Influence of Pavement Distress on Capacity Loss and Their Implications for PCE

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A Thesis Submitted for the Award of Doctorate Degree of Philosophy

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Thank GOD

For

HIS MERCIES

&

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Abstract

The subject of this study is the extent of pavement distress impact on traffic capacity of uninterrupted road link sections. It aimed to ascertain whether road pavement distress would have significant influence on roadway capacity loss. Pavement distress is a persistence problem in Nigeria and indeed many developing countries - it is reflected in terms of increase in the followings among others: increase in travel time, and road user costs. Potholing, edge subsidence and pavement cracking under tropical climate are problematic in developing countries. Even though governments in Nigeria have spent huge sums of money to dampen the effects of poor pavement conditions, the progress made so far is painfully small.

The objectives were to measure roadway capacity in the presence of pavement distress and compare with that taken without the influence pavement distress. To that effect a pavement distress impact study was carried out at 12 selected sites in Nigeria for a period of six months under daylight and dry weather conditions. Based on the circumstances prevalent at the time of survey in Nigeria the study assumed that density was a resultant of speed and flow hence not directly affected by pavement distress. This implies that roadway capacity loss was fully the result of speed changes. Vehicle types, volumes and speeds were collected at each surveyed road section and the results analysed. Capacities of the road section were estimated for three sections ('without distress', 'transition' and 'with distress') of the road link and it was found that capacities on 'without distress and 'with distress' sections differed significantly. After achieving the aim of the study, the roadway capacity loss was related to pavement distress using polynomial modelling and multiple regression techniques. Results confirm that pavement distress has relationship with roadway capacity loss and the study concludes that a significant decrease in capacity of about 30% was found and is attributable to road pavement distress.

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Finally, I dedicate this thesis to the memory of my late father Benjamin Ireye Edigbe whose love and practical support kept me sane through many of life darkest moments and my children Alero, Tosan, Timi, and Mofe for their endless patience without which I would not have finished this thesis. Above all I am thankful to GOD for HIS undeserved kindness.

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INTRODUCTION

1.1 BACKGROUND TO THE RESEARCH PROBLEM

The Nigerian road system constructed in the early 1900s, essentially as a feeder network for the new railroads, and increased to 71,870 km by 1962, 93,200km by 1965, 114,768km by 1980, and 193,200km of paved and unpaved roads in 1998 is in poor condition. Even though the total length of all categories of road has continued to rise in Nigeria, the major problems today include maintaining the existing road networks and keeping the 58,000km network of paved road open to vehicles for safe and efficient passage, as there is the near total dependence on road transportation in Nigeria. Out of the 58000 kilometres of paved roads only 9 per cent can be categorised as 'good', the remainders are in poor conditions (FMWH *1998*). Poor roads include Shagamu-Ore-Benin, Iwo-Osogbo, Lagos-Ibadan, Lagos-Badagry, Ibadan-Ilorin, Calabar-Uyo, Aba, and Ife-Ibadan motorways and majority of the trunk roads among others.

Given that the justification for the construction of roads is that they promote social development and economic growth, then the tests of optimising road use would call for road surfaces to be free from physical defects such as potholes, loose aggregates, and broken edges, rutting and cracking. This has not been the case with many developing countries. For example, in Nigeria about 81 percent of paved roads are in poor conditions according to FMWH Assessment for Maintenance Draft Document, (FMWH *1998*) often as a result of neglect, resource shortages, and to a large extent lack of maintenance.

In 2004 there are many potholes on motorways (referred to as expressway in Nigeria) trunk roads and local roads. The governments drive for cheap roads has not dampened the influence of pavement distress on road capacity and their implications for road users. The so called low cost roads has attracted dependence on the traditional methods of laying asphalt on a collection of materials used traditionally for road construction with little attention paid to the terrain and suitability of the design and construction method.

Asphalt paved roads have 'unforgiving' materials in that their use is sensitive to engineering precisions lest errors in the construction process be rectified at considerable effort and expense – often only by way of removal and replacement of defective work. Besides the success and failure of the surfacing depends not only on the design, but also on the extent to which that design is realised in construction process. So it is not surprising that majority of the roads are in poor conditions.

The introduction of Petroleum Trust Fund -PTF demonstration roads in the early 1990s did little in the long term to dampen the chronic problem pavement distress. Beginning of 2000, the familiar problem of potholes resurfaced and up till the time of this research-2004 the potholes are present in large numbers on many motorways, trunks and local roads. The PTF, Petroleum Trust Fund, is a semi-governmental board that was set up to handle a portion of the proceeds from Nigeria's oil exports. The Fund itself is a monument to the inability of the federal government to keep from frittering away the money. Thus, in question is the sustainability of the newly built roads in the face of dwindling funds at the present time.

Investment loss in Nigeria due to poor road conditions in 1998 alone was estimated to be $ 1 billion a year with an additional vehicle operating costs of about (US $625 million) a year according to the Federal Ministry of Works (*2000*). It has during the recent years been declining due to lack of maintenance.

Over the years vehicle population has risen from 55,000 in 1970 to 1.5 million in 1998 according to Road Vision Committee (2000). The commercial vehicle traffic growth rate is estimated at 3.5 percent per annum (1998-2003), with passenger car traffic growth rate of 3.5 percent per annum (1998-2002), and a projected growth of 4.5 percent per annum from 2002 to 2007 according to the Federal Ministry of Works and Housing (*1998*). Even though roads are designed with an estimated traffic operating capacity over time, these large increases in traffic growth have consequences for the sustainability of the road system in terms of roadway management because adequacy of road maintenance and the robustness of road construction are subject to question.

In a country where few receive formal driving training and passing the licensing exam requires more cash than know-how, driving style is bizarre and reckless. Drivers of slower moving vehicles move out of the way of those driving faster vehicles. Vehicles veer away from pedestrians. Timid drivers acquiesce to aggressive drivers. Drivers of slow cargo trucks signal to the following vehicles when it's safe to pass. Of course, there is a distinct lack of lane markings, traffic sign, and traffic control apparatuses; overgrown bushes and trees narrowing what is left of a distressed carriageway width, rusting heaps of rubbish, burnt automobiles and several carved in spots on the highways. There are no structured action plans at the present time aimed at influencing the behaviour and attitudes of road users. Education and training, publicity, engineering and enforcement actions are mere intuitive - often referred to in Nigeria as fire brigade approach).

In 1998 many lives were lost on the federal Enugu - Umuahia - Aba - Port Harcourt express road, Lagos - Ibadan express road, Benin- Shagamu express road due to poor road surfaces often potholes. In 1999 the Umuahia-Ohafia road caved in at Iseke, a few kilometres from Umuahia. The road caved-in on several spots, making motorists including the author of this thesis to detour in selected places, driving through farmlands and remote villages, criss-crossing abandoned terrain to reconnect the highways that are often worse during wet and dark weather conditions. Temper flayed and some motorists exchanged blows after accusing each order of 'dangerous driving'. It is the same story in 2000 to the present time- 2004. Therefore it is not surprising that there is a growing disquiet amongst road users in Nigeria about the deplorable state of the roads at the moment.

The relationship between pavement (surface) distress and roadway capacity loss has not, however, received much research attention, partly because many developing countries base their road management systems on the parameters of developed countries often with contrasting outcomes. Studies into the influence of pavement distress on road capacity have been very limited if at all and this may not be unconnected with the fact that poor road conditions are associated with developing countries. The Nigeria Road Research Institute itself is in dire need of pothole-free internal roads and it is not surprising that till 2004 no known research on roads and traffic has been undertaken.

