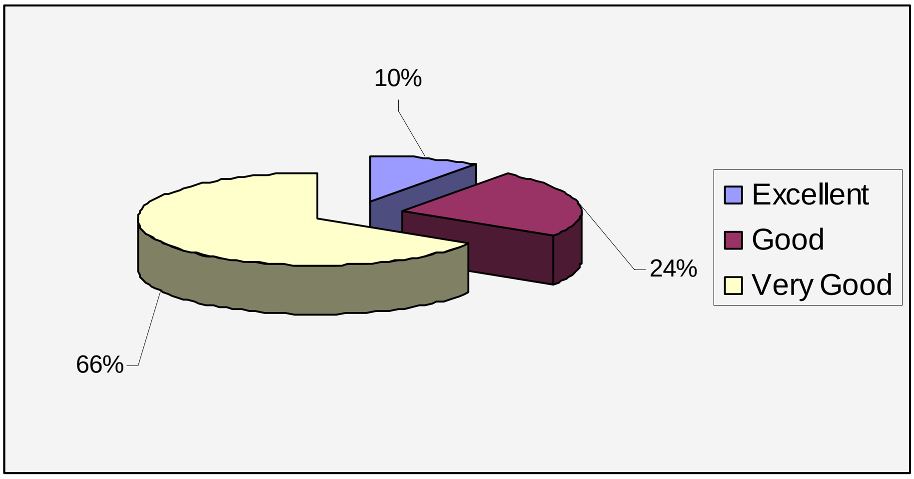


Figure (3-17): Distribution for pavement condition on the ring road – both directions.

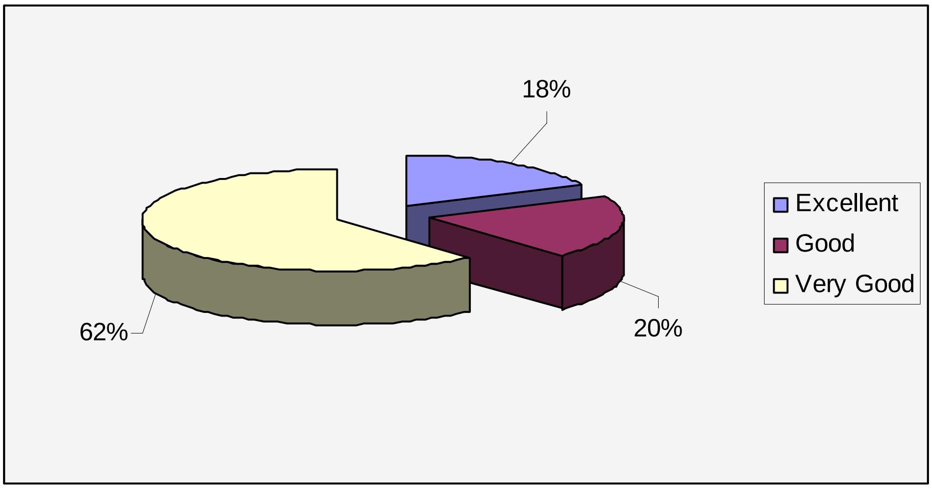


Figure (3-18): Distribution for pavement condition on the ring road – inner carriageway.

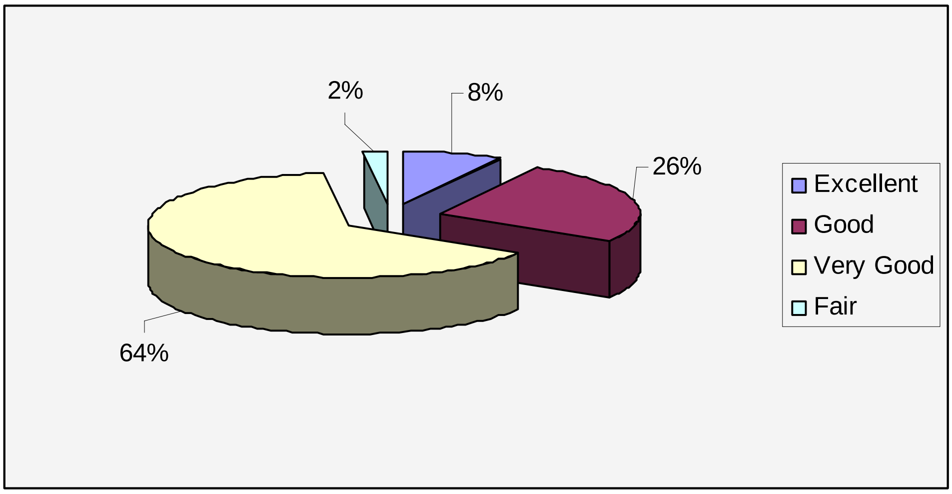


Figure (3-19): Distribution for pavement condition on the ring road – outer carriageway.

Table (3-5): Summary of PCI calculations

Location		Inner Carriageway			Outer Carriageway			Both Dir
from km	to km	PCI-1	PCI-2	Average PCI	PCI-1	PCI-2	Average PCI	PCI
0	2	84	91	88	78	82	80	84
2	4	90	90	90	76	84	80	85
4	6	92	91	92	72	87	80	86
6	8	77		77	79		79	78
8	10	88	90	89	80	90	85	87
10	12	80	90	85	74	88	81	83
12	14	85	91	88	78	89	84	86
14	16	74	82	78	81	74	78	78
16	18	71	79	75	80	76	78	77
18	20	74	74	74	78	74	76	75
20	22	72	71	72	71	72	72	72
22	24	66		66	55		55	61
24	26	62		62	68		68	65
26	28	69		69	63		63	66
28	30	78		78	83		83	81
30	32	79		79	78		78	79
32	34	77		77	84		84	81
34	36	76		76	83		83	80
36	38	83		83	82		82	83
38	40	78		78	64		64	71
40	42	75		75	71		71	73
42	44	80		80	69		69	75
44	46	72		72	66		66	69
46	48	73		73	69	65	67	70
48	50	72		72	73	63	68	70
50	52	70	68	69	67	61	64	67
52	54	74	74	74	56	68	62	68
54	56	76	76	76	65	72	69	72
56	58	78	69	74	72	76	74	74
58	60	73	69	71	78	71	75	73
60	62	71	67	69	81	78	80	74
62	64	73	69	71	71	71	71	71
64	66	75	70	73	72	64	68	70
66	68	75	68	72	60	62	61	66
68	70	58	64	61	59	77	68	65
70	72	67	66	67	72	77	75	71
72	74	76	76	76	85	80	83	79
74	76	77	74	76	78	84	81	78
76	78	70		70	77	88	83	76
78	80	65	75	70	76	90	83	77
80	82	80	76	78	79	87	83	81
82	84	75	76	76	71	90	81	78
84	86	78	76	77	75	78	77	77
86	88	72	74	73	74	80	77	75
88	90	66	75	71	82		82	76
90	92	83		83	80		80	82
92	94	93		93	94		94	94
94	96	91		91	90		90	91
96	98	91		91	93		93	92
98	99.7	91		91	94		94	93

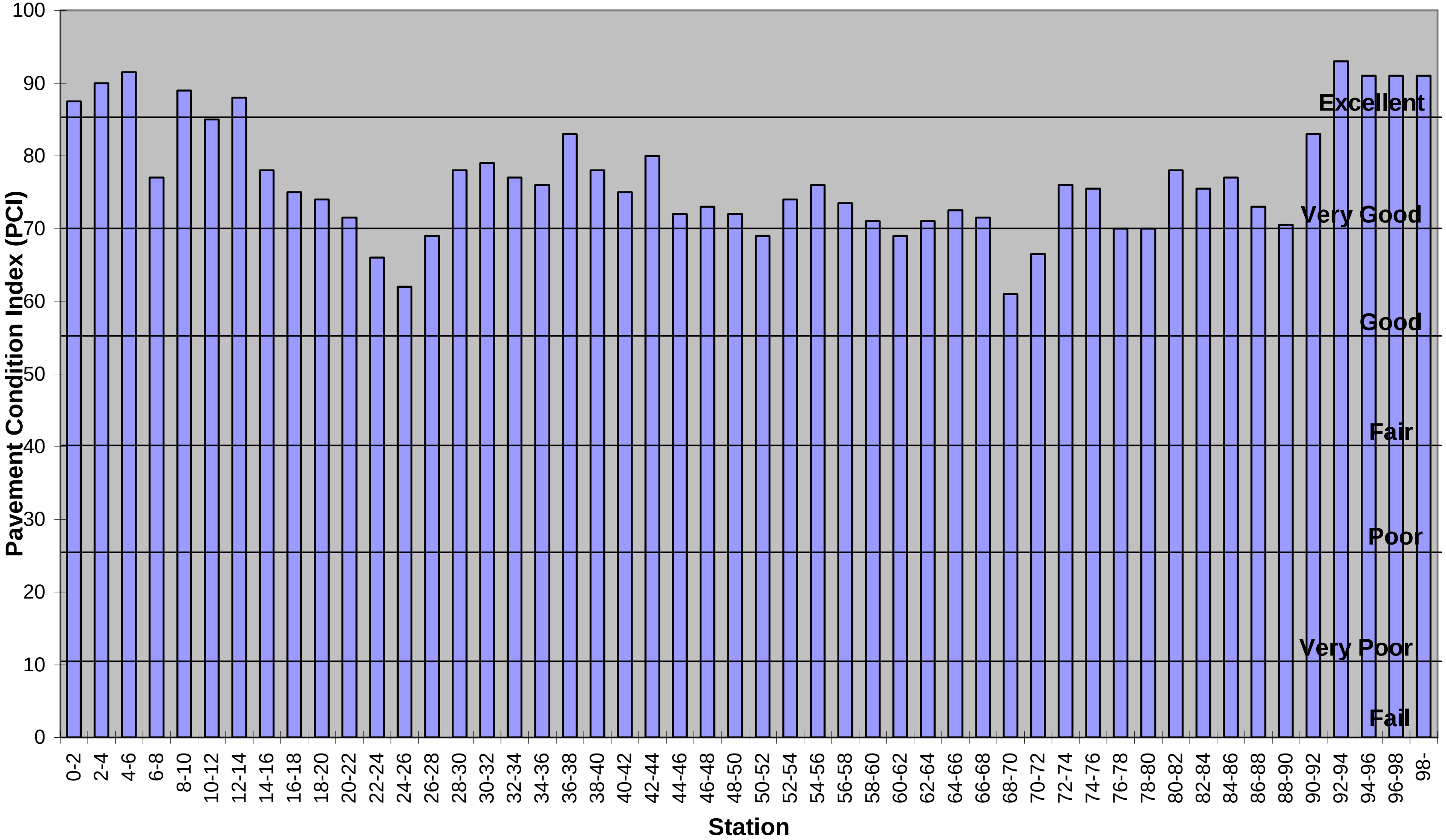


Figure (3-20): PCI distribution on the ring road - inner carriageway.

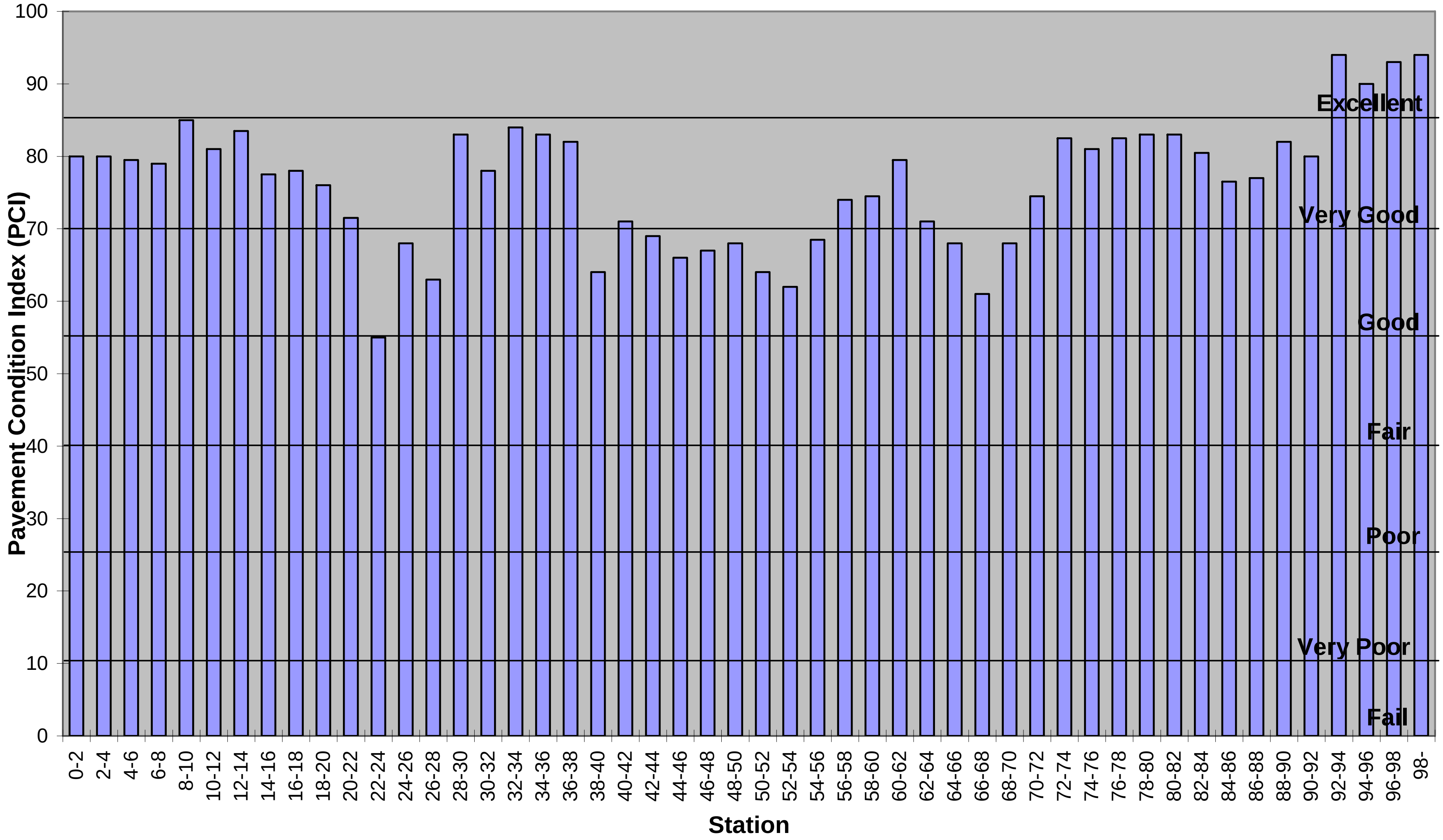


Figure (3-21): PCI distribution on the ring road - outer carriageway.

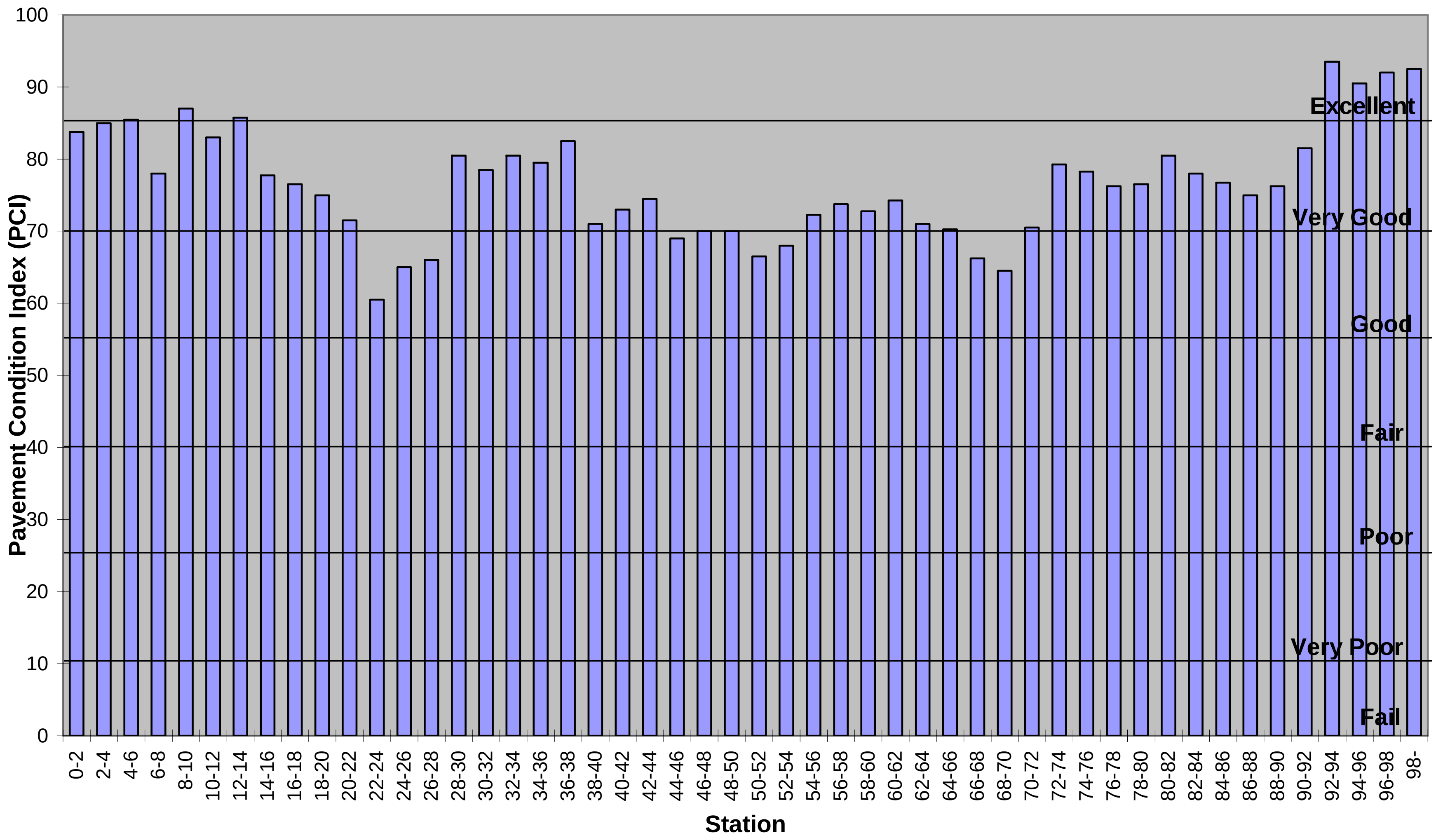


Figure (3-22): PCI distribution on the ring road – both directions.