In one study carried out by Transport and Road Research Laboratory - TRL (*1991*), the influence of pot-holed road surfaces on vehicle speed was examined. The study suggested an average speed reduction of about of 6 km/h but this study suggests an average speed reduction of 40km/h. This significant difference implies that there is a clear need for empirical studies that will directly address the question of potential contributions of poor road surfacing to capacity loss. It is this relationship that is the concerns of this thesis.

From the foregoing, it is clear that initiatives and measures that include research into the influence of pavement distress on capacity loss have to be taken in other to tackle issues on poor road conditions. At the moment, Nigeria is still saddled with poor provision of road system so that often, road pavement distresses pose itself as a major constraint on her socio-economic growth prospect.

This study is based on the hypothesis that the extent of road capacity loss resulting from pavement distress is significant. The aim behind this exercise is to establish whether roadway capacity can be sustained in the presence of pavement distress and the implications of pavement distress for passenger car equivalency values-PCEs.

1.2 OBJECTIVES OF THE STUDY

The objectives of this thesis are to investigate the following:

i) The extent of pavement distress per surveyed road length;

ii) The capacity of road section without pavement distress under dry weather and day light conditions;

iii) The capacity of road section with pavement distress influence under dry weather and day light conditions;

iv) The road capacity loss resulting from pavement distress under dry weather and day light conditions; and

v) The effects of pavement distress on passenger car equivalency values – PCEs.

1.3 METHOD OF THE STUDY

The method of study is empirical based with observations and sample surveys taken at various locations in Nigeria. The set-up of the study used by Van Goeverden *et al* (*1998*) was modified and adopted for this study bearing in mind that a 'before and after' approach could be difficult to employ. This is so because we would have to rely on the pavement distress to be repaired before the study can be completed. It is very likely that road repairs may take long to achieve so a more suitable approach would be a 'with and without' pavement distress road link.

The extent of pavement distress per road length would first be established and a standard roadway capacity model based on extrapolating free flow observations is used to estimate roadway capacity loss for empirical analysis.

Different methods exist for empirically estimating the capacity of a road section, carriageway, or lane according to Minderhoud *et al.* (*1997*). These include: estimation with headways, estimation with traffic volumes and speeds, and estimation with traffic volumes, speeds and densities. However, two main groups can be distinguished as follows: In first group, capacity is measured directly from the roadway. These methods are workable if a road section forms a bottleneck where capacity is frequently reached. In the second group capacity is estimated by extrapolating free-flow observations.

In order to estimate capacity loss resulting from pavement distress, two sections of road in close proximity were selected such that the upstream sections was in a good state of repair and the downstream section suffered from pavement distress. Three types of vehicles were distinguished: private car, light goods vehicles, and heavy goods vehicles.

Vehicle speeds and flows on the upstream and downstream sections were recorded for short time intervals over the length of the survey period, which enabled the capacities of the upstream and downstream sections to be estimated and capacity loss determined.

The effect of different types of vehicle within a traffic stream is normally accommodated for, by converting vehicles into passenger car units (*PCU*) using PCE values. However, observation of vehicles travelling through distressed sections of surveyed road suggested that the PCU values applicable to 'normal' roadway conditions were not appropriate to distressed sections as they could lead to inaccurate road capacity values. More specifically, although the speeds of all vehicle types were observed to be lower on distressed sections in comparison with normal sections, it was noted that the magnitude of this speed reduction was proportionately greater for cars and light goods vehicles than heavy goods vehicles. Even though the PCE values as employed in Nigeria (FMWH, *1998*) were adopted in this study, we have attempted to estimate and use PCE values that could reflect the effects of pavement distress on roadway capacity.

The extent of road capacity loss resulting from pavement distress is particularly emphasised, as the principal aim of the investigation. Nevertheless a predictive model that related road capacity loss to number of potholes, relative area of distress and maximum depth of pothole was presented.

1.4 SIGNIFICANCE OF THE STUDY

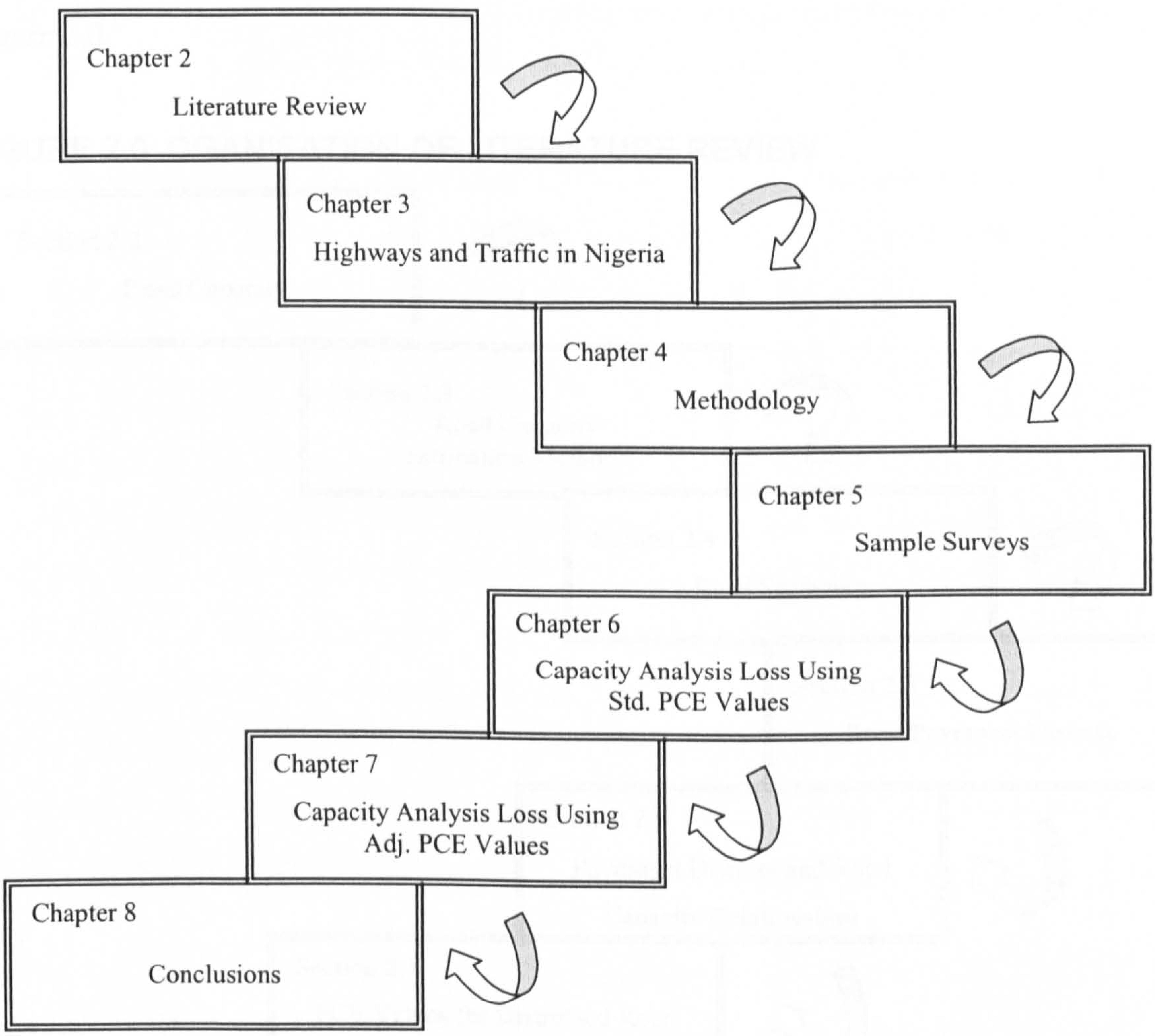
There are a number of studies including that of the Federal Ministry of Works and Housing-FMWH road network study on road deterioration in Nigeria *(FMWH, 1998)*. However, the extent of poor road conditions on roadway capacity, has neither been fully explored, nor well understood. This study is a first attempt to look into the extent of capacity loss resulting pavement distress and organised in a way, which offers results based on a synthesis of aggregate roadway capacity and pavement distress data. Its significant is in its attempt to show that by mapping out specific areas where action is needed roadway capacity loss resulting from pavement distress can be avoided.