CHAPTER 4

PAVEMENT ASSESSMENT AND REHABILITATION

4.1 Introduction

This chapter focuses on pavement assessment and rehabilitation, which includes field samples, and pavement assessment and rehabilitation. Structure assessment of the existing pavement of the Ring Road is based on the AASHTO method for flexible pavement. Material characterization was carried out by taking cores and open pits. All field work and subsequent laboratory tests were carried out by GARBLT main laboratory.

The pavement assessment and rehabilitation includes the following three steps:

1. Data collection: Gathering all of the information necessary Gathering all of the information necessary to conduct an evaluation of the pavement present condition and its rehabilitation needs.

2. Pavement evaluation: Assessing the current condition of the pavement, identify the key types of deterioration present, identify deficiencies that must be addressed by rehabilitation, and identify uniform sections for rehabilitation and design over the Ring Road length.

3. Selection of rehabilitation techniques: Identifying the most efficient rehabilitation technique suited to the correction of existing distress and achievement of desired improvements in the structural capacity and functional adequacy of the pavement.

4.2 Data Collection

Several elements of data collection were conducted in order to identify the optimum pavement rehabilitation plan for the Ring Road, namely:

1. Pavement distress survey

2. Field sampling and testing

3. Roughness Measurement

4.2.1. Pavement Distress Survey

As a part of the Pavement Assessment, We conducted a detailed distress survey for the entire Ring Road. We have already a detailed Chapter (3) on the methodology and findings of the field inspection survey. Recorded all distress types in a special form created for this task. The field data were then coded into a computer program to compute values of the pavement condition index (PCI).

4.2.2. Field Sample and Testing

4.2.2.1. Ring Road km numbering

The Ring Road has a total length of 99.7 km. The km 0.0 is set at the beginning of the main carriageway, above Mansouriya Canal. The end of the Ring Road is established at the end of the main carriageway, where the El-Wahat Link merges with 6th of October Road (km 99.7). As the Ring Road has the approximate shape of a loop, the use of cardinal directions (N, S, NE, SW, etc.) is not practical. In order to differentiate between the two carriageways, we adopted the following convention:

1. OUTER Direction – is the carriageway in the increasing km direction (counter-clockwise).
2. INNER Direction – is the carriageway in the decreasing km direction (clockwise).

4.2.2.2. Lane numbering

As mentioned in chapter three, the lane numbering convention used for the Ring Road was shown in Figure (3-1). The numbering of lanes starts from the outer shoulder for each direction of the Ring Road.

4.2.2.3. Sampling Plan

Core samples and open pits were taken only on embankment sections, and not on bridge sections because of structural integrity. Locations of core samples and open pits were randomly selected with an average spacing of 10 km for core samples and 20 km for open pits.

The following criteria were applied during the random selection of field samples.

1. Average interval spacing for core samples is 10 km.
2. Average interval spacing for open pits is 20 km.
3. No open pits and core samples taken at the same location.
4. No field samples at bridges or tunnels.
5. At least one core sample and one open pit for each lane per road direction.
6. Since Lanes 1 and 2 experience higher truck traffic, the cores in each carriageway will be assigned as follows:
    1. Three cores from Lane 1.
    2. Three cores from Lane 2.
    3. Two cores from Lane 3.
    4. Two cores from Lane 4.

Tests on the field samples were conducted at GARBLT main laboratory. The objective of the laboratory tests was to determine the properties of the pavement material and thickness of the different pavement layers. All tests were carried out according to AASHTO and GARBLT standard conditions.

For open pits, GARBLT laboratory informed us that no open pits can be taken from the traffic lanes. Instead, GARBLT laboratory said that open pits can be only from the shoulder. This is because of the capability of the saw cutting machine that is available at GARBLT. GARBLT laboratory said they can not cut an open pit in areas with asphalt concrete layers for more than 15 cm. Although the approved action plan had no open pit taken at the same station as the core, GARBLT laboratory insisted on taking the open pits at core locations in order to make sure that the pavement thickness is not far from 15 cm. It was agreed to have the open pits on the shoulder and to reasonably assume thicknesses for the base and subbase layers. We were told that the Ring Road pavements consists of at least 20-cm of subbase and 30-cm of base course. The thickness of asphalt concrete layers was determined from the core samples. GARBLT laboratory extracted three open pits and 3 open pits.

4.2.3. Roughness Measurements

GARBLT provided us with roughness measurements for the Ring Road pavement. The roughness condition is represented by the International Roughness Index (IRI). The IRI roughness standard scale for different road classes is shown in Figure (4-1). The higher the value, the rougher is the pavement.

IRI is used to define a characteristic of the longitudinal profile of a traveled wheel track and constitutes a standardized roughness measurement. The commonly recommended units are meters per kilometer (m/km) or millimeters per meter (mm/m). The IRI is based on the average rectified slope (ARS), which is a filtered ratio of a standard vehicle's accumulated suspension motion (in mm, inches, etc.) divided by the distance traveled by the vehicle during the measurement (km, mi, etc.). IRI is then equal to ARS multiplied by 1,000.

GARBLT data includes measured IRI from km 0 to km 92. Details of the supplied data are included in the Appendix (C). The range of observed IRI was from 1.82 to 4.72 with an overall average of 3.21. The Ring Road segment from km 50 to km 70 experiences higher IRI (average 3.72). The overall distribution of pavement roughness condition along the Ring Road is depicted in Figure (4-2). IRI observed on the Ring Road fall in the normal range for older pavements. About 63% of the Ring Road has a roughness index less than 3.5.

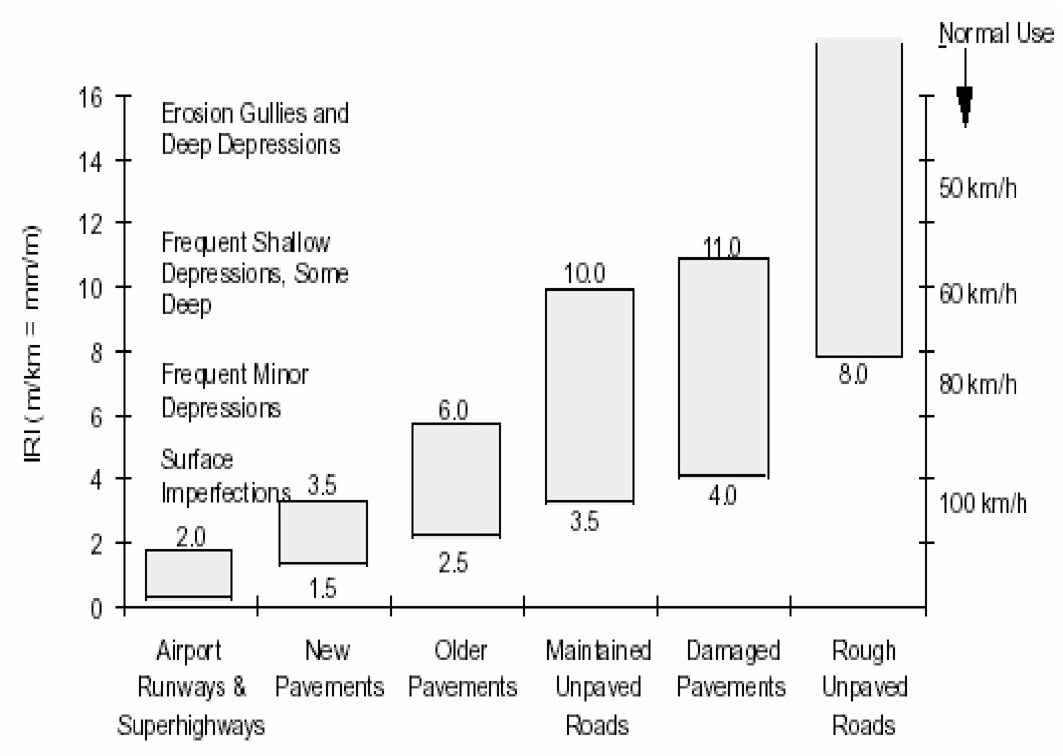


Figure (4-1): IRI roughness standard scale.

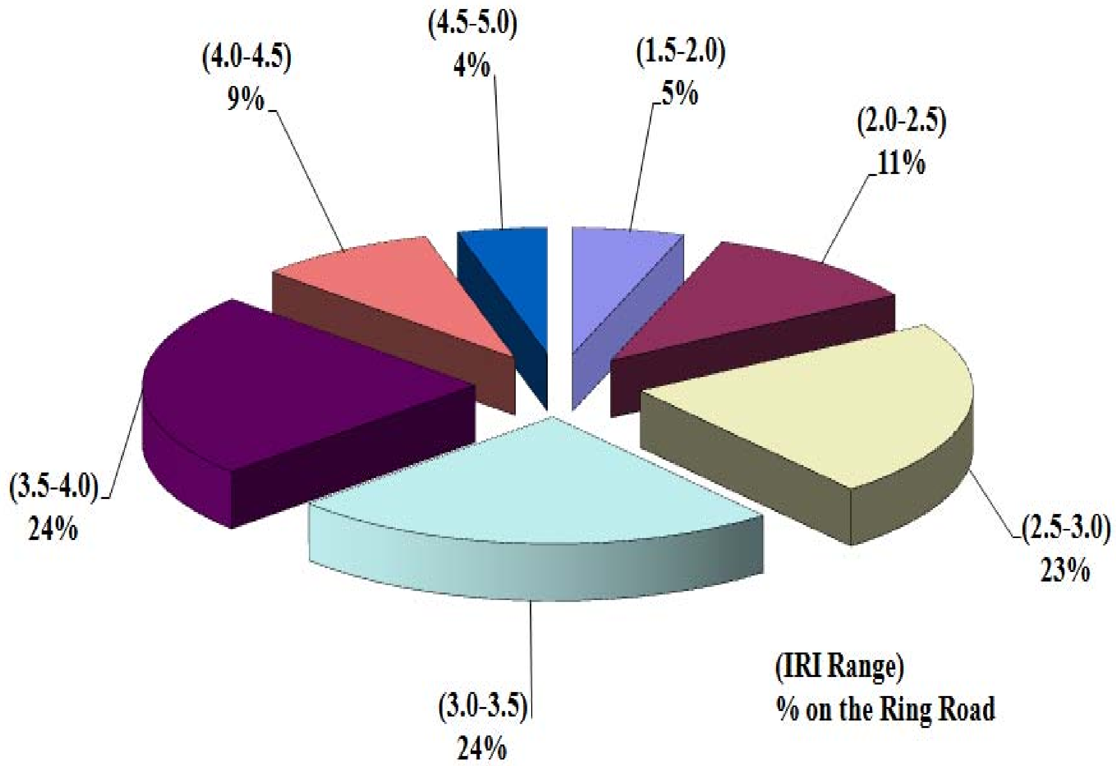


Figure (4-2): Distribution for pavement roughness condition.

4.3 Results of Laboratory Tests

4.3.1. Core Samples

A total of 20 cores were taken from the Ring Road. Locations of core samples are shown in Table (4-1). As example for the recorded field work is shown in Figure (4-3) and Figure (4-4). Figure (4-5) shows the average measured thicknesses of core samples along the Ring Road. The average measured thickness of cores is in the range 13-31 cm.

Table (4-1): Locations of core samples.

km	Outer direction	Inner direction
1.5	Lane 1	
4.7		Lane 4
12.0	Lane 4	
17.0		Lane 1
22.5	Lane 3	
26.0		Lane 3
32.0	Lane 2	
38.5		Lane 2
44.5	Lane 1	
49.0		Lane 1
53.8	Lane 4	
58.2		Lane 2
64.0	Lane 2	
67.0		Lane 3
73.5	Lane 3	
77.0		Lane 1
84.0	Lane 1	
88.3		Lane 4
94.0	Lane 2	
96.5		Lane 2

Figure (4-3): Sample of core extraction.

Figure (4-4): Sample of core extraction.

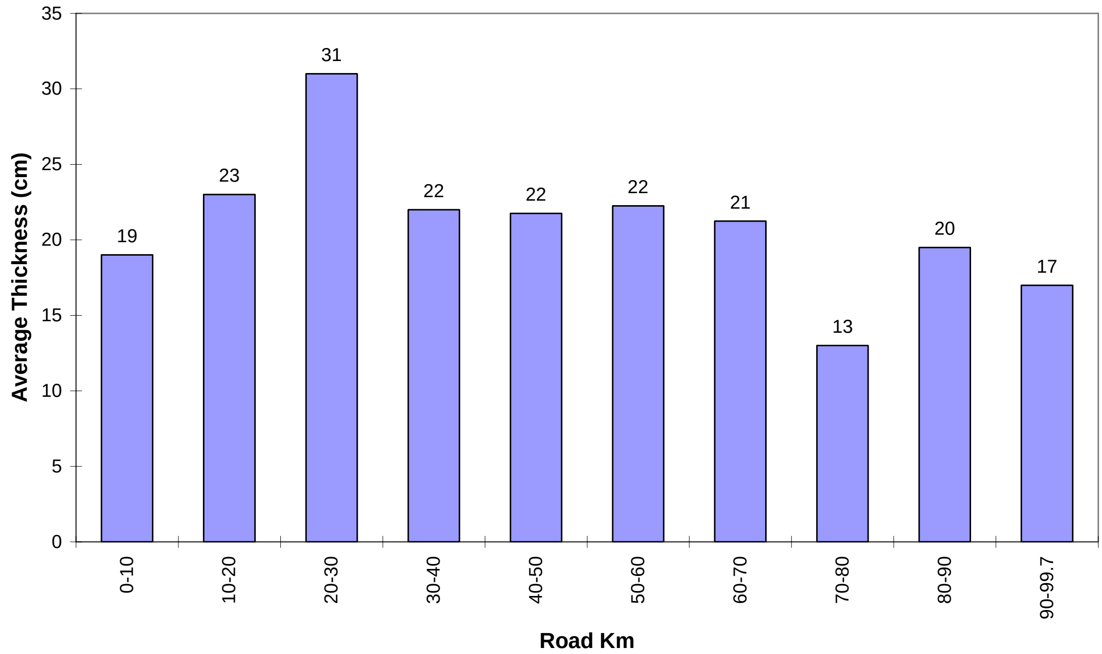


Figure (4-5): Average measured thicknesses of core samples.

4.3.2. Open Pits

A total of three open pits were made at the Ring Road at the following road stations.

1. Station (77+000), Inner carriageway.
2. Station (84+000), Outer carriageway.
3. Station (94+000), Outer carriageway.

As example for the recorded field work is shown in Figure (4-6) to Figure (4-9). Open pits were used to extract samples for laboratory testing for asphalt concrete layers, base, and subbase courses. A list of the laboratory tests carried out on the open pits is as follow:

1. Tests on the Asphalt Slabs:
   - 1.1 Percentage of asphalt
   - 1.2 Sieve analysis of mineral aggregate
   - 1.3 Percentage of natural particles in the mineral aggregate
   - 1.4 Prepared molds in the lab
     - 1.4.1 Marshall Stability and flow

1.4.2 Specific gravity

2. Tests on the base course:

   1.1 Sieve analysis
   1.2 Atterberg limits
   1.3 Modified Proctor
   1.4 CBR Value
   1.5 Los Angeles abrasion
   1.6 Specific gravities
   1.7 Water absorption and disintegration

GARBLT tests results of the asphalt concrete slabs showed that the asphalt concrete layers have an average percentage of asphalt of about 5.7%. The average observed bulk density of Marshall Molds was 2.28 ton per cubic meter. The average measured Marshall Stability of the remolded specimens was about 2,050 pounds.

GARBLT tests results of the base course material showed that the material can be classified as 'A-1-a' (according to AASHTO classification system) for the samples taken at stations (77+000) (Inner carriageway) and (94+000) (Outer carriageway). The general description of soil group A-1 is well-graded mixtures of stone fragments or gravel ranging from coarse to fine with a non-plastic or slightly plastic soil binder.

The base sample taken at station (84+000) (outer carriageway) has a plasticity index of 8, and hence is classified as 'A-2-4'. The average maximum dry density in the modified Proctor test was equal to 2.21 ton per cubic meter. The abrasion in the Los Angles machine was less than 50%. The measured water absorption was less than 5%.

Figure(4-6): Sample of open pit extraction.

Figure (4-7): Sample of open pit extraction.

Figure (4-8): Sample of open pit extraction.

Figure (4-9): Sample of open pit extraction.

4.4 Homogenous Design Units

Frequently in large pavement rehabilitation projects such as upgrading the Ring Road, the properties of the pavement vary along the length of the project. If the variations in these properties are not recognized in the selection of the rehabilitation alternative, then parts of the project will be over or under designed. Thus, it was important to isolate unique factors that influence potential pavement performance into separate sections called analysis units. The following factors were used to delineate the Ring Road into homogenous design units:

1. Pavement surface condition (PCI and IRI).
2. Number of lanes.
3. Traffic volumes.
4. Percentage of trucks.
5. Pavement cross section.