Road maintenance strategies are often least informed and policy has done little to set road transportation on the long-term path. Such strategies are, however very important for Nigeria, which seeks to evolve as a world-class industrial economy with competitive prowess. The question is can it achieve this status on the evidence of its current road transportation experience.

1.5 OGANISATION OF THE THESIS

The layout of this thesis is as shown in table of contents and note that the first figure of the figures and tables in this thesis denotes that chapter number. For example Figure 3.0 or Table 3.0 means first figure or table in chapter 3. The remainder of this thesis is in eight chapters as shown below in Figure 1.0.

FIGURE 1.0 OGANISATION OF THE THESIS



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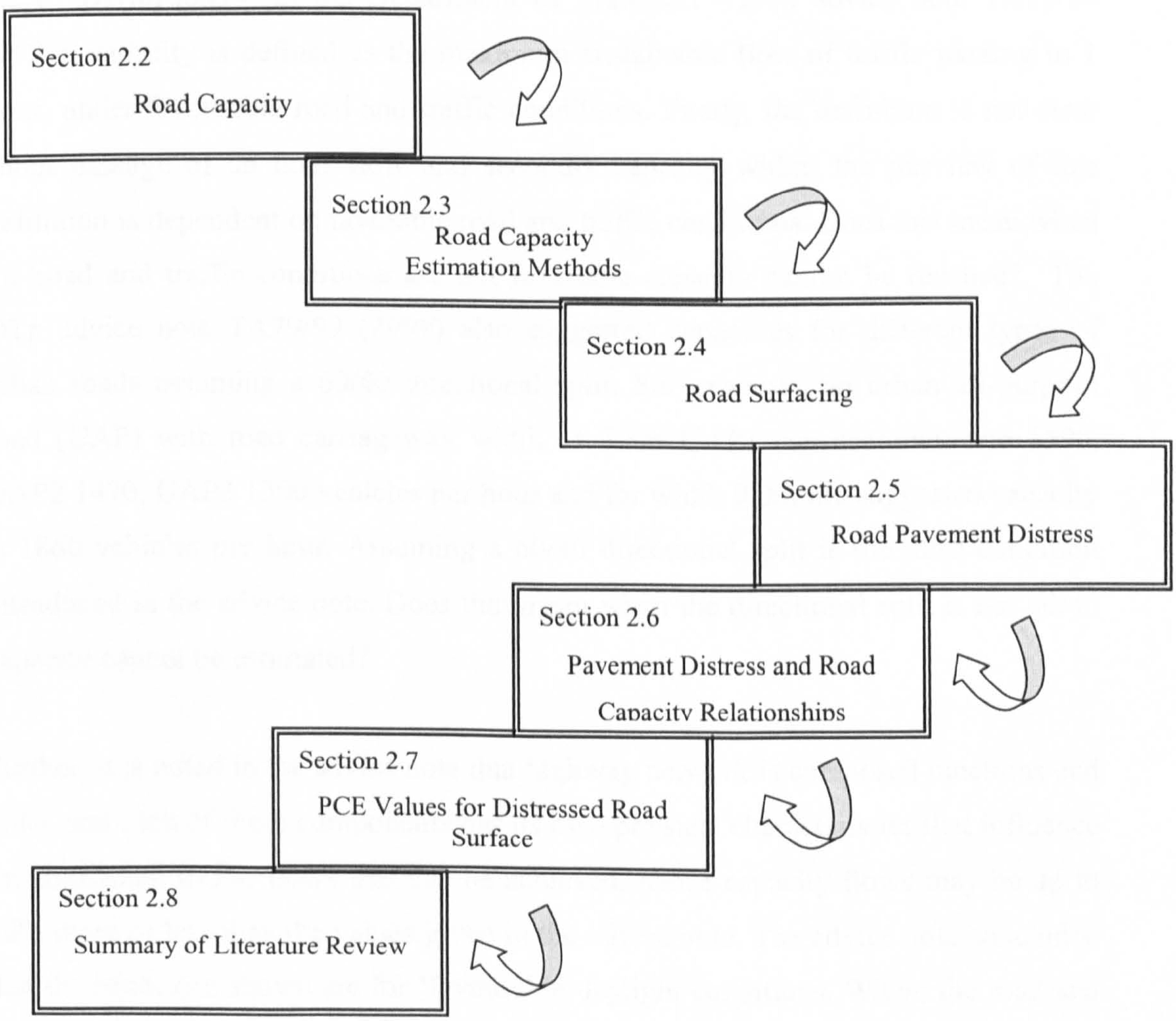
LITERATURE REVIEW

2.1 OVERVIEW:

In the previous chapter - 1.2, we set out the objectives of this study. It is imperative that literature on relevant previous works to this study and theoretic framework is reviewed in order to support arising arguments in the later chapters. Accordingly this chapter on literature review has been divided into seven sections as shown below in Figure 2.0.

FIGURE 2.0 OGANISATION OF LITERATURE REVIEW



2.2 ROAD CAPACITY:

Road capacity loss on a road link is the negative difference in road capacity between the link sections. For the purpose of computing road capacity loss, the road capacities of the road section must the known. Before reviewing literature on the road capacity estimation methods it is worth starting with road capacity definitions and there adaptability in context. Given that the road links in this study has two distinct sections; one section is with from pavement distress and the other section without pavement distress. Section 2.2.1 will be concerned with the definitions of road capacity; Section 2.2.2 will review literature on the significance of road capacity; while section 2.2.3 will be concerned with the passenger car equivalency values and section 2.2.4 will focus on factors influencing road capacity

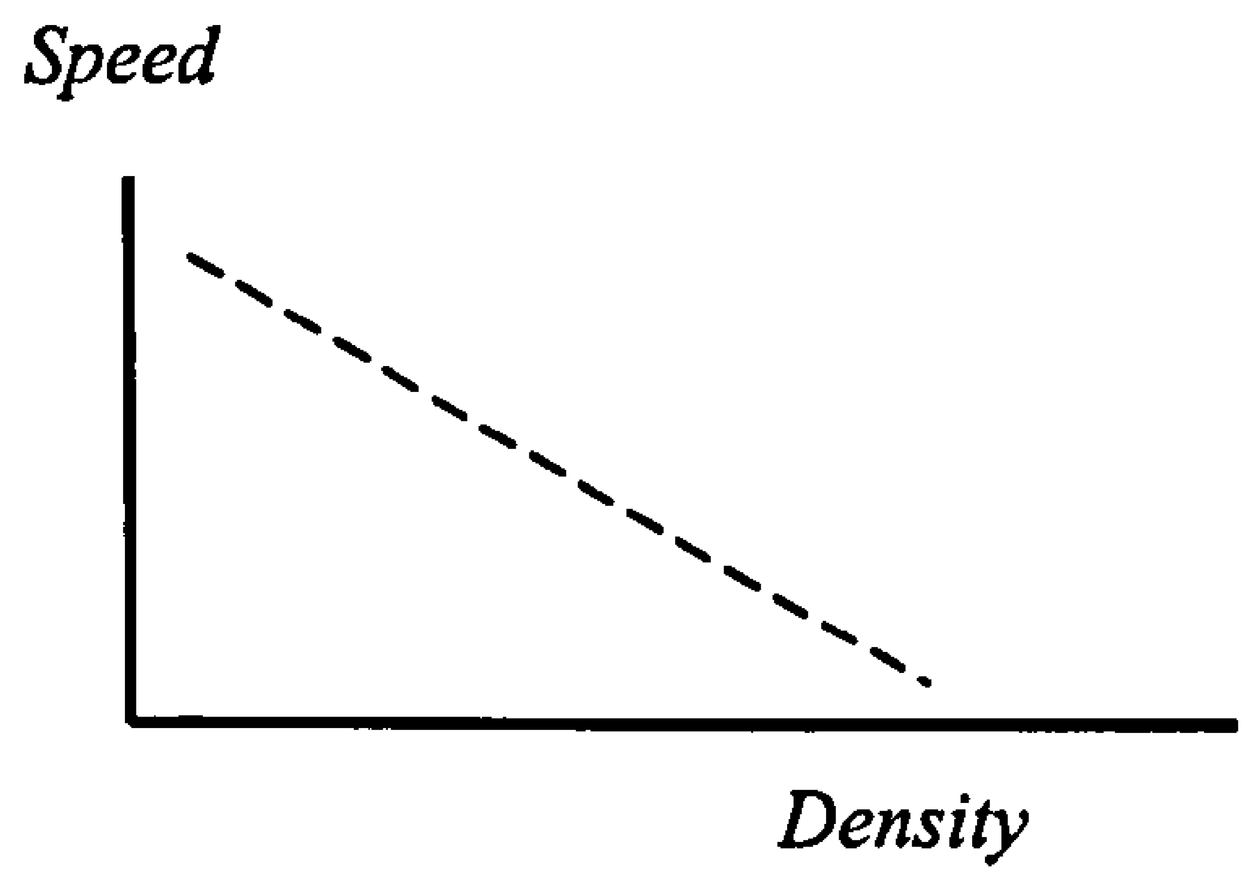
2.2.1 Definitions - In the Department of Transport - DTp advice note TA79/99 (*1999*), capacity is defined as the maximum sustainable flow of traffic passing in 1 hour, under favourable road and traffic conditions. Firstly, the definition is not clear about passage of an hour flow and secondly capacity within the purview of this definition is dependent on favorable road and traffic conditions. Does that mean when the road and traffic conditions are not favorable capacity cannot be reached? The DTp advice note TA79/99 (*1999*) also suggested capacities for different types of urban roads assuming a 60/40 directional split. For example, an urban all-purpose road (UAP) with road carriageway width of 7.3m UAP1 can accommodate 1590, UAP2 1470, UAP3 1300 vehicles per hour and for width 9.0m the suggested capacity is 1860 vehicles per hour. Assuming a 60/40 directional split is the third condition introduced in the advice note. Does that mean when the directional split is not 60/40 capacity cannot be estimated?

Further, it is noted in the advice note that highway network is composed junctions and links, and each of these components has its own physical characteristics that influence the maximum traffic flows that can be achieved, hence capacity flows may be up to 10% more or less than the values given in the advice note. The advice note concluded that the capacities shown are for 'favourable'daylight conditions. Where the road and traffic conditions are unfavourable, suitable capacity estimation method would have to be used. The methods include estimation with headways, estimation with traffic volumes, estimation with traffic volumes and speeds, and finally estimation with traffic volumes, speeds and densities. In sum, capacity definition by the advice note is restrictive and cannot be employed with confidence on road sections with pavement distress. Thus it's safe to assume that within the purview of this definition road capacity cannot be reached under unfavourable conditions; hence an all-encompassing definition of road capacity is required.

However, the Highway Capacity Manual -HCM (*1985*) on the hand defined road capacity as 'the maximum number of vehicles which has a reasonable expectation of passing over a given section of a lane or a roadway in one direction (or in both period directions for a two-lane or a three-lane highway) during a given time period (one hour in the absence of a time modifier) under prevailing roadway, traffic and control conditions'. The HCM (*1985*) attempted to address the perceived deficiencies in DTp advice note TA79/99 (*1999)* but how is 'reasonable expectation to traverse' to be taken in context. Reasonable expectation surely refers to some high probability of certain flow but the HCM (*1985*) manual was not clear on 'reasonable expectation', 'prevailing conditions' and 'given time period'. In any case the HCM (*1985*) definition itself has since been superseded by the HCM special- report 209 (*1994*) that defines road capacity of a fixed facility as 'the maximum hourly rate at which vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period (usually 15 minutes) under prevailing road, traffic and control conditions'. The definition recognises prevailing road and traffic conditions, the potential for substantial variations in flow during an hour, and focuses analysis on intervals of maximum flow.

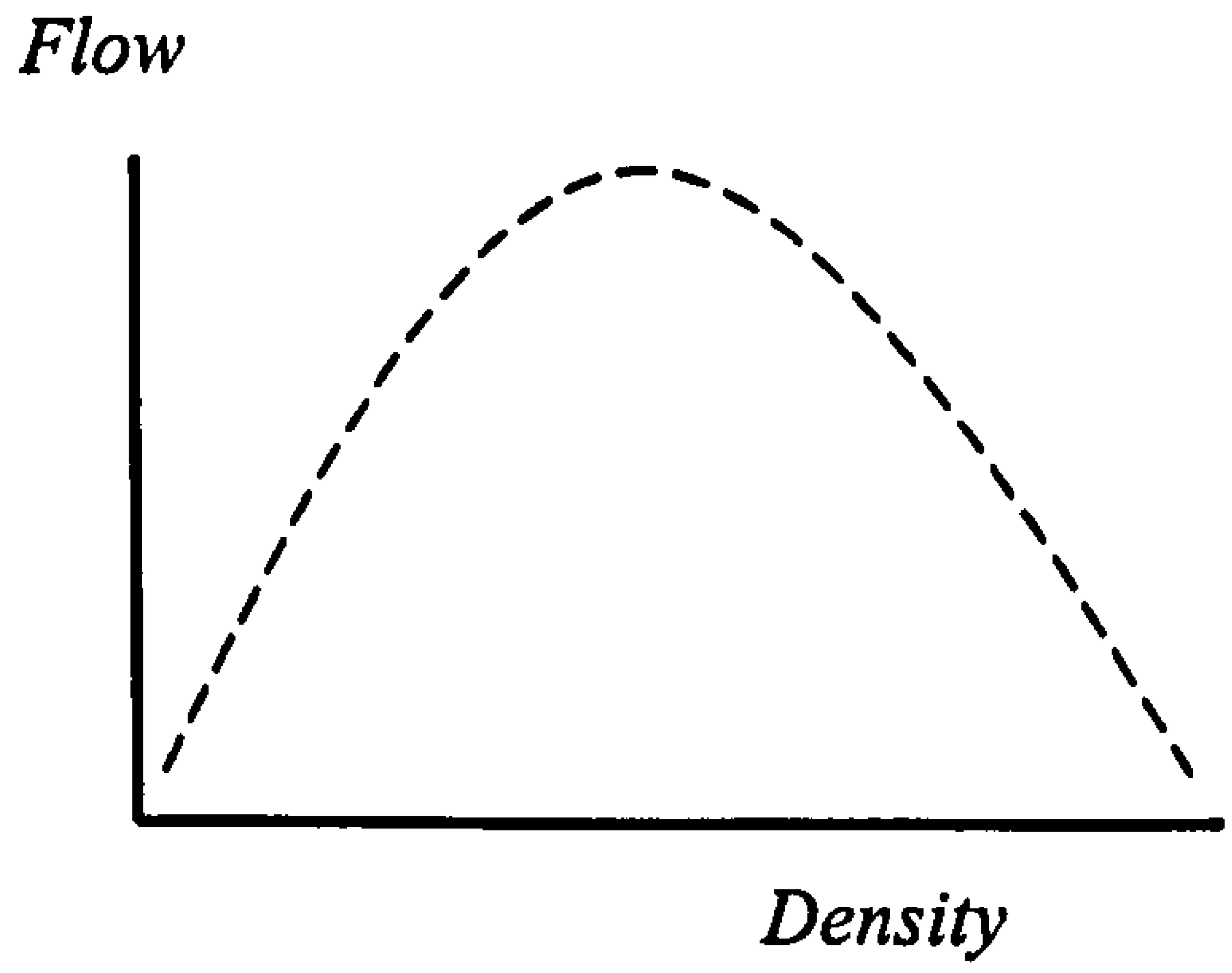
2.2.2 Significance - Road capacity is significance because it's an important indicator of road performance and can point road managers in the right road maintenance and traffic management direction. Three primary measures namely: flow, speed and density characterise the operational state of any given traffic stream. The fundamental diagram illustrates the observed relationship between three variables, Speed – space mean speed, flow, and density. The relationships are shown below in Figures 2.2, 2.3 and 2.4.