Pavement surface condition is based on the PCI survey and IRI measurements provided by GARBLT. The number of lanes was determined during the road Inventory subtask. Information of traffic volumes and percentage of trucks were extracted from the Traffic Report from GARBLT. Data of the existing pavement cross section were based on the cores and open pits sampled from the Ring Road and tested by GARBLT main laboratory. The analysis units were identified with the cumulative difference method recommended in the AASHTO Guide. A plot of the aforementioned variables versus the stations along the Ring Road is shown in Figure (4-10).

The Ring Road was divided into the following eight homogenous stretches (analysis units) for pavement assessment and rehabilitation. Unit attributes are summarized in Table (4-2).

1. Unit 1: km 0 to Km 2.9 Mansouriya Canal – Mariutiya Canal S
2. Unit 2: km 2.9 to km 22.8 Mariutiya Canal S – Ain Sokhna Road
3. Unit 3: km 22.8 to km 29.1 Ain Sokhna Road – Qattamiya

4. Unit 4: km 29.1 to km 37.3 Qattamiya – Suez Road
5. Unit 5: km 37.3 to km 47. Suez Road – Ismailia Desert Rd
6. Unit 6: km 47.7 to km 69.9 Ismailia Desert Rd – Warak Bridge No. 2
7. Unit 7: km 69.9 to km 89.2 Warak Bridge No. 2 – Mariutiya Canal N
8. Unit 8: km 89.2 to km 99.7 Mariutiya Canal N – 6th of Oct. City Rd

Table (4-2): Attributes of the analysis units.

Unit	From	To	PCI	IRI	No. of lanes	Traffic volume (veh/day)	% Trucks	Asphalt thickness (cm)
1	Mansouriya Canal	Mariutiya Canal S	82	3.1	4	31,000	13	19
2	Mariutiya Canal S	Ain Sokhna Road	82	3.1	4	100,000	13	21
3	Ain Sokhna Road	Qattamiya	70	2.9	3	100,000	13	31
4	Qattamiya	Suez Road	78	3.5	3	100,000	13	22
5	Suez Road	Ismailia Desert Rd	70	3.4	2	100,000	26	22
6	Ismailia Desert Rd	Warak Bridge No. 2	70	3.4	4	115,000	21	22
7	Warak Bridge No. 2	Mariutiya Canal N	78	3.0	4	90,000	21	16
8	Mariutiya Canal N	6th of Oct. City Rd	92	---	3	50,000	32	16

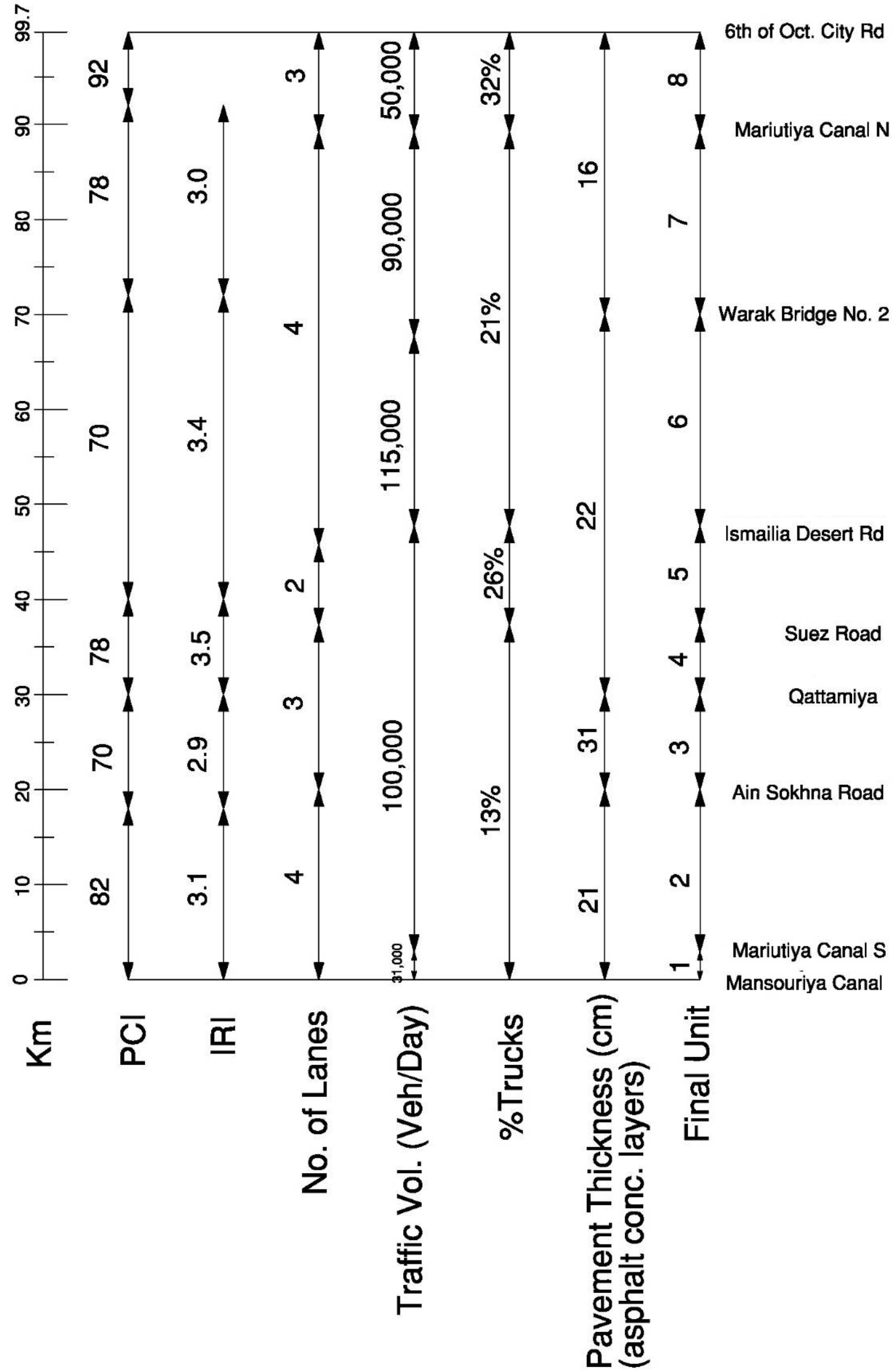


Figure (4-10): Defining analysis units for pavement assessment.

4.5 Pavement Assessment and Rehabilitation

4.5.1. Methodology

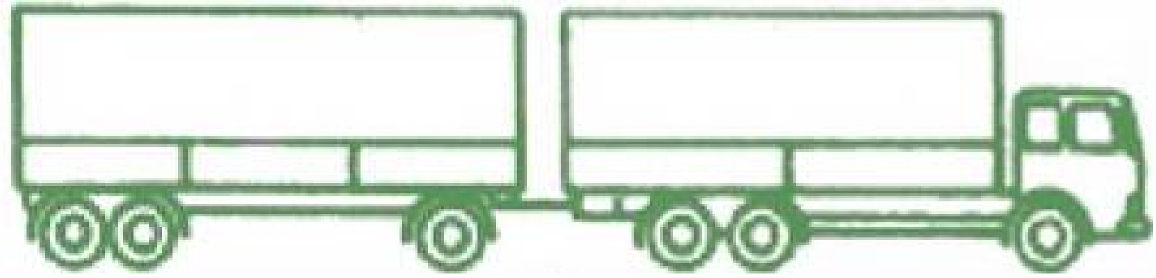
The AASHTO design procedure for flexible pavement was adopted to conduct assessment of the existing pavement along the Ring Road. The design equations require a number of inputs related to loads, pavement structure and sub grade support.

The inputs for AASHTO method can be grouped as follow.

1. Truck Factor.
2. Design Traffic.
3. Design EASL.
4. Material Characterization.
5. AASHTO Input parameters.

4.5.1.1. Truck Factor

AASHTO Method requires that all traffic be converted into equivalent single axle loads (ESAL). Truck factors are used to convert the truck traffic into ESAL. GARBLT list of allowable trucks on the Egyptian highways and selected the most critical truck Figure (4-11). The Egyptian Code for Highways recommends considering that 60% of the trucks are loaded and 40% are unloaded. Out of the 60% loaded trucks, 10% were considered to be overloaded (i.e., exceeding the allowable load limit). The overloaded truck was assumed to have a total weight of 70 ton (i.e., 10 ton over the maximum allowable weight limit).



Figure(4-11): Axle loads of the design truck.

Detailed calculations of the truck factors are included in the Appendix (D). The calculated truck factors for the loaded (70 ton), loaded (60 ton), and unload trucks (40 ton) were 22.3, 12.5, and 2.6, respectively. The weighted average truck factor for the entire truck mix is equal 9.5.

4.5.1.2. Design Traffic

Once the truck factors are computed, the design ESAL can be computed from the design traffic and the expected growth rate. The design traffic is calculated as the product of the average daily traffic, percentage of trucks, pavement design life, and the growth factor over the design life. The ESAL is then obtained by multiplying by the truck factor.

A direction distribution factor (D_D) was used to account for the differences in loading according to the Ring Road direction. The direction distribution was set to 60%. In addition to the direction distribution factor, a lane distribution factor (D_L) was considered to account for the differences in traffic loading among lanes of the same direction. As per the Egyptian Code for Highways (ECP, 2008), the recommended lane distribution factors are summarized in Table (4-3).

Table (4-3:) Lane distribution factors, D_L

No. of lanes in each direction	% of ESAL in design lane
2	90
3 or more	80

The design life time for flexible pavement was taken 15 year, as per the Egyptian Code for Highways. Based on the recommended of the Egyptian Code, the annual growth rate in traffic on the Egyptian roads typically varies from 2% to 4%. We considered the upper limit of the recommended annual growth rate, which equals to 4%.

4.5.1.3. Design EASL

The ESAL for the design lane can be calculated from Equation (4-1) and (4-2):

$$ESAL_{first\ year} = AADT \times \%T \times D_D \times D_L \tag{4-1}$$

$$ESAL_{15} = ESAL_{first\ year} \times GF \tag{4-2}$$

Where:

$ESAL_{15}$: Is the 15-year ESAL on the design lane.

GF : Is the growth factor corresponding to the pavement design life and annual growth rate.

AADT:Is the average annual daily traffic.

The design EASL was calculated for the delineated homogenous Ring Road sections. The above equations were used to calculate the design EASL. Values of the design EASL are summarized in Table (4-4).

Table (4-4): Design EASL

Unit	**From**	**To**	**Design EASL (million)**
1	Mansouriya Canal	Mariutiya Canal S	135
2	Mariutiya Canal S	Ain Sokhna Road	434
3	Ain Sokhna Road	Qattamiya	434
4	Qattamiya	Suez Road	434
5	Suez Road	Ismailia Desert Rd	975
6	Ismailia Desert Rd	Warak Bridge No. 2	805
7	Warak Bridge No. 2	Mariutiya Canal N	630
8	Mariutiya Canal N	6th of Oct. City Rd	534

4.5.1.4. Material Characterization

AASHTO combines pavement layer properties and thicknesses into one variable called the design structure number (SN). The layer coefficients vary from material to material. AASHTO recommends Figures for the layer coefficients based on some measured material characteristics. The layer coefficients for asphalt concrete layers depend on Marshall Stability, whereas the layer coefficient for the base and subbase course depends on CBR values. The values of a1, a2, a3, were equal to 0.39, 0.13, 0.11 are included in the Appendix (E), respectively for every one inch of layer. The drainage coefficients were set at 1.0.

4.5.1.5. Reliability and Serviceability

Other Input parameters required for the AASHTO method include the selection of reliability, overall standard deviation, initial serviceability (P_i), and terminal serviceability (P_t).

AASHTO defines Reliability as 'the probability that the load applications a pavement can withstand in reaching a specified minimum serviceability level is not exceeded by the number of load applications that are actually applied to the pavement'. The overall standard deviation is a measure of the spread of the probability distribution for ESAL. Initial serviceability is the serviceability index once the road is opened to the public, whereas terminal serviceability is the index at the end-of-life. The following values were assumed:

1. Reliability = 95%
2. Overall standard deviation = 0.45
3. Initial serviceability index = 4.2
4. Terminal serviceability index = 2.5
5. CBR of road embankment = 15.

4.5.2. Structural Assessment of the Existing Pavement

The structural assessment of the existing pavement was carried out based on the AASHTO Guide for Design of Pavement Structures. The structure number (SN) was calculated based on the measured thickness and material characteristics. The required SN was calculated based on the calculated design ESAL. Details of the SN calculations are included in the Appendix (E). Table (4-5) summarizes the structure numbers of existing pavement as well as the required structure numbers to sustain the design ESAL.

Table (4-5): Existing and required SN.

Unit	From	To	SN of existing pavement	Required SN to sustain the design ESAL
1	Mansouriya Canal	Mariutiya Canal S	5.32	5.51
2	Mariutiya Canal S	Ain Sokhna Road	5.63	6.44
3	Ain Sokhna Road	Qattamiya	7.16	6.44
4	Qattamiya	Suez Road	5.78	6.44
5	Suez Road	Ismailia Desert Rd	5.78	7.14
6	Ismailia Desert Rd	Warak Bridge No. 2	5.78	6.97
7	Warak Bridge No. 2	Mariutiya Canal N	4.86	6.75
8	Mariutiya Canal N	6th of Oct. City Rd	4.86	6.61

4.5.3. Pavement Rehabilitation

Pavement Rehabilitation consists of structural enhancements that extend the service life of an existing pavement and/or improve its load carrying capacity. Asphalt pavement rehabilitation typically involves milling and resurfacing of the existing asphalt pavement to mitigate the effects of pavement defects such as rutting and cracking. Milling is commonly used to remove a distressed surface layer from an existing pavement. Rehabilitation techniques may be grouped as follows:

1. Major rehabilitation consists of structural enhancements that both extend the service life of an existing pavement and/or improve its load-carrying capability;
2. Minor rehabilitation consists of non-structural enhancements made to the existing pavement sections to eliminate age-related, top-down surface cracking that develop in flexible pavements due to environmental exposure.

The AASHTO method was adopted to design the required overlay for the purpose of structural improvement. The required thickness of the overlay is a function of the structure capacity required to meet the design traffic and the structural capacity of the existing pavement. The thickness of overlay can be computed from equation (4-3) as follows:

$$D_{OL} = \frac{SN_{design} - SN_{existing}}{a_{OL}} \tag{4-3}$$

Where:

D_{OL} : is the required overlay thickness (cm).

a_{OL} : is the structural coefficient for the overlay.

Table (4-6) summarizes the required thicknesses of overlay. The recommended overlays are only applicable for embankment areas, not for bridges or tunnels. For bridge and tunnels, the rehabilitation plan will include fixing bridge joints and any water leakage, and a function overlay for the distressed surface areas.

Table (4-6) Thickness (cm) of overlay

Unit	From	To	Structural overlay thickness (cm)	Non-structural overlay
1	Mansouriya Canal	Mariutiya Canal S	----	
2	Mariutiya Canal S	Ain Sokhna Road	5	
3	Ain Sokhna Road	Qattamiya	----	3-cm milling and resurfacing
4	Qattamiya	Suez Road	5	
5	Suez Road	Ismailia Desert Rd	8	
6	Ismailia Desert Rd	Warak Bridge No. 2	7	
7	Warak Bridge No. 2	Mariutiya Canal N	12	
8	Mariutiya Canal N	6th of Oct. City Rd	11	

CHAPTER 5

RATIONAL ANALYSIS

5.1 Accident Data

As we mentioned before the Ring Road has a total length of 99.7 km. The km 0.0 is set at the beginning of the main carriageway, above Mansouriya Canal. The end of the Ring Road is established at the end of the main carriageway, where the El-Wahat Link merges with 6th of October Road (km 99.7). The General Authority for Roads, Bridges and Land Transport (GARBLT) has divided the Ring Road into four stretches as follow:

1- From Mansouriya Canal at km 0+000 to Ain Sokhna Road km 23+000.
2- From Ain Sokhna Road km 23+000 to Suez Road at km 37+300.
3- From Suez Road at km 37+300 to Warak Bridge at km 70+000
4- From Warak Bridge km 70+000 to El-Wahat Link at km 99+700.

Appendix (D) shows the reports that GARBLT provided about accidents which occurred in the Ring Road. The first group of reports represents the number of accidents, Number of deaths and Number of injuries in year of 2009 and 2010, It illustrates also the date, location, geometry (straight/curved portion), and the time of each accident (day/night).

The second group of reports represents the causes of accidents according to the traffic opinion for each accident mentioned in the previous reports. These reports summarise the number of accidents, number of death, number of injury at every black spot location.

The overall distribution of number of accidents, deaths, and number of injuries occurred on the Ring Road in 2010 and 2009 are depicted in Figure (5-1) to Figure (5-6), In year 2010 the charts illustrate that stretch no three has the largest number of accidents by 52% and followed by stretch no one by 25% but most of deaths occurred on stretch no one by 42% versus 39% for stretch three, the percent of injures was 40% on stretch three versus 32% for stretch no one, at all cases stretch four had the smallest number of accidents, deaths and injuries by 4%, 3% and 4% respectively. In year 2009, the largest number of accidents occurred in stretch no three by 42% followed by stretch no one by 33%, the largest number of deaths occurred in stretch no one by 45% followed by stretch no three by 37%, the largest number of injuries occurred in stretch no one by 52% followed by stretch no three by 32%. Stretch no one has no accidents in 2009.