Figure 2.2



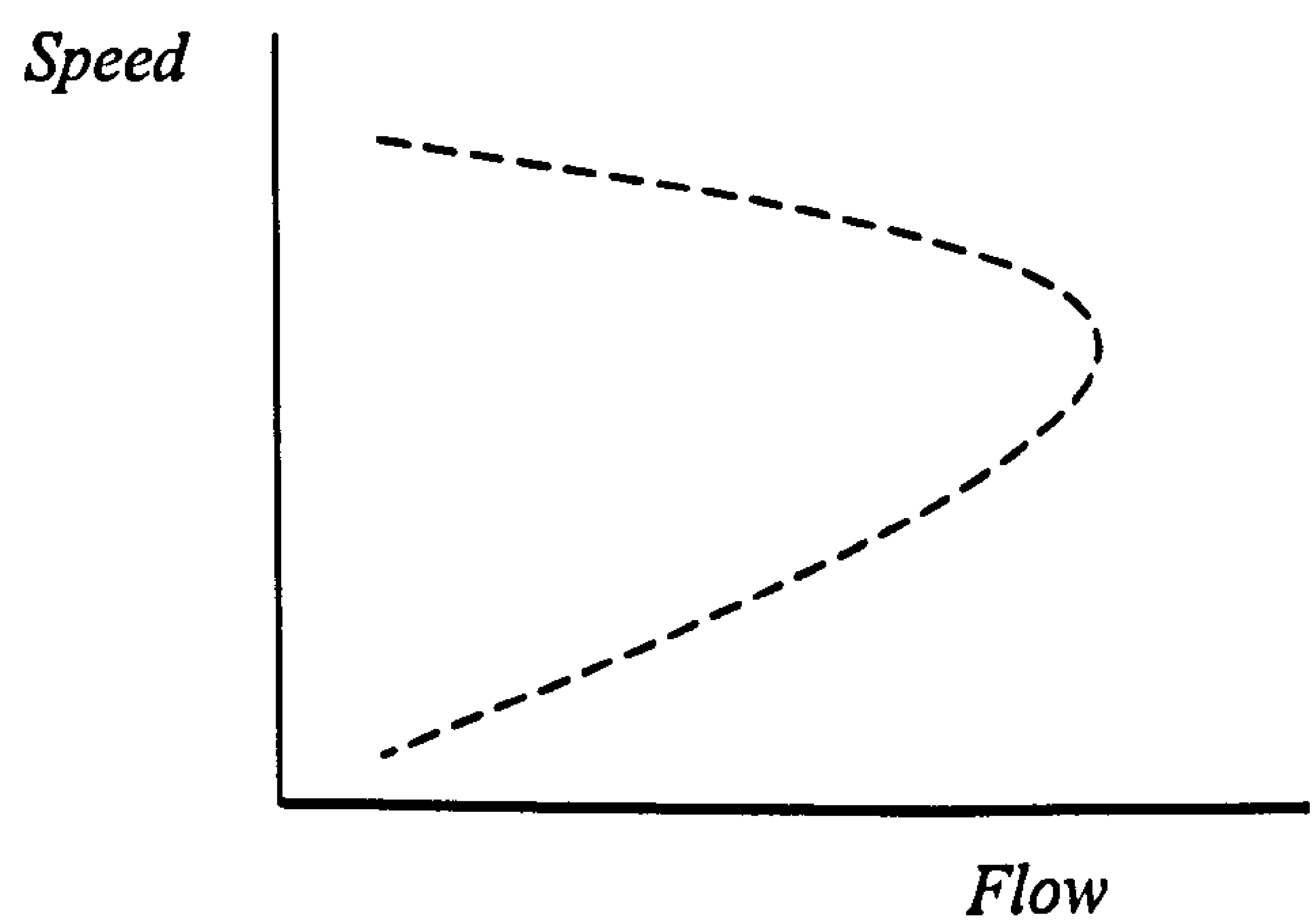
In figure 2.2 above, in a given traffic stream, density will increase relative in decrease in vehicle speed and vice versa.

Figure 2.3



In figure 2.3 above, in a given traffic stream, density will increase relative in increase in traffic flow till capacity is reached at the apex point, thereafter traffic flow will decrease relative to increase in density.

Figure 2.4



In figure 2.4 above, in a given traffic stream, traffic flow will increase relative in decrease in vehicle speed till capacity is reached at the apex point, thereafter traffic flow will decrease relative to decrease in vehicle speed. Speed is an important parameter when describing traffic flow and the knowledge of vehicle speed is significant for traffic management. Speed measurements obtained from by the use of timing devices using short baselines are time mean speed; where the mean travel time is used to calculate the mean speed then it is the space mean speed that is obtained. Where a stopwatch is used it is often assumed that a skill observer can read to 0.2s but difficulties of a constant reaction time often mean that the level of accuracy is approximately 0.5s according to R. Salter and N Hounsell (*1996*). Statistical techniques are often used to analyse speed data and it's often assumed that speed is normally distributed around a mean with limited deviations to either side of the mean speed.

Flow is the number of vehicles passing a given point on the road per unit time. Traffic stream is made up of different types of vehicle and the road terrain is not uniform, some section may require a climb, another descend and yet another rough even though it's flat. Therefore the performance of different vehicle types on different terrains is accounted for by way of passenger car equivalency values. These are values are applied to vehicle volumes when converting to flows.

2.2.3 Passenger Car Equivalency Values (*PCEs*) - PCE values have been used extensively in the *Highway capacity Manual* (HCM) (*1994*) (*1997*) to establish the impact of trucks, buses and recreational vehicles on traffic operations. It was defined in HCM (1*965*) as 'the number of passenger cars that are displaced by a single vehicle of a particular type under a prevailing traffic and road conditions. For two-lane highways, PCEs are given as a function of the type of terrain, and level of service or average upgrade speed for trucks, buses and recreational vehicles according to Transportation Research Board Special report 209 (*1994*).

According to Seguin, Crowley and Zwieg *(1998),* PCEs can be defined as the ratio of the mean lagging headway of a subject vehicle divided by the mean lagging headway of the basic passenger car. Lagging headway is defined as the time or space from the rear of the leading vehicle to the rear of the vehicle of interest; it is composed of the length of the subject vehicle and the inter-vehicular gap. Cunaign (*1984*) calculated PCEs from speed distributions of passenger cars and trucks at a given volume for specific length of grade. Separate speed distributions were used to compute the relative number of passing that would have been performed per mile of highway if each vehicle continue at its normal speed for the given traffic and physical conditions, assuming no interference when overtaking occurs. The use of such equivalents is central to highway capacity analysis where mixed traffic stream are present.

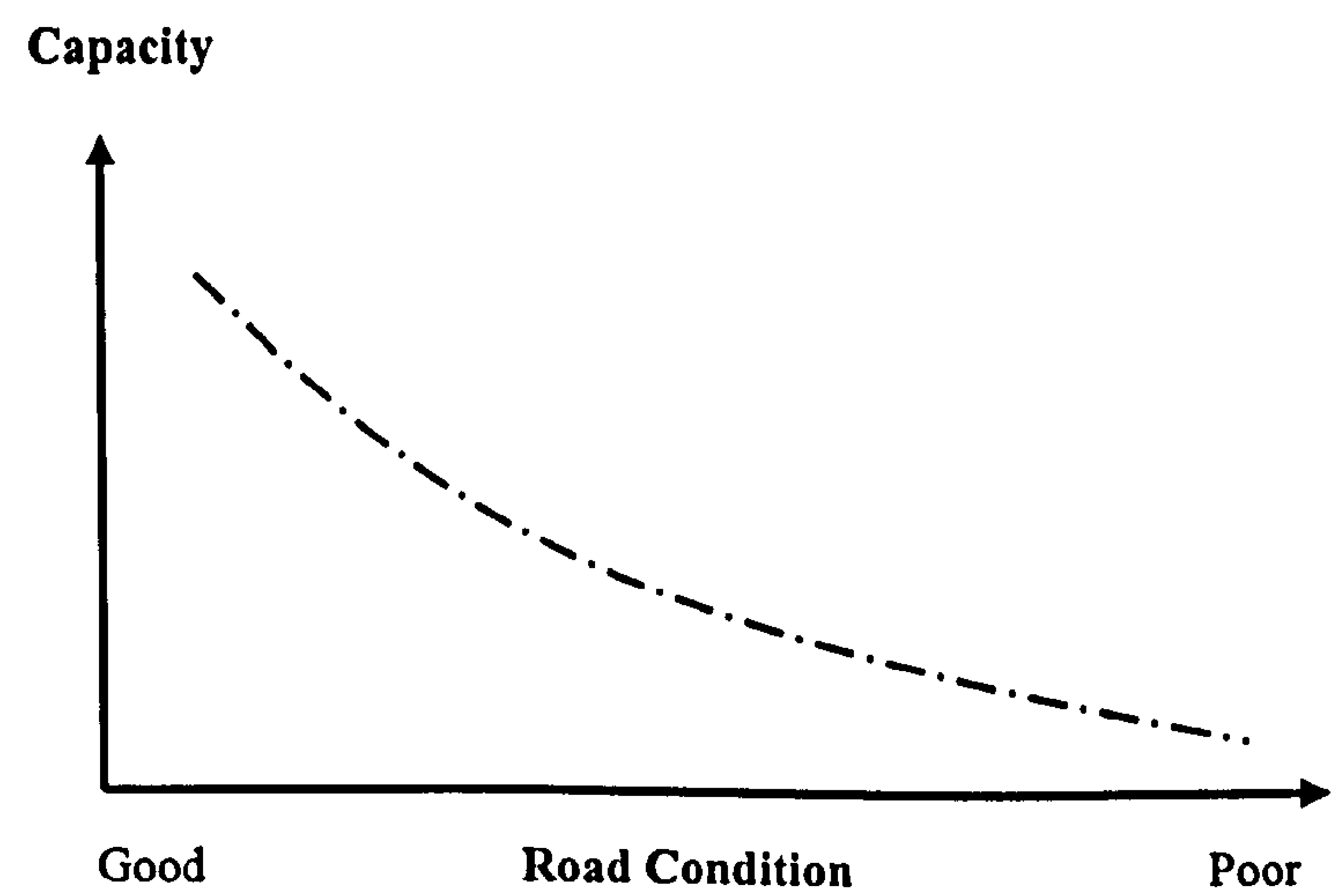
2.2.4 HCM Level of Service - For the purpose of measuring *quality* of service provided by a roadway at a given rate of traffic flow per lane or per carriageway as perceived by the driver of the vehicle, the parameters, speed and flow are important. Even though road capacity is reached when speed is at optimum speed, it is often difficult to establish the optimum speed. In the HCM where it has been used extensively, the service flow set at 2800 vehicles per hour is considered by HCM as ideal and modified to take into account prevailing conditions that include ratio of flow to the ideal capacity, directional split of traffic, lane width and restricted shoulder width and the also the presence of heavy good vehicles in the traffic stream. But we are not too concerned with the measurement of service quality in this study. Nevertheless, six levels of services were described in HCM Special Report 209(*1994*) as Level A – free-flow operation with average speeds near 60mph (96km/h) and 70mph (112km/h) on motorways; Level B reasonable free-flow conditions with average speed over 57mph (91km/h) and 70mph on motorways; Level C - stable flow with average speeds over 54mph (86km/h) ; Level D – borders unstable flow with average speeds about 50mph (80km/h) ; Level E – capacity operation with average speed in the region of 30mph (48km/h) and Level F describes condition where demands exceeds capacity.

It can be seen from the discussion so far, that roadway capacity analysis encapsulates the effects resulting from three variables, namely density, speed and flow and for a given stable traffic condition the three parameters are directly related. For the purpose of measuring *quantity*, the parameters, density and flow are important, because density, which describes the quality of service experienced by the stream, is the number of vehicles per unit length of the road. And flow, which measures the quantity of the stream and the demand on the fixed facility, is the number of vehicles passing a given point on the road per unit time.

2.2.5 Factors Influencing Road Capacity - According to Salter *et al* (*1996*) roadway capacity is constrained by factors associated with the traffic, ambient and road conditions. Traffic conditions refer to the characteristics of the traffic stream and the stream components that use the facility, such as traffic composition, directional distribution, proportion of different types of vehicle and their performance capability. Ambient conditions are usually weather, visibility, level of pedestrian activity, number of parked vehicles, and frontage activity among others. While road Conditions include road surface and geometric parameters are, number and direction of lanes, lane widths, shoulder widths, lateral clearances from edge of pavement, design speed, type of intersections, horizontal, and vertical alignments.

Since the study is based on pavement distress, our interest lies with the influence of road condition mainly road surface on road capacity. Our concern is measuring the number of vehicles passing a given point on the road surface with and without pavement distress per unit time. As shown below in Figures 2.5 road capacity decreases relative to increase in road deterioration. So, it is also reasonable to assume that road capacity loss will result from pavement distress. Since road capacity is central to this study, we shall review literature in the next section on the estimation methods.