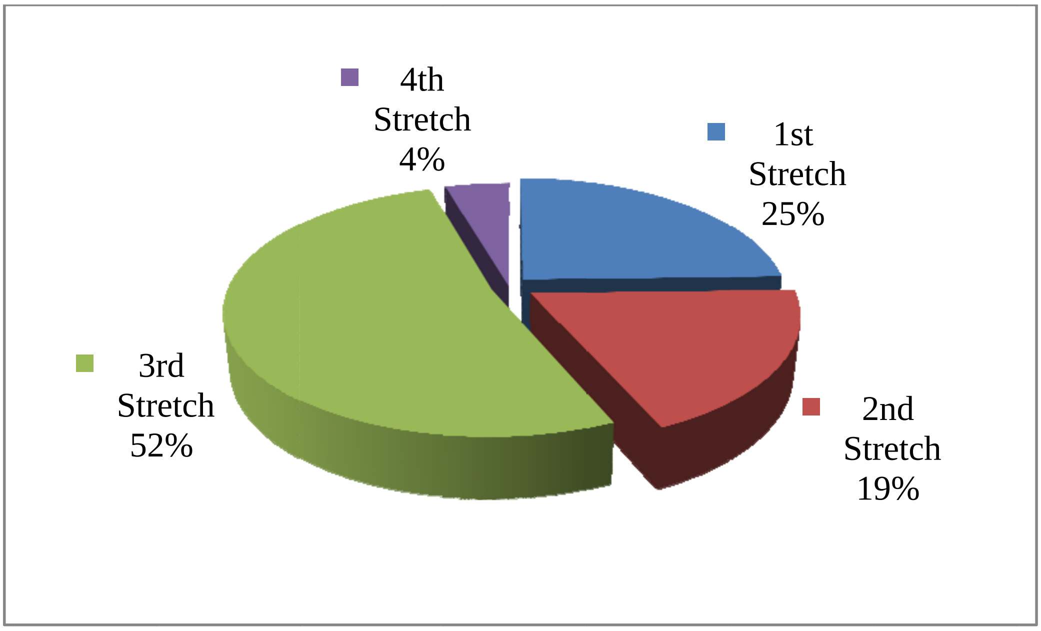


Figure (5-1): Distribution for the number of accidents on the Ring Road in 2010.

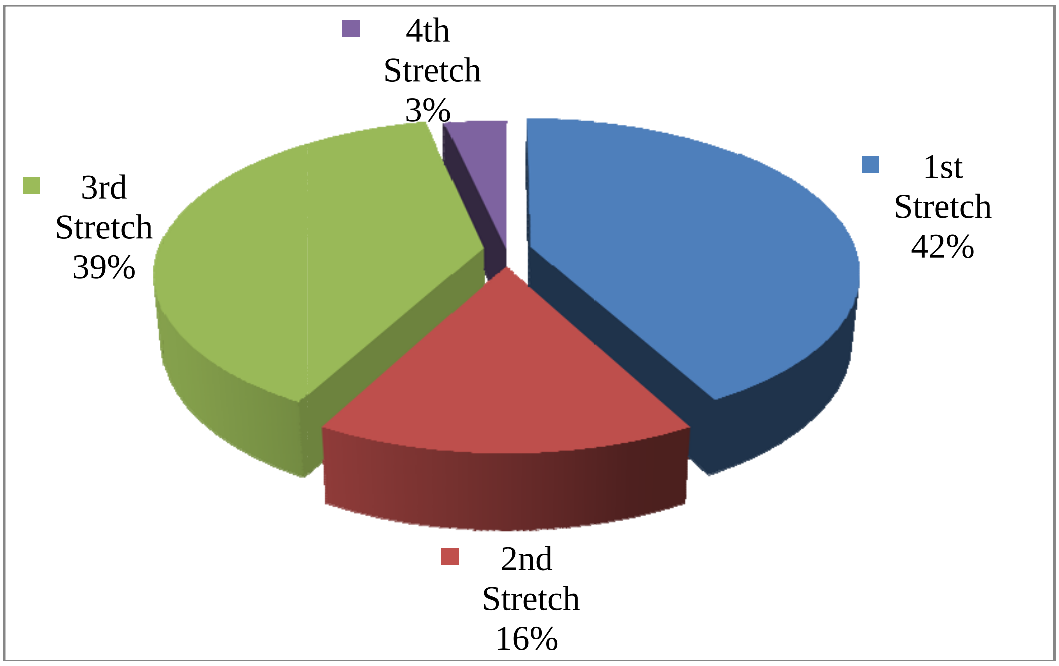


Figure (5-2): Distribution for the number of death on the Ring Road in 2010.

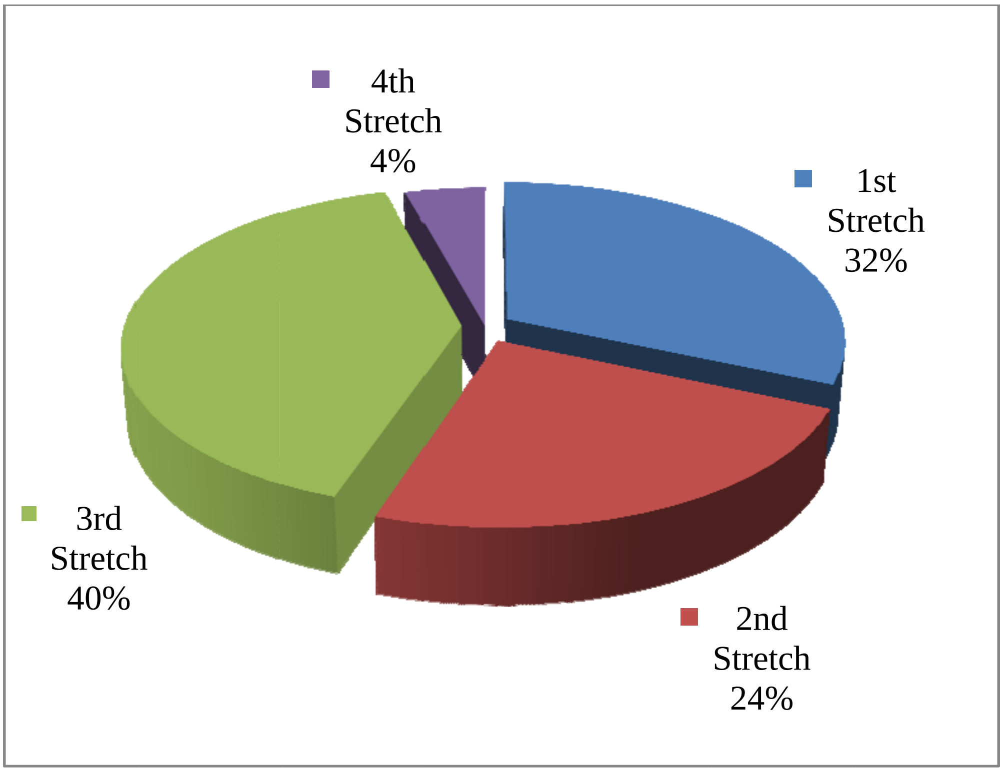


Figure (5-3): Distribution for the number of injury on the Ring Road in 2010.

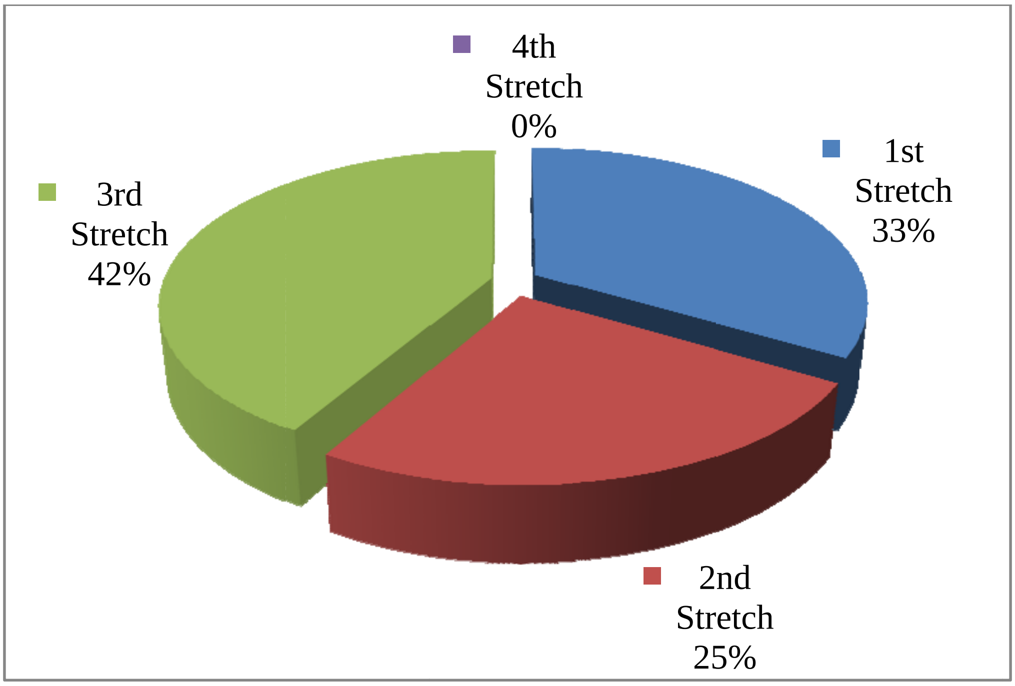


Figure (5-4): Distribution for the number of accidents on the Ring Road in 2009.

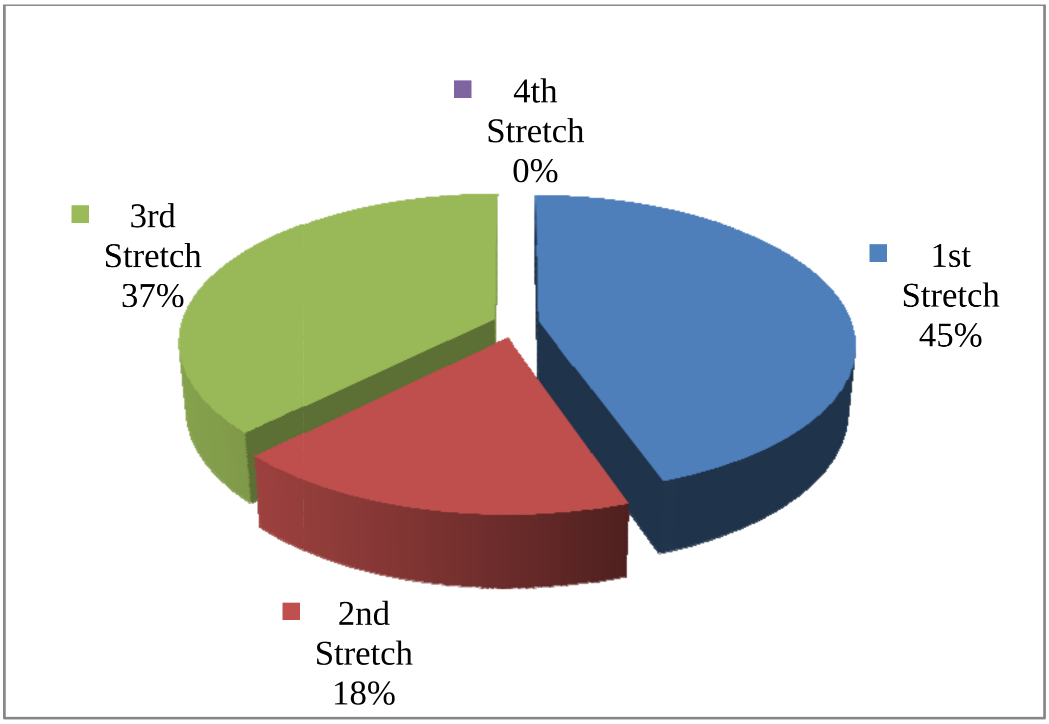


Figure (5-5): Distribution for the number of death on the Ring Road in 2009.

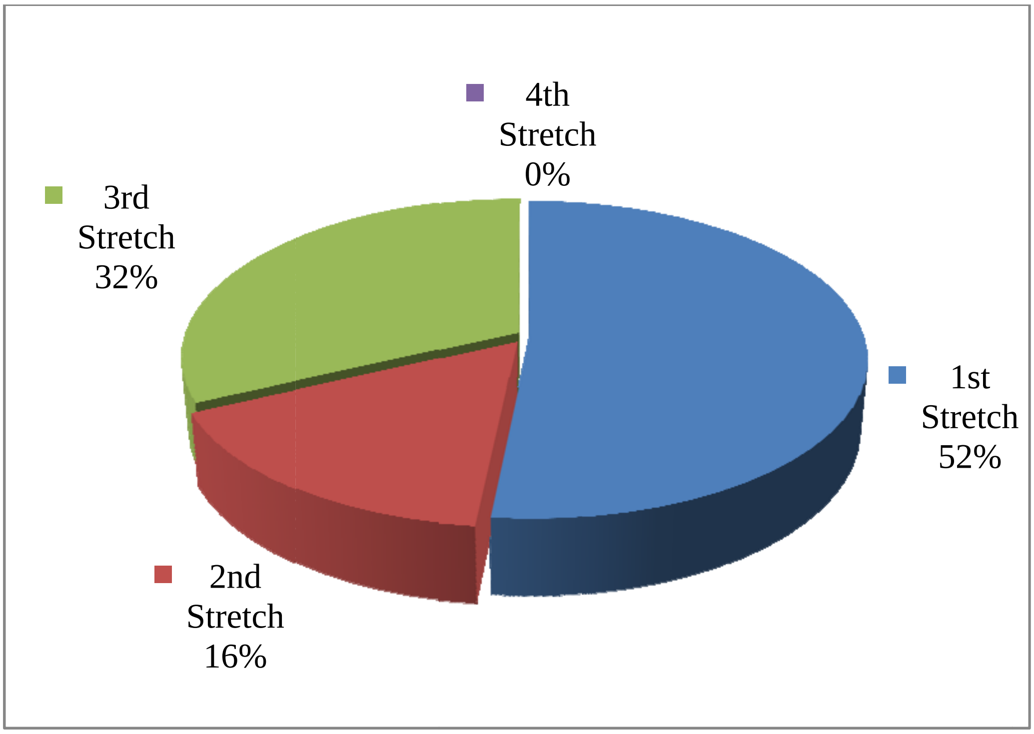


Figure (5-6): Distribution for the number of injury on the Ring Road in 2009.

The overall Distribution of number of accidents occurred in day and night on the Ring Road in 2010 and 2009 are depicted in Figure (5-7) and Figure (5-8), the charts illustrate that more than ninety percent of accidents occurred in day while a small percent of accidents occurred in night.

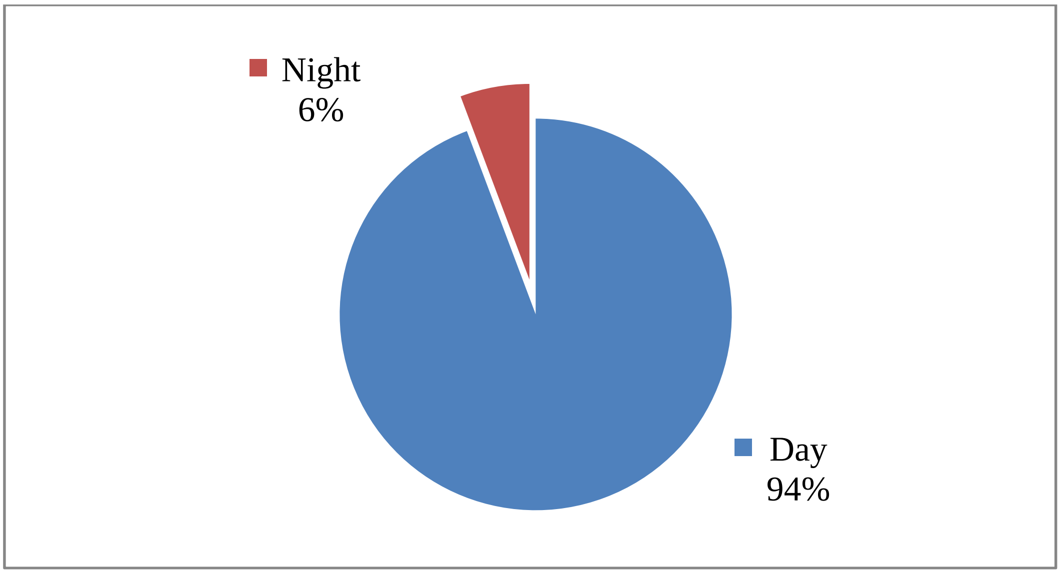


Figure (5-7): Distribution of time of accidents (day/night) on the Ring Road in 2010.

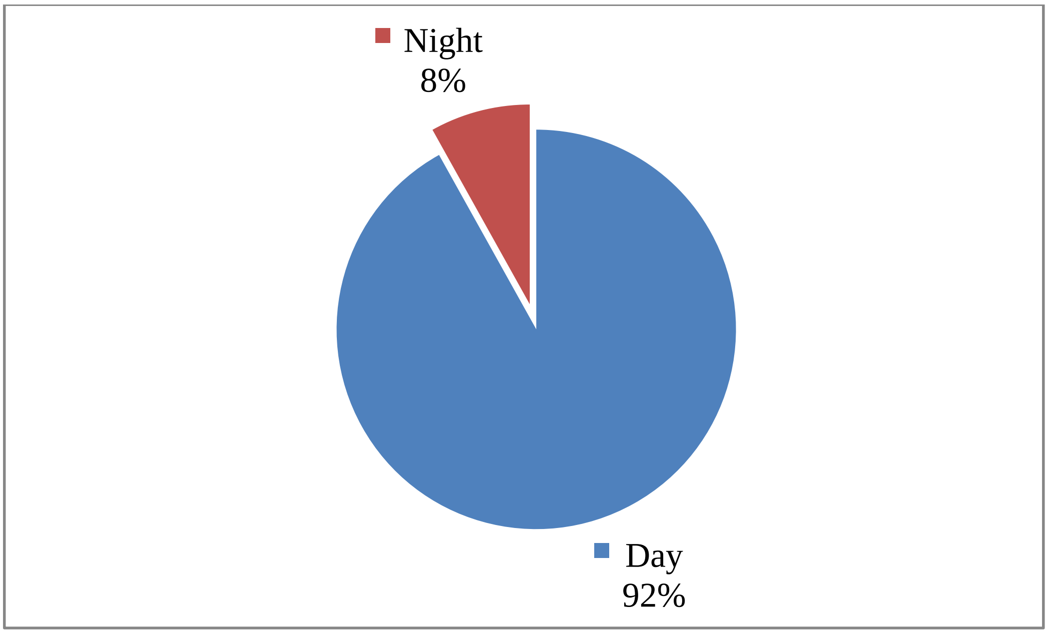


Figure (5-8): Distribution of time of accidents (day/night) on the Ring Road in 2009.