Figure 2.5 Road Capacity v. Road Condition



2.3 ROAD CAPACITY ESTIMATION METHODS:

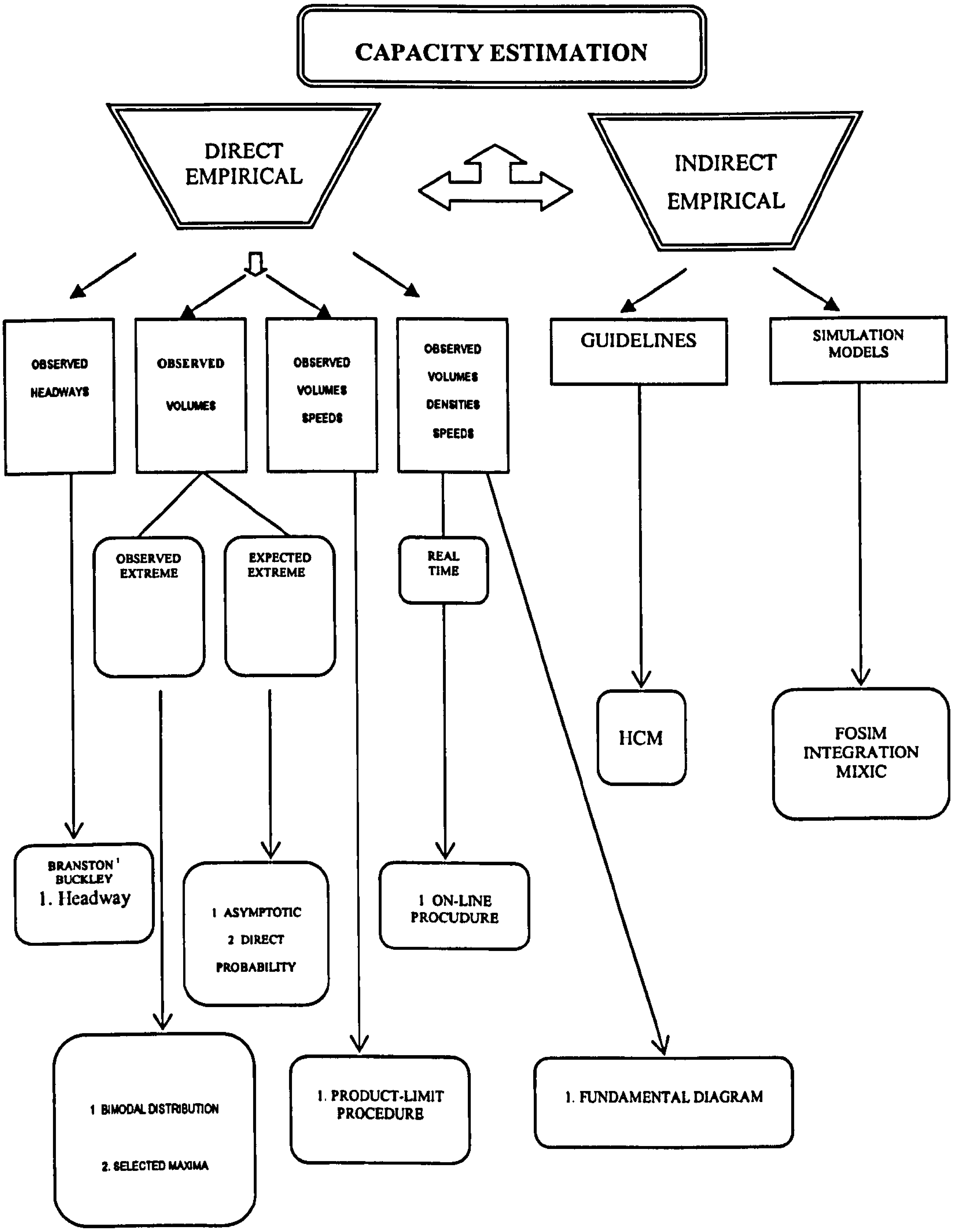
The capacity-estimation problem was divided into two categories: the direct-empirical studies and indirect-empirical methods according to Minderhoud et al (*1998*). Table 2.0 below presents a scheme in which the various approaches (with corresponding definitions) are distinguished. All the methods are a mixture of observation and theory. It could be argued that some methods have more theoretical justification than other especially those that have to contend with probabilistic functions. For example the basic principle of headway models is determination of the parameters of the compound probability density function of headways. Estimation by flow, speed and density rely on the fundamental relationship between these parameters. Estimation with traffic volume on relies much on high traffic volume data and observations even then the results are still probabilistic, and may not bear resemblance to the practical value. Traffic volume and speed estimation method are basically concerned with the level of service provided by the roadway at a given rate of traffic flow.

According to Minderhoud *et al (1998),* the capacity-estimation problem consists of a series of essential points of interest that include among others; Type of Data To Be Collected, Location Choice for Observations, Choice for Appropriate Averaging Interval, Needed Observation Period, Required Traffic State, and Lane. An overview of the capacity estimation methods and their characteristics formulated by Minderhoud *et al (1998)* is shown below in Table 2.1 It includes the characteristics that may be applied as criteria for assessment namely:

- Data needs (headways, traffic flows, speeds and density),
- Required traffic state (free flow measurements and / or congested flow measurement) and,
- Outcome (a single capacity value, a capacity value distribution)

As shown in Table 2.0 road capacity estimation methods by way of direct empirical is most suited to this study, section 2.3.1 will focus on observed headways, section 2.3.2 will be concerned with observed volume, while section 2.3.3 will focus on observed volumes and speeds, and section 2.3.4 will be concerned with Observed volumes, densities and speeds.

Table 2.0 Classification of Road Capacity Estimation Problems



Source: Minderhoud et al *(1998)*

Table 2.1 Overview of Capacity-Estimation Methods and Their Characteristics

Methods	Data needs				Traffic State		Outcome	
	Headway	Flow	Speed	Density	(Q)	(C)	q_c	F(q)
Headway Models	Yes				Yes		Yes	
Bimodal Distribution		Yes			Yes	Yes		Yes
Selected Maximal		Yes			Yes	Yes		Yes
Direct Probability		Yes				Yes	Yes	
Asymptotic		Yes				Yes	Yes	
Product Limit		Yes	Yes		Yes	Yes		Yes
Online Selection		Yes	Yes		Yes	Yes	Yes	
Fundamental Diagram.		Yes	Yes	Yes	Yes		Yes	

Source: Minderhoud et al *(1998)*

Note that F (q) is the probability that the capacity value q_c is higher than a given value q. Note also that in the table (Q) represents free flow (C) represents congested flow (under the condition of a congested traffic state upstream leading to maximum congested flow intensities).

2.3.1 Observed Headways - The estimation method by headway models is based on the theory that, at the capacity level of the road, all driver-vehicle elements are constrained. Thus, distribution of headways will depend on traffic volume and capacity of the highway. Drivers may travel at lower speeds; keep shorter distances between vehicles ahead or may choose to travel on a different lane of the carriageway because of poor road surface. Because of good surface conditions, drivers may travel at higher speeds given a certain traffic density, may keep shorter distances between vehicles ahead without lowering speed, or may choose a different lane of the carriageway (multi-lanes). If drivers cannot maintain their desired speed by overtaking slower moving vehicles then free flow conditions no longer exist and the highway will show signs of congestion.

Headway models include the exponential distribution, the displaced exponential distribution, the dichotomised exponential distribution, the Branston's generalised queuing model (GQM) *(1976)*, and the Buckley's semi-Poisson model (SPM) *(1968)*. Both the GQM and SPM are based on the Poisson point process but with some slight differences in the assumptions concerning driver behaviour in traffic flows. Equations 2.3 and 2.4 are the basis for capacity estimation with headway distribution models. The time headway is defined by the time between successive vehicles (measured from rear bumper to rear bumper) that pass a given point in a lane in a traffic stream:

$$h_m = \sum \frac{h_p}{n} \quad (Sec\ per\ vehicle) \qquad (2.3)$$

$$q = \frac{n}{T} = \frac{1}{h_m} \quad (Vehicle\ per\ sec) \qquad (2.4)$$

$$q = \frac{3600}{h_m} \quad (Vehicles\ per\ hr) \qquad (2.5)$$

Where

h_p = time of headway vehicle p to preceding vehicle (sec per vehicle);

h_m - mean time headway(sec per vehicle);

q = intensity; and

n = total number of vehicles passing the measuring point during time T.