The overall Distribution of number of accidents occurred in straight and curve portions on the Ring Road in 2010 and 2009 are depicted in Figure (5-9) and Figure (5-10), the charts illustrate that more than 97% of accidents occurred in curved portions while a small percent of accidents occurred in straight portion of the Ring Road.

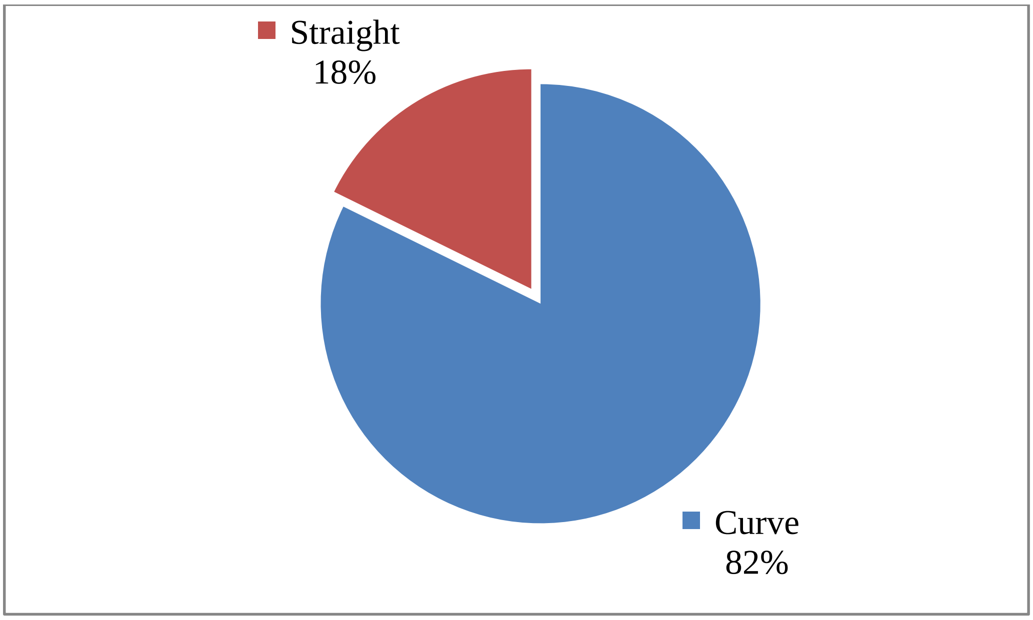


Figure (5-9): Distribution of accidents on (straight/curved) sections of the Ring Road in 2010.

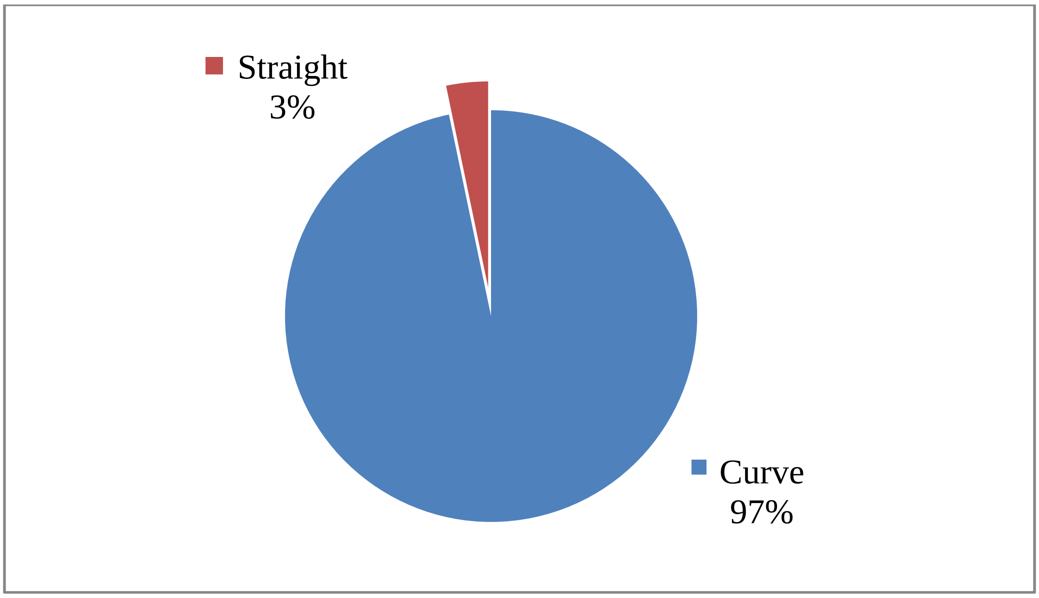


Figure (5-10): Distribution of accidents on (straight/curved) sections of the Ring Road in 2009.

5.2 Accident Estimation

To develop a general model for accidents, data available has been splitted into two groups the first was road way characteristics such as longitudinal profile grade, radius of horizontal curves, structure number, thickness of asphalt layers**,** pavement condition index, number of lanes, and international roughness index, and traffic data such as average daily traffic and percent of trucks on the Ring Road.

Simple Regression Analysis gives the correlation between number of accident at all accident locations and each of the studied parameters using different mathematical forms; linear, logarithmic, power, Polynomial, and exponential regression models to find the most significant relationship correlating number of accidents and considered parameters.

Number of Accidents (NA) and longitudinal profile grade (G) for all accidents locations on the Ring Road was regressed and the Polynomial relationship was plotted in Figure (5-11). Equation (5-1) represents the relationship between NA and G.

$$NA = 2.992G^2 - 2.983G + 2.290 \qquad R^2 = 0.362 \qquad (5\text{-}1)$$

The coefficient of determination (R^2) was found to be 0.362. Regression analysis was conducted after omitting one point which represents number of accidents at km 37+300 at Suez Road due to the upnormal value for number of accidents as shown in Figure (5-12). Equation (5-2) is a good representative for the relationship between NA and G.

$$NA = 3.122G^2 - 6.627G + 4.854 \qquad R^2 = 0.777 \qquad (5\text{-}2)$$

The relation between (NA) and horizontal curve radius (RC) shown in Figure (5-13). Equation (5-3) states the obtained relationship where R^2 was found to be 0.012 which shows poor relation between (NA) and (RC) but the existing of horizontal curve is significant in accident occurrences as we will see in multiple regression analysis.

$$NA = -0.001RC + 10.22 \qquad R^2 = 0.012 \qquad (5\text{-}3)$$

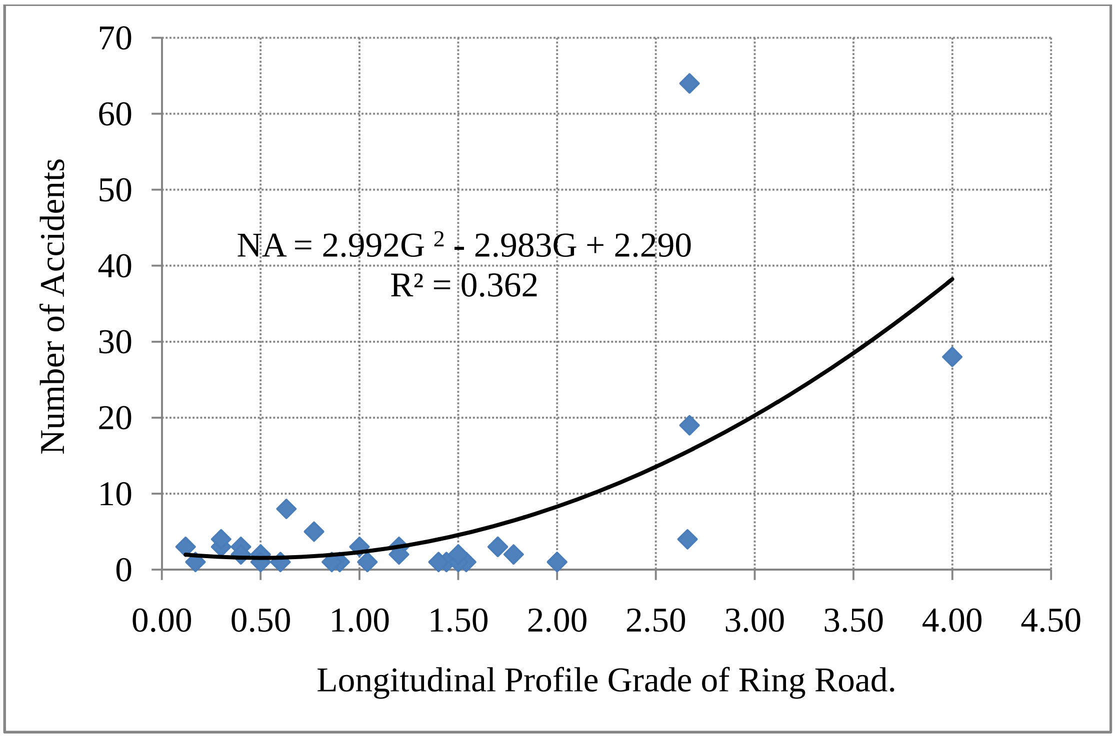


Figure (5-11): Number of accidents – longitudinal profile grade plot for the Ring Road.

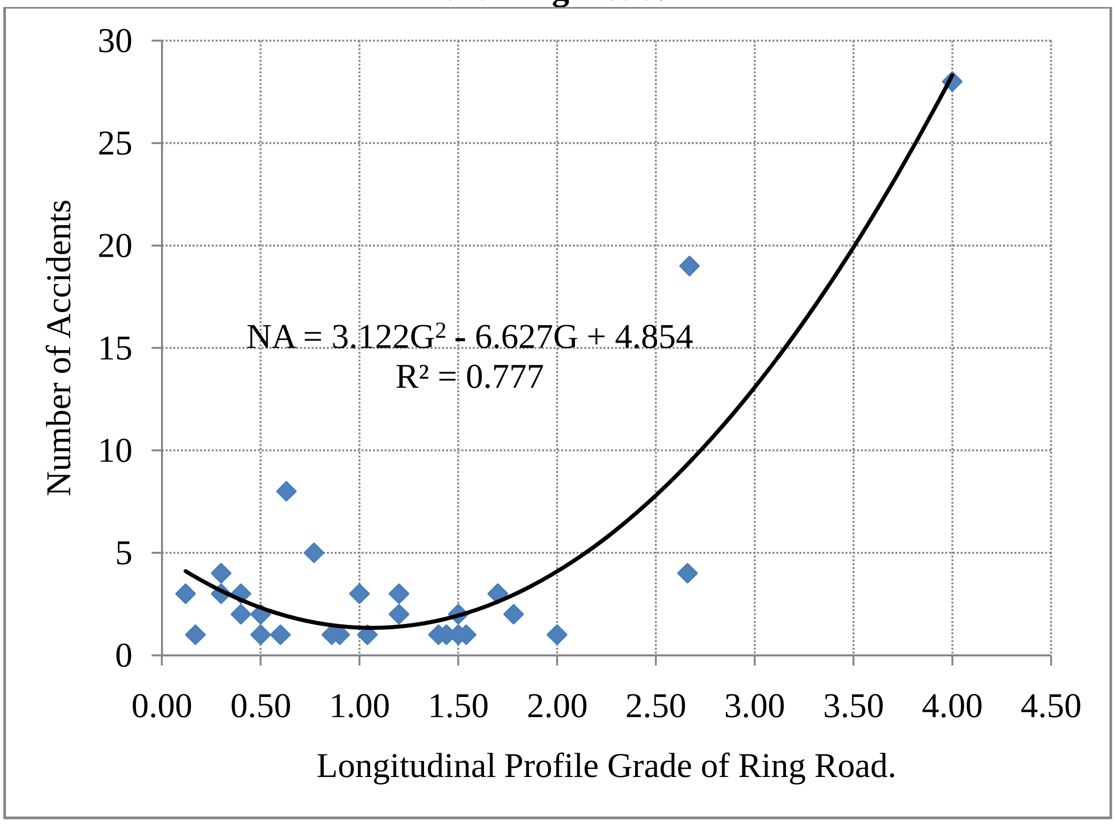


Figure (5-12): Number of accidents – longitudinal profile grade plot for the Ring Road.

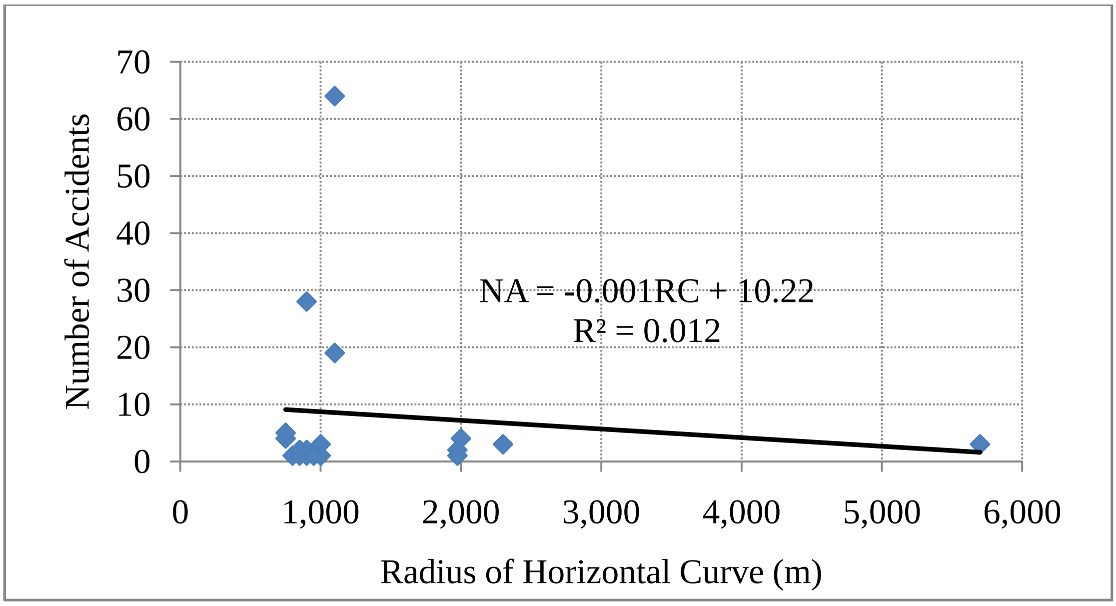


Figure (5-13): Number of accidents – horizontal curve radius plot for the Ring Road.

Figure (5-14) shows the relationship between (NA) and structure number (SN). This relationship is represented in Equation (5-4) with R^2 value of 0.002 which shows poor relation between NA and SN.

$$NA = -\ 0.037SN^2 + 0.765SN + 2.409 \qquad R^2 = 0.002 \qquad (5\text{-}4)$$

R^2 becomes 0.516 when the two points which represents number of accidents at km 23+000 at Ain Sokhna Road and at km 37+300 at Suez Road due to the odd value for number of accidents as shown in Figure (5-15). Equation (5-5) provides a good representative for the relationship between NA and SN.

$$NA = 2.541SN^2 - 33.30SN + 109.6 \qquad R^2 = 0.516 \qquad (5\text{-}5)$$

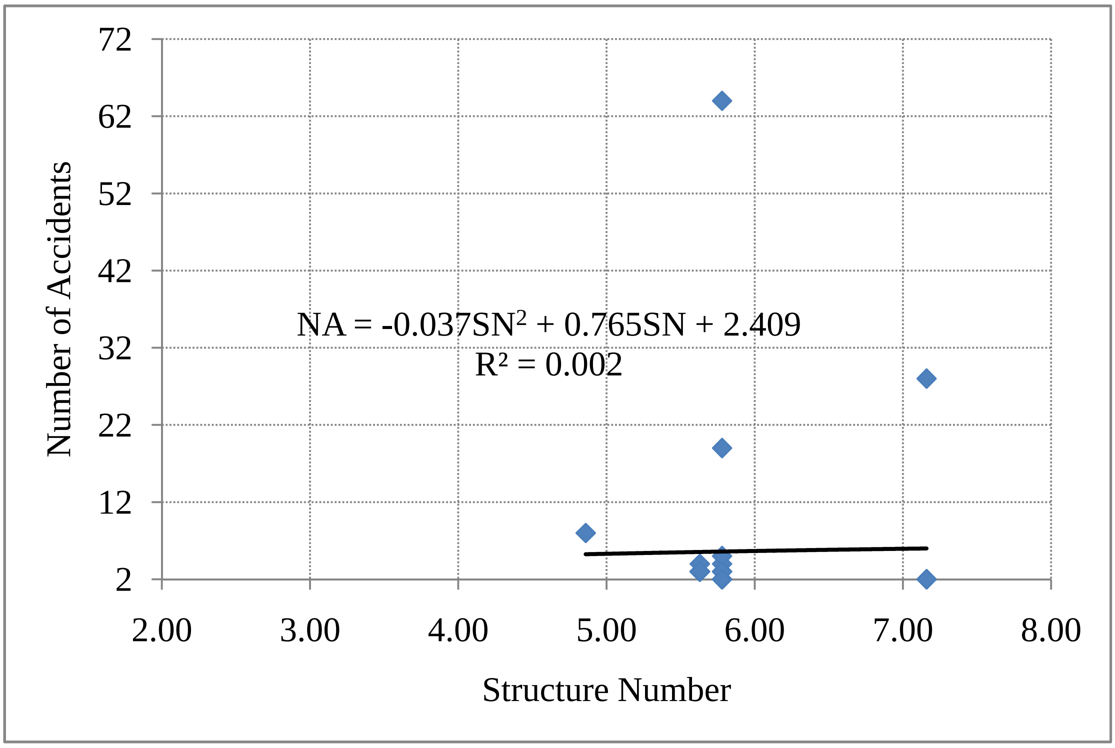


Figure (5-14): Number of accidents – structure number plot for the Ring Road.

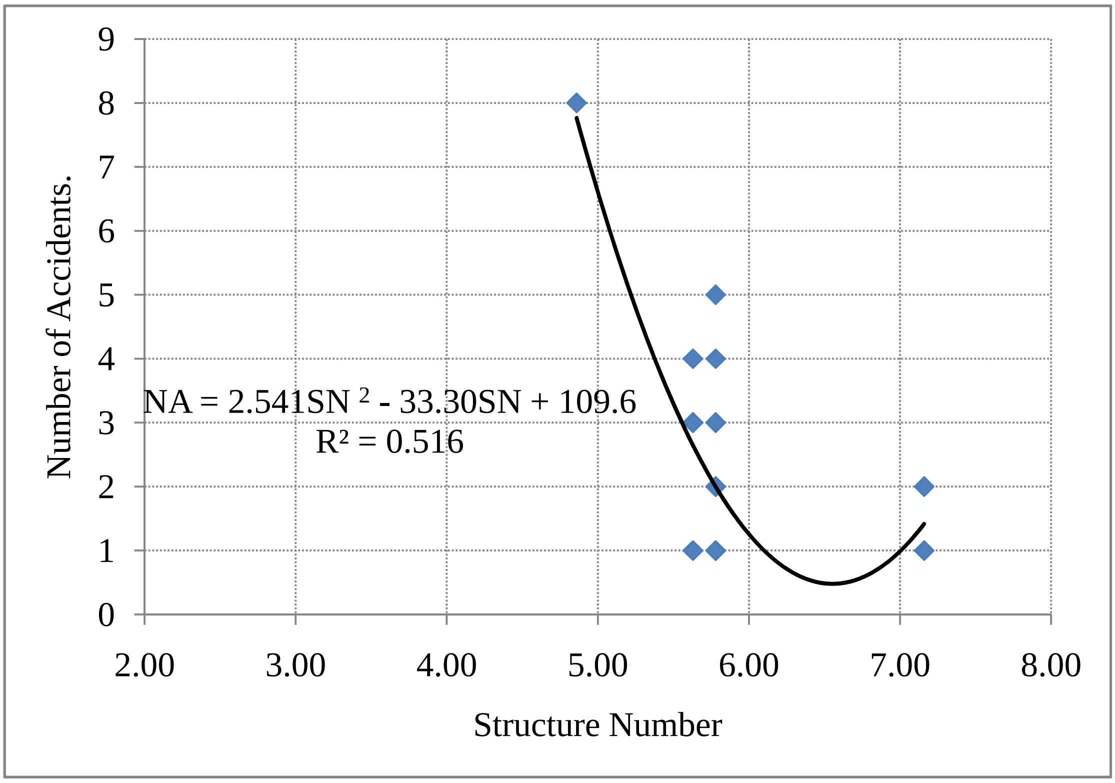


Figure (5-15): Number of accidents – structure number plot for the Ring Road.

The relationship between (NA) and thickness of asphalt layer (TH) was given by the Equation (5-6) and the regression plot curve is shown in Figure (5-16). R^2 for Equation (5-6) was found to be 0.001 which shows that there is no relation between (NA) and (TH).

$NA = 0.015TH^2 - 0.819TH + 15.92$ $\quad R^2 = 0.001$ $\quad$ (5-6)

R^2 becomes 0.445 when the two points which represents number of accidents at km 23+000 at Ain Sokhna Road and at km 37+300 at Suez Road due to the up normal value for number of accidents as shown in Figure (5-17). Equation (5-7) is better representative for the relationship between (NA) and (TH), however the relation still not significant.

$NA = 0.026TH^2 - 1.499TH + 22.18$ $\quad R^2 = 0.445$ $\quad$ (5-7)

Figure (5-18) and Equation (5-8) shows the relationship between (NA) and Pavement Condition Index (PCI). R^2 for Equation (5-8) was found to be 0.005 which shows that there is no relation between (NA) and (PCI).

$NA = 0.073PCI + 0.679$ $\quad R^2 = 0.005$ $\quad$ (5-8)

The relationship between (NA) and number of lanes (La) was given by the Equation (5-9) and the regression plot curve shown is shown in Figure (5-19). R^2 for Equation (5-9) was found to be 0.001 which indicates that there is no relation between (NA) and (La).

$NA = - 0.644La + 7.724$ $\quad R^2 = 0.001$ $\quad$ (5-9)

R^2 becomes 0.301 when the two points which represents number of accidents at km 23+000 at Ain Sokhna Road and at km 37+300 at Suez Road due to the up normal value for number of accidents as shown in Figure (5-20). Equation (5-10) is better representative for the relationship between NA and La, however the relation still not significant.

$NA = 0.781La - 0.06$ $\quad R^2 = 0.317$ $\quad$ (5-10)

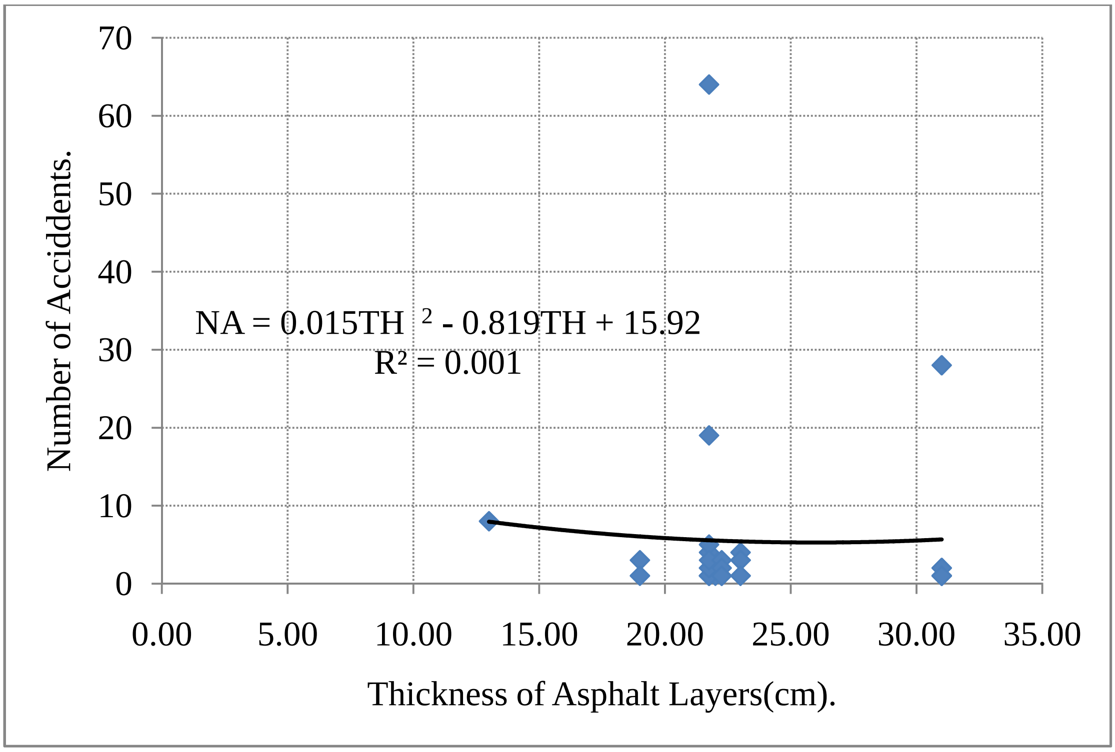


Figure (5-16): Number of accidents – thickness of asphalt layers plot for the Ring Road.

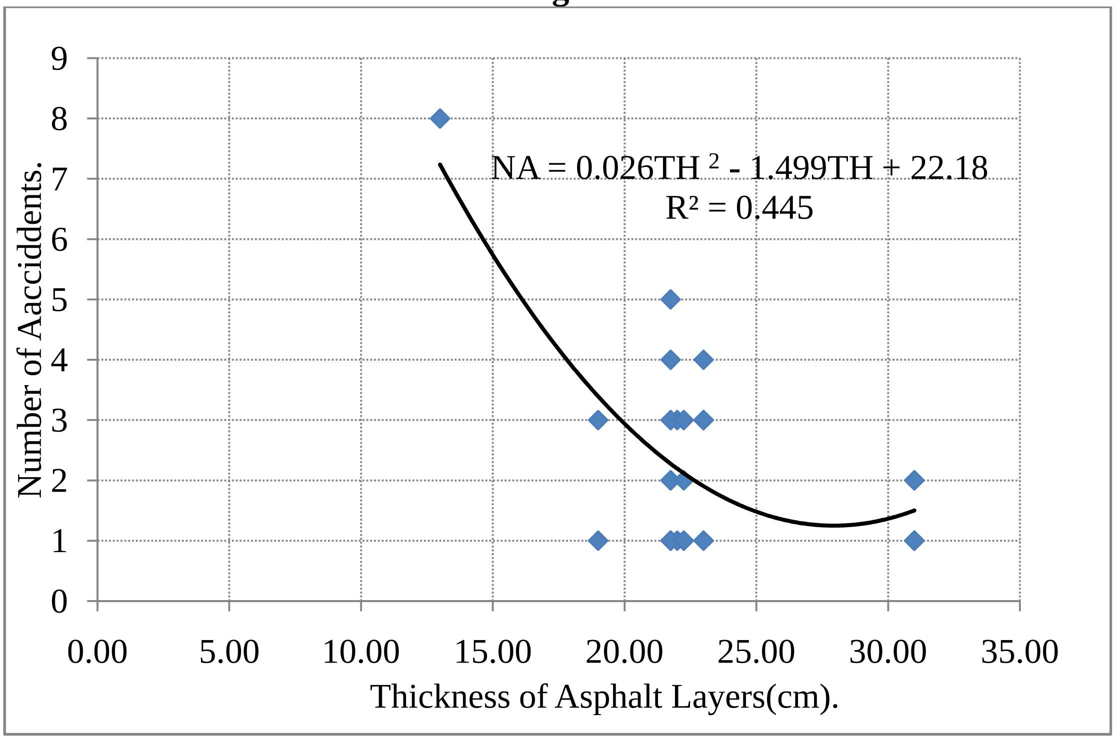


Figure (5-17): Number of accidents – thickness of asphalt layers plot for the Ring Road.

The regression analysis was carried out to obtain the relationship between (NA) and average daily traffic (ADT) in Figure (5-21). R^2 for Equation (5-11) was found to be 0.018 which shows very poor relation between (NA) and (ADT).

NA = - 28.7ln (ADT) + 336.5 $R^2 = 0.018$ (5-11)

Figure (5-22) indicates the relationship between (NA) and percent of truck (PT). R^2 for Equation (5-11) was found to be 0.041 which shows poor relation between (NA) and (PT).

NA = 0.417PT - 2.179 $R^2 = 0.041$ (5-12)

The relationship between (NA) and international roughness index (IRI) is shown in Figure (5-23). Equation (5-13) states the obtained relationship where R^2 was found 0.035 which shows very poor relation between (NA) and (IRI).

NA = 6.298IRI - 13.97 $R^2 = 0.035$ (5-13)

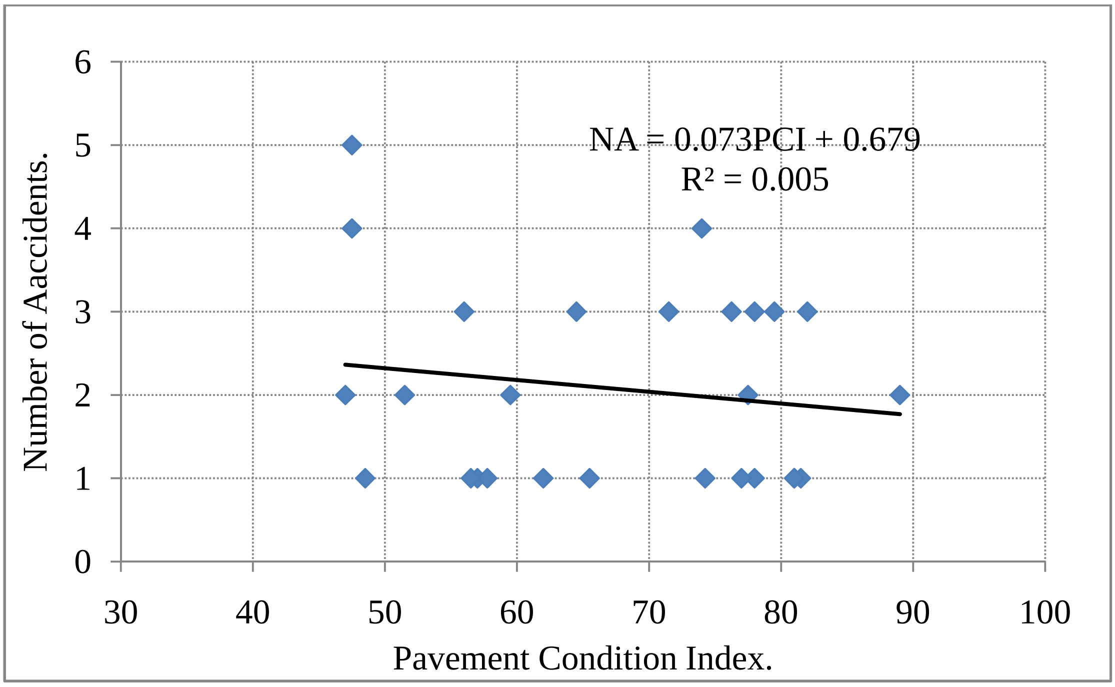


Figure (5-18): Number of accidents – pavement condition index plot for the Ring Road.

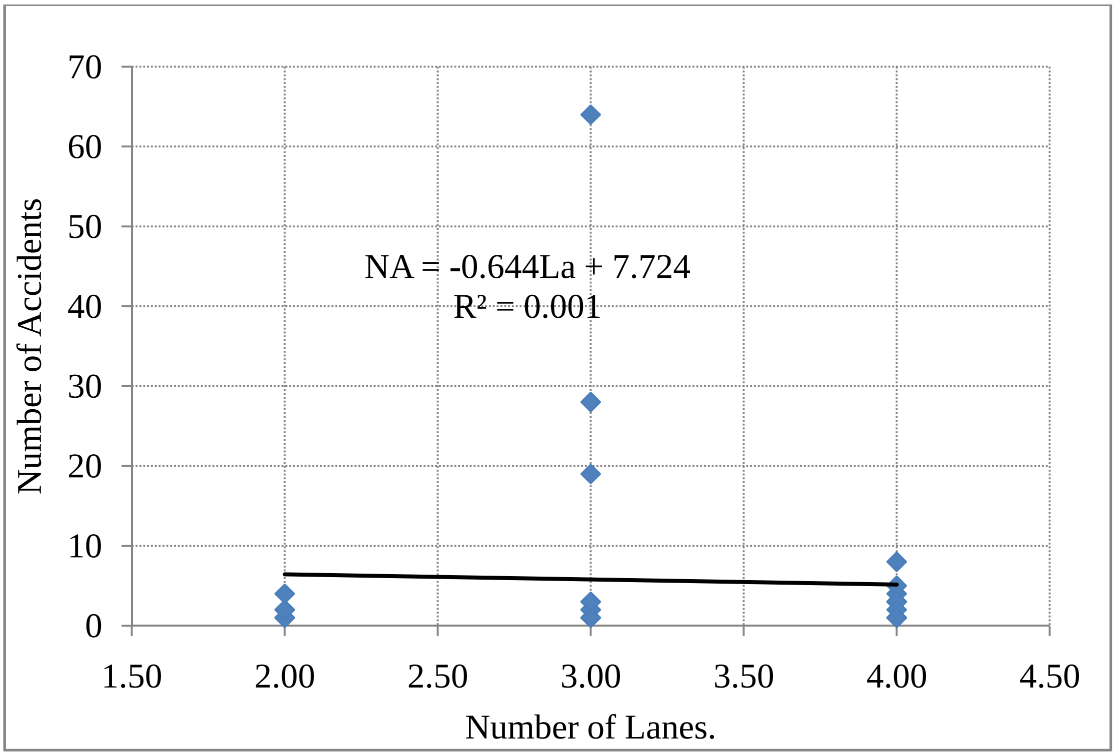


Figure (5-19): Number of accidents – number of lanes plot for the Ring Road.

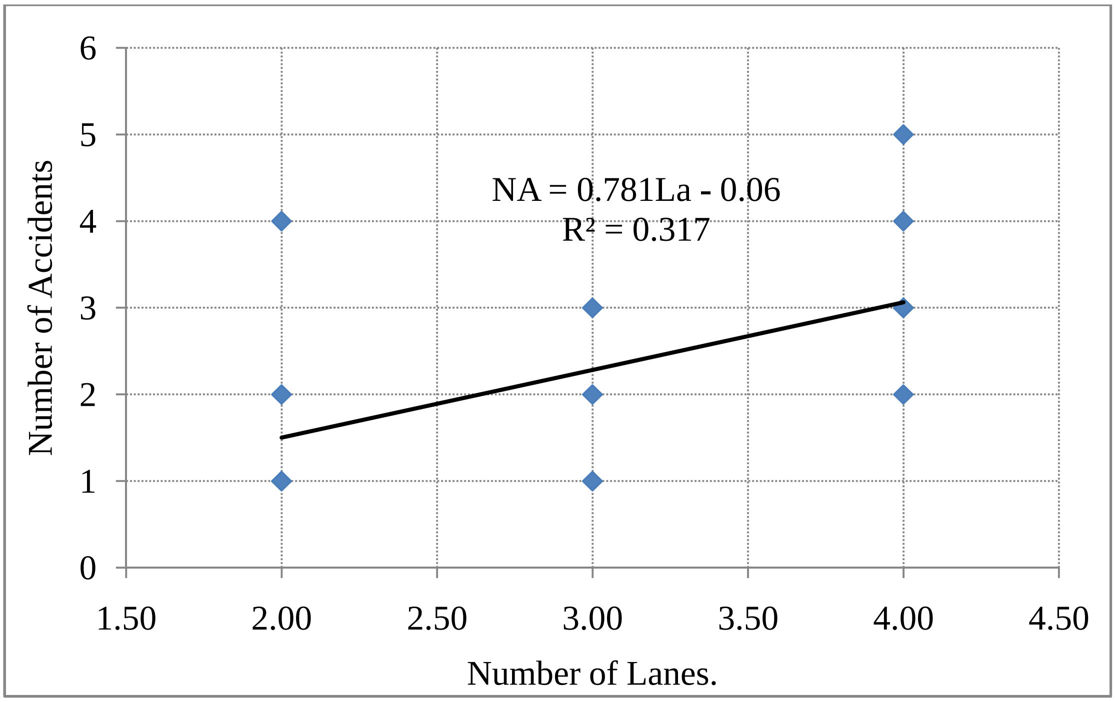


Figure (5-20): Number of accidents – number of lanes plot for the Ring Road.

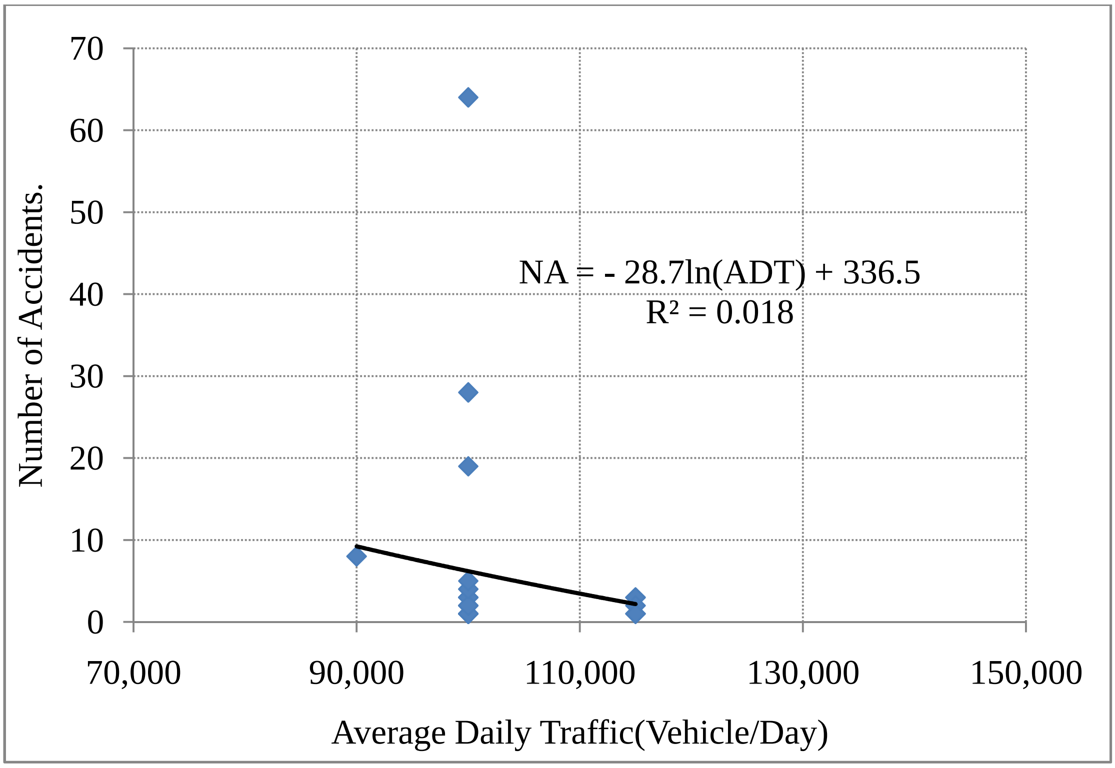


Figure (5-21): Number of accidents – average daily traffic plot for the Ring Road.

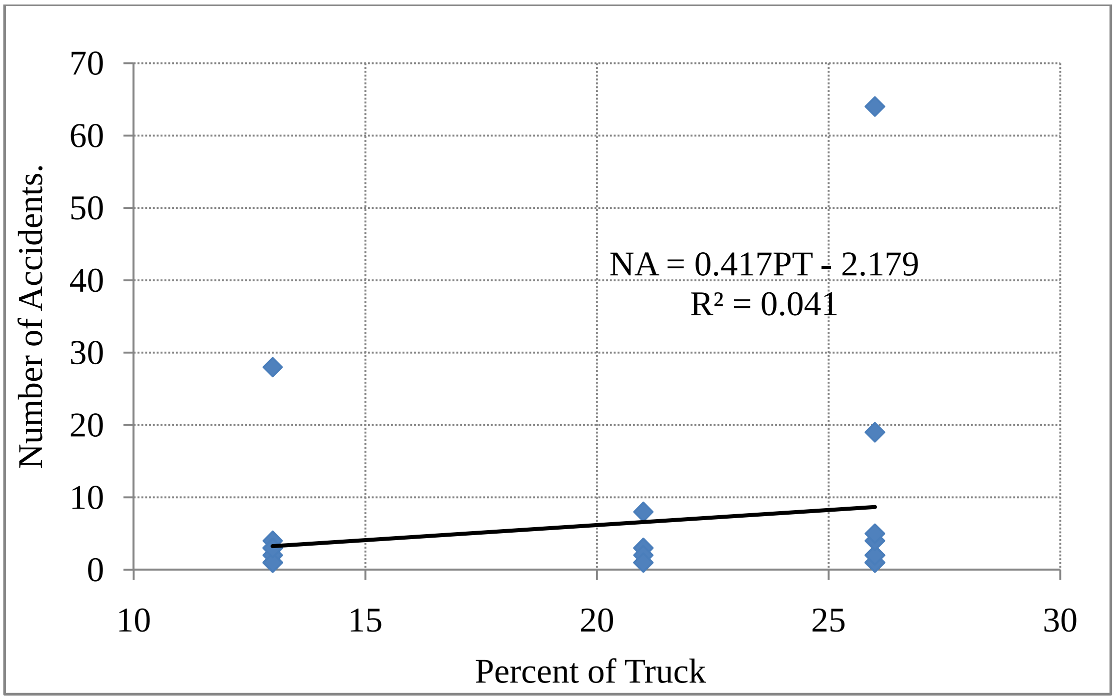


Figure (5-22): Number of accidents – percent of truck plot for the Ring Road.

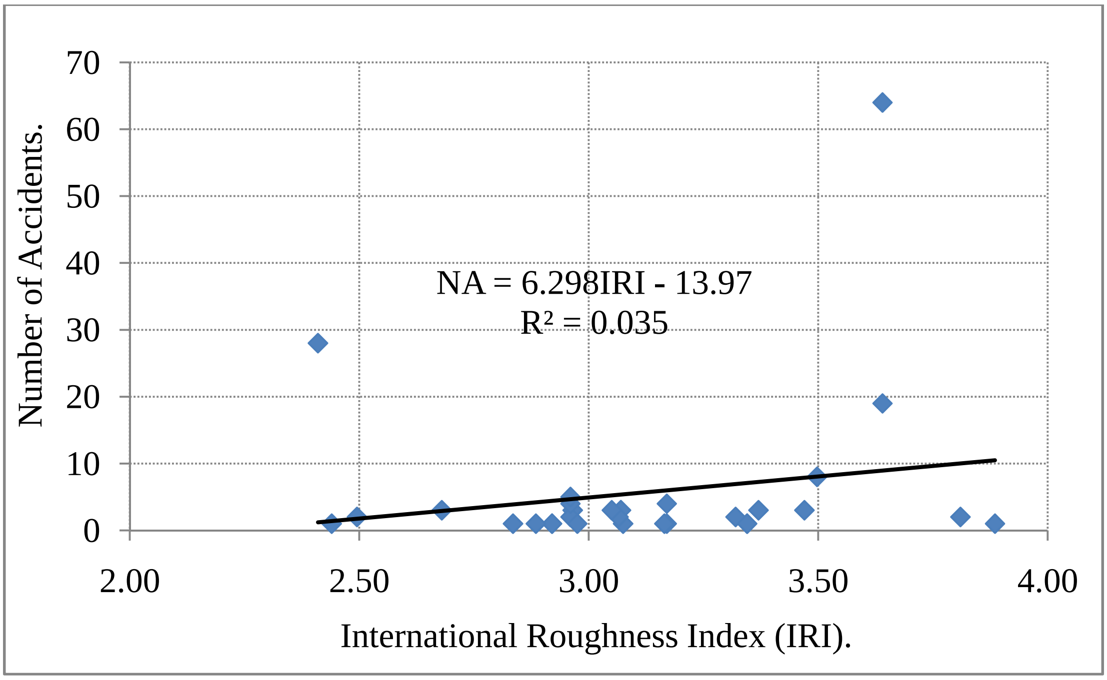


Figure (5-23): Number of accidents – international roughness index (IRI) plot for the Ring Road.

5.3 Pavement Condition Estimation

To develop a general model for PCI, Simple Regression Analysis gives the correlation between PCI along the Ring Road and each of the studied parameters using different mathematical forms; linear, logarithmic, power, Polynomial, and exponential regression models To find the most significant relationship correlating PCI and considered parameters.

PCI and Percent of Truck PT for all accidents locations on the Ring Road were regressed and were plotted in Figure (5-24). Equation (5-14) provides a good representative for the relationship between PCI and PT.

$PCI = -1.689PT + 100.1$ $R^2 = 0.608$ (5-14)

PCI and Longitudinal Profile Grade G were regressed and were plotted in Figure (5-25). Equation (5-15) provides a better representative for the relationship between PCI and G; however the relation is still not significant.

$PCI = 6.280G + 60.41$ $R^2 = 0.340$ (5-15)

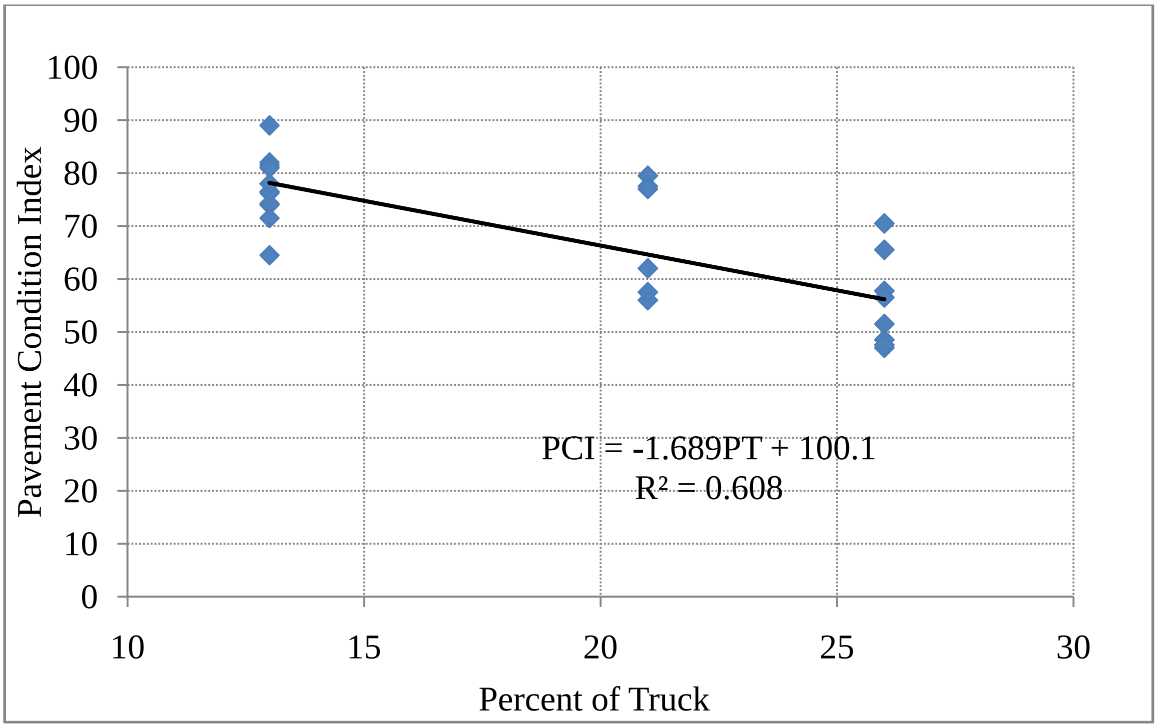


Figure (5-24): Pavement condition index – percent of truck plot for the Ring Road.

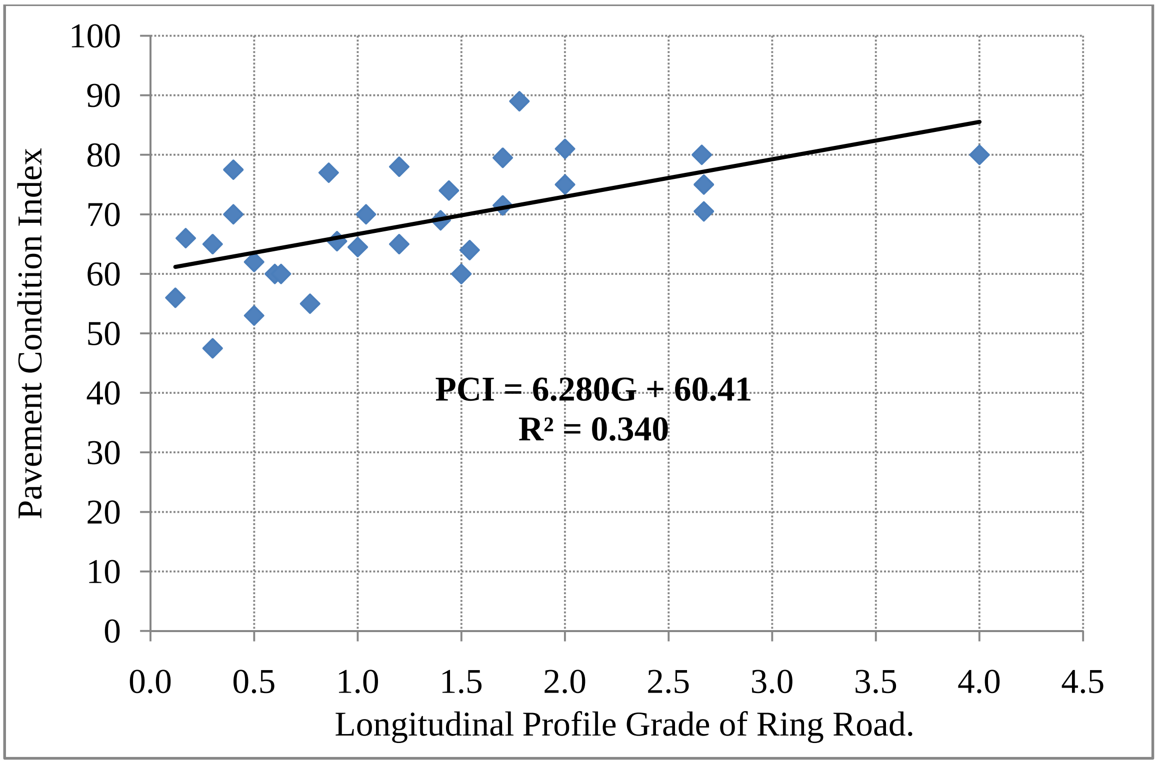


Figure (5-25): Pavement condition index – longitudinal profile grade plot for the Ring Road.

PCI and Thickness of Asphalt Layers TH were regressed and were plotted in Figure (5-26). Equation (5-16) provides a good representative for the relationship between PCI and TH.

$$PCI = 1.393TH + 39.46 \qquad R^2 = 0.528 \qquad (5\text{-}16)$$

PCI and No. of Lanes La were regressed and were plotted in Figure (5-27). Equation (5-17) provides a good representative for the relationship between PCI and La.

$$PCI = 9.642La + 36.82 \qquad R^2 = 0.524 \qquad (5\text{-}17)$$

PCI and Horizontal Curve Radius RC were regressed and were plotted in Figure (5-28). Equation (5-18) provides a poor relationship between PCI and RC, but the existing of horizontal curve is significant in PCI values as we will see in multiple regression analysis.

$$PCI = -\,0.002RC + 69.98 \qquad R^2 = 0.037 \qquad (5\text{-}18)$$

PCI and International Roughness Index IRI were regressed and were plotted in Figure (5-29). Equation (5-19) provides a poor relationship between PCI and IRI.

$$PCI = 10.31\,IRI + 38.61 \qquad R^2 = 0.162 \qquad (5\text{-}19)$$

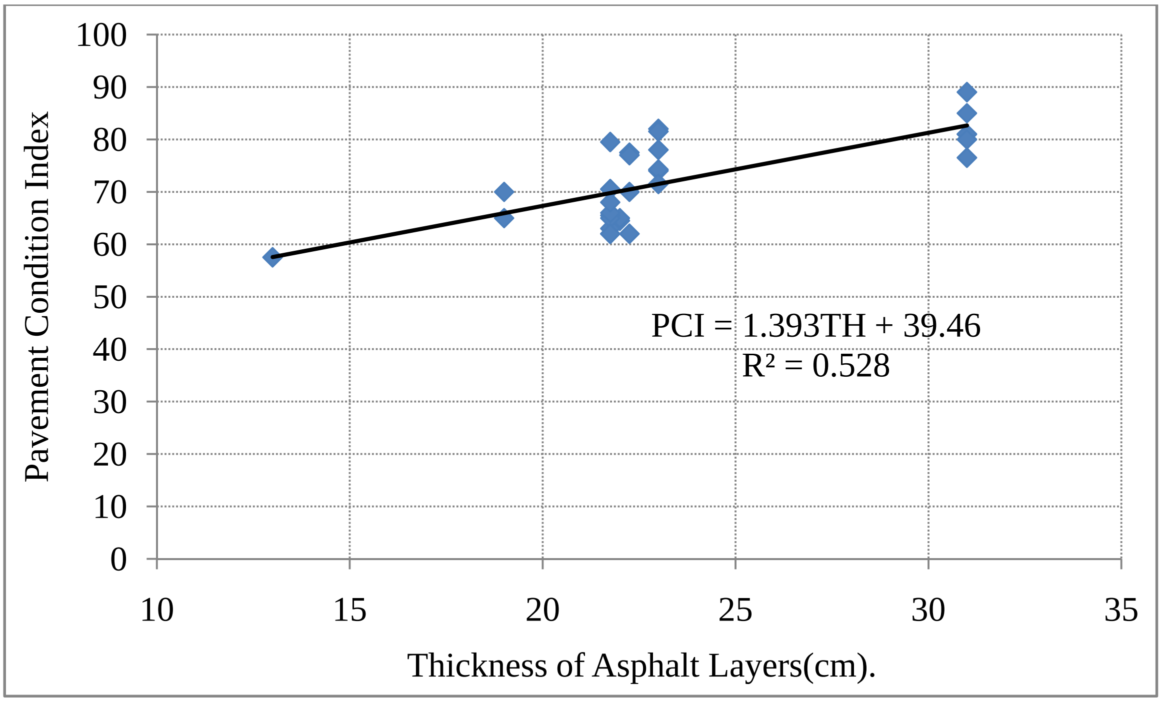


Figure (5-26): Pavement condition index – thickness of asphalt layers (cm) plot for the Ring Road.

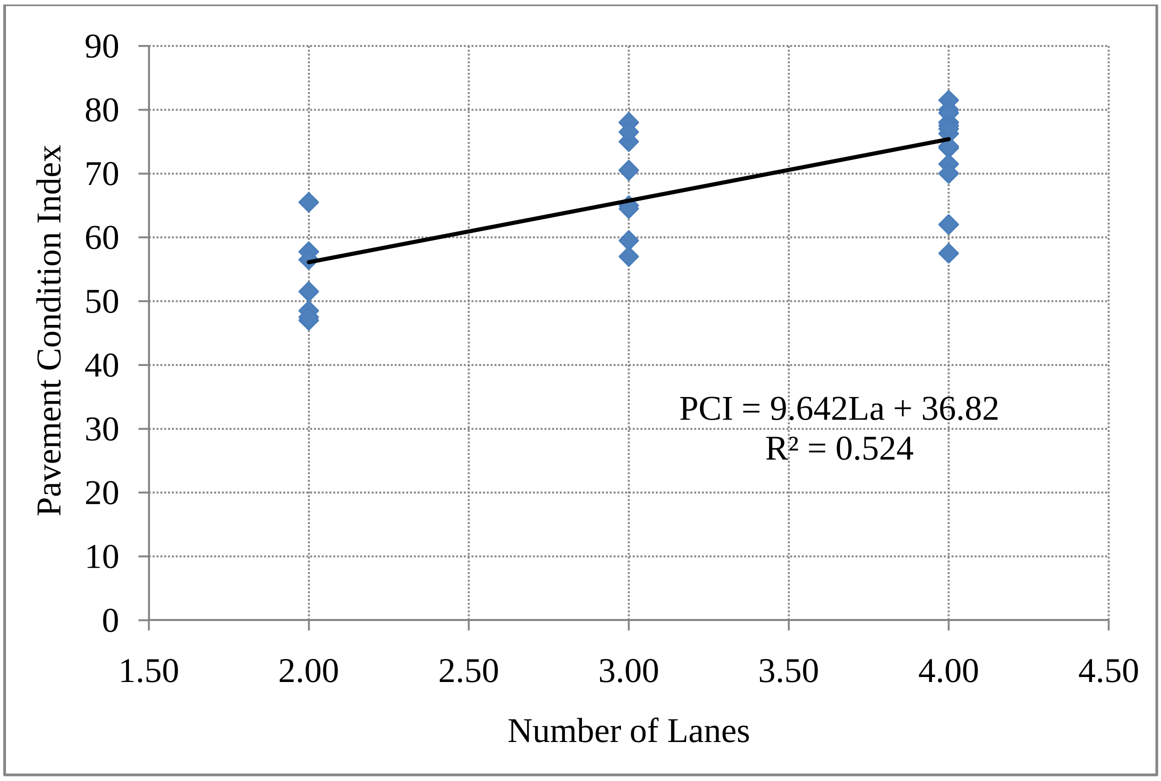


Figure (5-27): Pavement condition index – number of lanes plot for the Ring Road.

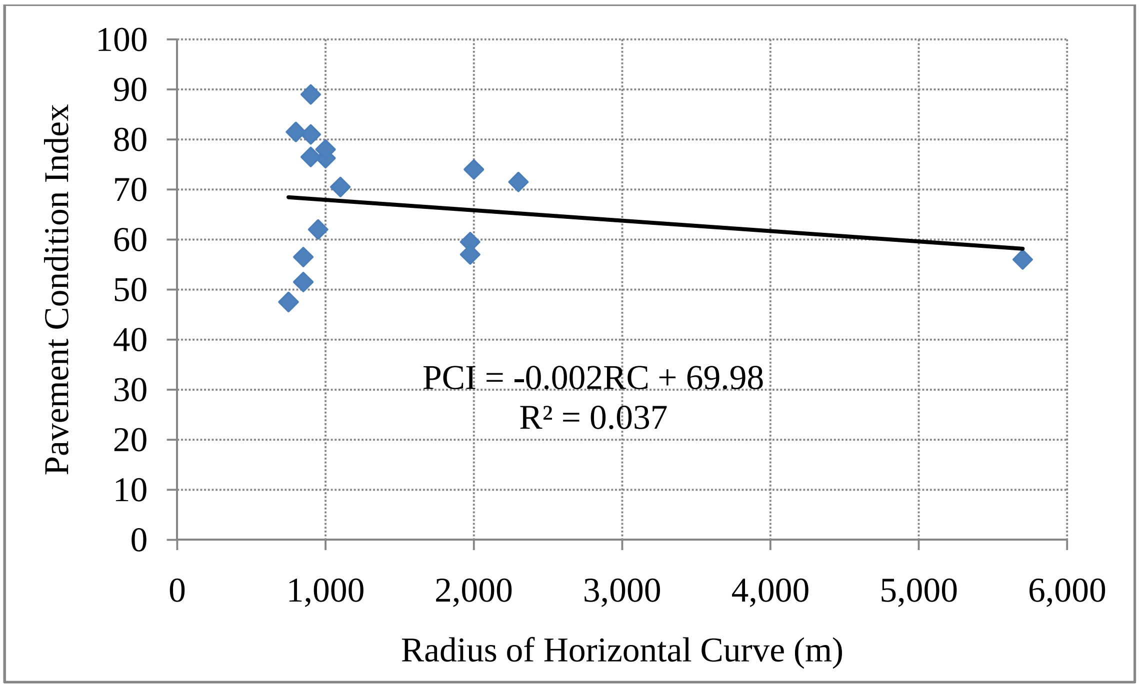


Figure (5-28): Pavement condition index – radius of horizontal curve plot for the Ring Road.

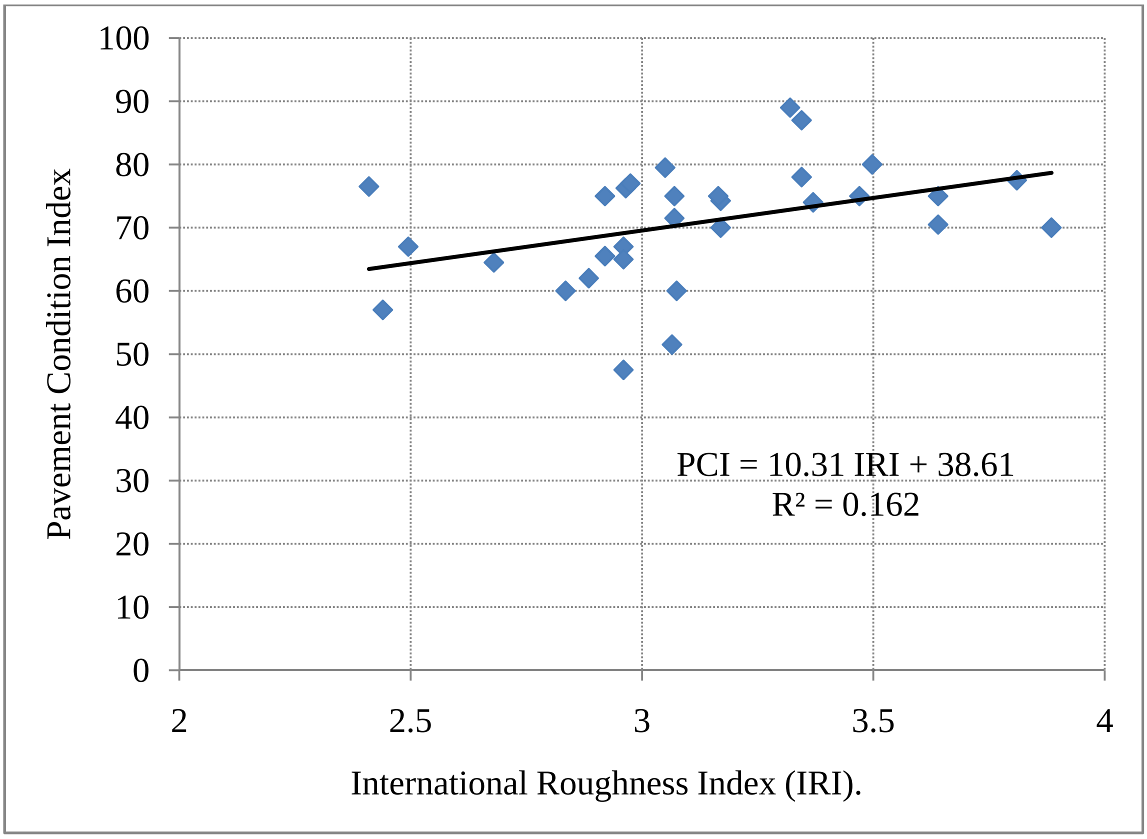


Figure (5-29): Pavement condition index – radius of horizontal curve plot for the Ring Road.

5.4 Multiple Regression Analysis

5.4.1 Accident Multiple Regression Analysis

Multiple regression analysis was conducted to test the relationship between the number of accidents NA values and the selected parameters, Many of parameters contribute together to cause accidents, therefore simple regression analysis may give improper results, So Multiple Regression Models would be the proper one and the combined effect of these parameters on NA must be taken into consideration.

As mentioned earlier, the studied parameters are the independent variables while the NA represents the dependent variable. The analysis was conducted using the software program "SPSS, version 16". The analysis was conducted on the entire data set. After several trials, it was found that the relationship was best expressed through a linear function in the form:

$$NA = - 5.383 + 2.513*G + 1.103*La + 0.651*RC + 0.081*PT - 0.224*TH – 0.068*PCI + 3.120*IRI \quad (5\text{-}20)$$

Where:

G: Longitudinal Profile Grade in Percent.
La: Number of Lanes.

RC: Horizontal Curve Occurrence (1 for Curve and 0 for Straight).

PT: Percent of Truck.

TH: Thickness of Asphalt Layers (cm).

PCI: Pavement Condition Index.

IRI: International Roughness Index.

The output sheet for the best multiple regression analysis for all data set is given in Table (5-1). Table (5-2) shows the model summary. Also Figure (5-30) show scatter plot for standardized residual and Figure (5-31) shows the observed and Expected value for the dependent variable NA.

Table (5-1): Output sheet for multiple regression analysis for the selected (NA) Model.

Model		Unstandardized Coefficients	
		B	Std. Error
1	(Constant)	- 5.383	10.058
	G: Longitudinal Profile Grade in Percent.	2.513	1.013
	La: Number of Lanes.	1.103	1.044
	RC: Horizontal Curve Occurrence.	0.651	1.341
	PT: Percent of Truck.	0.081	.183
	TH: Thickness of Asphalt Layers (cm)	-0.224	.193
	PCI: Pavement Condition Index.	-0.068	.086
	IRI: International Roughness Index.	3.120	2.149

Table (5-2): Model summary.

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.645	0.415	0.221	3.07383

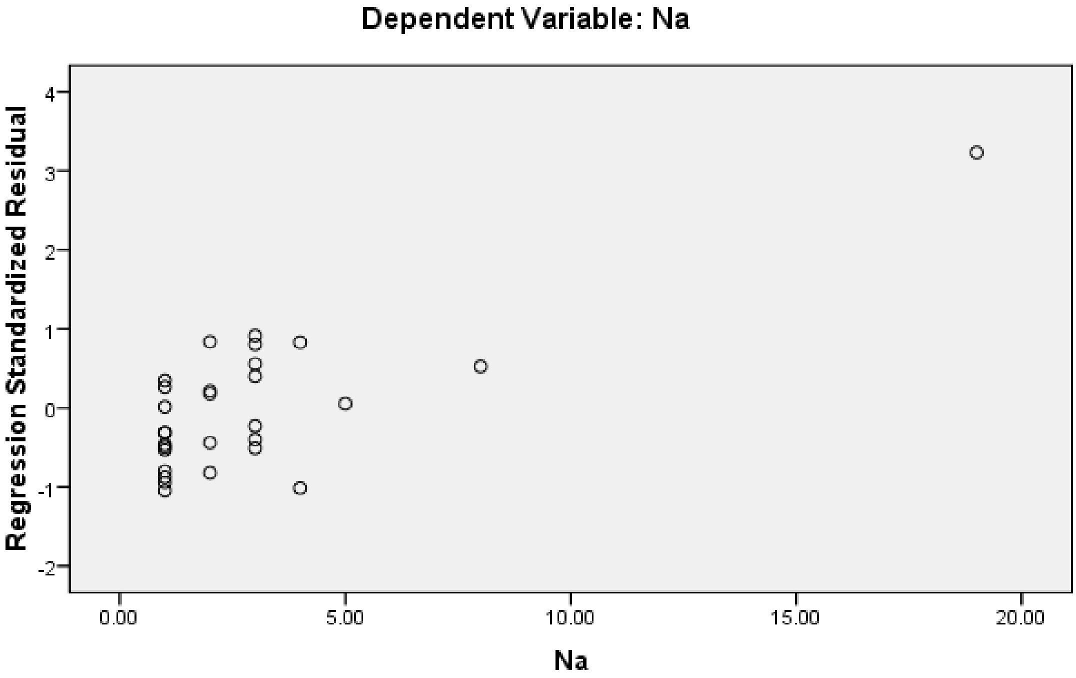


Figure (5-30): Scatter plot for Standardized Residual.

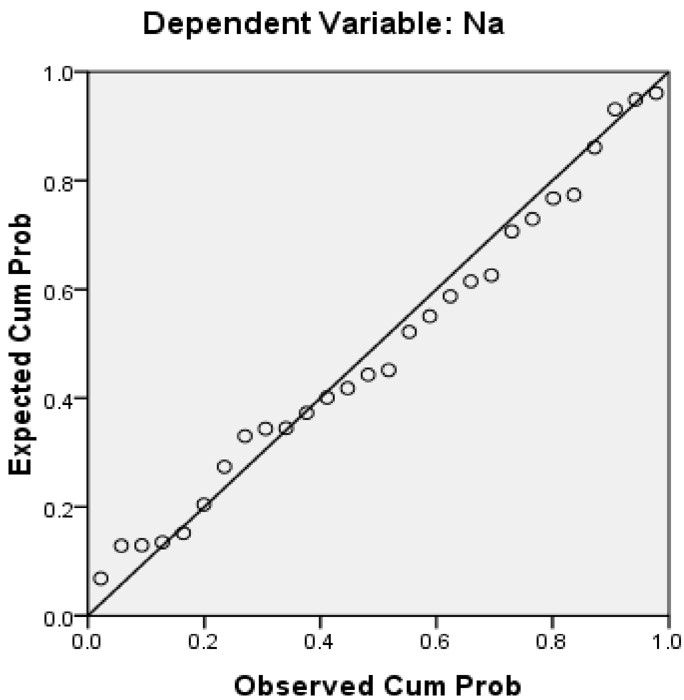


Figure (5-31): Observed and Expected value for the Dependent variable NA.

5.4.2 PCI Multiple Regression Analysis

Multiple regression analysis was conducted to test the relationship between the PCI values and the studied parameters along the Ring Road. The analysis was conducted on the entire data set as well as different groups of the data. After several trials, it was found that the relationship was best expressed through a linear function in the form:

$$PCI = 27.825 + 4.61*G + 0.275*TH - 1.188*PT - 4.975*RC + 3.836*La + 12.922*IRI \qquad (5\text{-}21)$$

The output sheet for the best multiple regression analysis for all data set is given in Table (5-3). Table (5-4) shows the model summary. Also Figure (5-31) show scatter plot for standardized residual and Figure (5-32) shows the observed and Expected value for the dependent variable PCI.