Note that; h_m = mean time headway (sec per vehicle); $\equiv L\, t_1 + (1\text{-}L)\, t_2$, where L is the proportion of restrained vehicles in the traffic stream, t_1, is the mean headway between restrained vehicles and t_2 is the mean headway between unrestrained vehicles. Since traffic stream on the highways is usually made up of both restrained and unrestrained vehicles, the observed headways distribution as contained in many literatures may be represented by:

Probability (headways $\geq$ t) $= L\ exp\ (-(t-e)\ /\ (t_1 - e)) + (1 - L)\ exp\ (-t\ /\ t_2)$ ... for $t \geq e$

Note that, drivers who are restrained by the action of the driver in front can approach to within minimum time headway of *e*. Where the theoretical probability of n vehicles say arriving per t minute interval = exp (-m) m^n / n!. And m = the summation of the number of vehicles per t minute interval multiply by the summation of the times observed (Σf_o) divided by (f_o). The models are based on the theory that driver-vehicle elements in a traffic stream can be divided into two groups; the constrained drivers (followers) and the free drivers (leaders). The distribution of tracking headways of constrained drivers at the capacity level of the road is expected to be the same as for constrained drivers in any stable (stationary) traffic stream.

Therefore, the capacity at a cross section of the road can be estimated with the reciprocal of the mean time headway of the constrained vehicles. However, the basic principle of headway models is determination of the parameters of the compound probability density function of headways *f* (h), given by:

$$f(h) = \phi \times g(h) + (1- \phi) \times b(h)$$

Where

ϕ = Fraction of followers, (constrained drivers) ($0 \leq \phi \leq 1$)

g (h) = followers' probability density function of tracking headway: and

b (h) = leaders' probability density function of free headway

However, a difficulty of the use of the negative exponential distribution even under free flowing conditions is that the probability of observing headway increases as the size of headway decreases. As vehicles have finite length and a minimum following headway this presents a problem when only a limited number of overtaking are observed. Wasielewski *(1976)* prefers the SPM model since in his opinion; the GQM falsely assumes the unconstrained vehicles also take their empty zone into account, whereas the SPM does not have a drawback. The GQM and the SPM models are virtually the same since the empty zone includes the clearance time part of the empty zone; a nonzero empty zone is always taken into consideration, even when the driver is unconstrained.

The advantage of headway models in estimating the capacity is that only the headways at one cross section of an arterial observed at flow below capacity are needed. Hence, it is not necessary to wait for a traffic state at about capacity level. Also, headway models for a single lane can be applied for both stable and unstable traffic conditions. But, the disadvantage according to Papendrecht et al (1980) is that the headway models substantially overestimate observed road capacity. This is probably caused by the implicit assumption of the models that the distribution of constrained drivers g(h) at capacity level can be compared with the distribution g(h) at flow below capacity. The headway method, therefore, is probably not the best way to derive a reliable roadway capacity value for this study because of the likelihood of capacity overestimation.

2.3.2 Observed Volume - The observed traffic flows according to Minderhoud *et al (1998)* can be grouped into observed extreme value approach (bimodal distribution and selected maximal) and expected extreme value approach (direct probability and asymptotic methods). In the observed extreme value methods, such as the bimodal distribution and the selected maximal, road capacity is estimated by using only known maximum traffic volumes acquired over certain period. The special character of the flow distribution may be explained by the existence of two different traffic states, one representing the traffic demand and the other representing the stochastic maximum flow level (both collected at the observation period).

Data collected only during the day can probably be depicted as a Gaussian curve. Two separate distributions are assumed to represent the compound distribution of the observed flow rates. For this method, only traffic volumes are counted at a cross section of a road (a bottleneck) and the traffic demand distribution depends strongly on the total observation period. The general form for a compound probability density function can be used to estimate the capacity. Its value may be estimated as the expectation of the mean by probability density function $b(q)$:

$$f(q) = \phi \times g(q) + (1-\phi) \times b(q) \qquad \text{Equation 2.1}$$

Where

ϕ = Fraction of the probability density function representing the traffic demand capacity;

g(q) = probability density function representing the traffic demand below: and

b(q) = probability density function representing the capacity state

According to O'Flaherty (*2002*) if the traffic flow is assumed to be random then the probability of exactly n vehicles arriving at a given point on the highway in any t second interval is obtained from the Poisson distribution which states that:

$$\text{Probability } (n \text{ vehicles}) = (q^t)^n \exp(-q^t) / n! \qquad \text{Equation 2.2}$$

Where: q is the mean rate of arrival per unit time

In equation 2.1 where the proportion of traffic demand capacity is 85 per cent say, then, $f(q) = 0.85\ g(q) + 0.15\ b(q)$. Note that 85 percent is merely a ratio of flow to capacity, but a major problem with the bimodal distribution method is the choice for the below-capacity probability density function according to Minderhoud *et al (1998).* The assumption that capacity can be estimated with a normal Gaussian-type distribution can be accepted, however, the assumption that traffic demand (the free-flow observations) also can be represented with a Gaussian-type distribution is doubtful and dependent on the observation periods chosen.

As for the selected maximal, the road capacity q_c is assumed to be equal to the selected traffic flow maximal (distribution) observed during the total observation period. Further, the observation of flow rates should take place over several days (cycles) until sufficient data are colleted for analysis. The data to be used with the selected maximal methods consists of hourly traffic volumes or flows observed in an averaging interval less than an hour.

Roadway capacity must be reached at least once during a cycle and the observation period can vary from one survey study to another. In any case when applying this method the number of capacity observations strongly affects the reliability of the calculated capacity value. Thus,

$$q_c = \sum_j \left(\frac{q_j}{n} \right)$$ Equation 2.3

Where

q_c = capacity value (vehicles per hour)

q_j = maximum flow rate observed over period j

n = number of cycles: and

j = length of cycle (period over which a maximum flow rate is determined

T = nj, thus the observation period T is divided into n cycles of duration j

When applying this basic method, the number of capacity observations strongly affects the reliability of the calculated capacity value. In addition, choosing the average value is rather arbitrary; taking the 90th percentile point, for example, might also be useful.

However, in the expected extreme value methods, such as the direct probability and asymptotic methods, also use observed extreme traffic flows to determine a capacity value; however these methods use extreme flow rates observed in the averaging intervals to predict a higher (unobserved) capacity value by statistical methods used in other disciplines, for example astronomy. With the direct probability method, a prediction of the largest possible value can be made on the assumption that the traffic flows conform to a theoretical model such as the Poisson process.

The direct probability method according to Hyde *et al (1986)* may be applied when the capacity level of the roadway has been reached. The capacity estimate resulting from the calculations can be considered as a certain exceptional value of the maximum flow. Thus, the capacity of a roadway is based on the expected maximum flow predicted from the distribution of traffic counts given an assumed traffic arrival process. Assumptions about the arrival process of the vehicles at the cross sections are need. Hyde *et al (1986)* suggested that the predicted capacity value using direct probability strongly depends on the duration of the averaging interval.

The asymptotic method relies on the theory that behaviour of the extreme values arising from any natural process can be described in terms of a simple statistical model. One important requirement is that the observations for all sampling intervals are independently (flow between sampling interval are not related), and identically (all counting are elements of the same distribution function) distributed. This implies, among other things, that the mean flow during the observation period must be constant.

Hyde *et al (1986)* concluded that because capacity estimate with this method strongly depends on the duration of the averaging interval, it appears that the expected maximum methods (although mathematically appealing) have little practical value for freeway design or modeling. The main reason for the great variance in the capacity values observed lies in the fact that only high traffic volumes are used in the calculations. Of course, very low flows are also measured in such intervals, but these values are not taken into account in calculation of the upper limit. In sum, estimation of capacity by way of maximum traffic volume may not be suitable for this kind of study for the various reasons mentioned earlier in this section

2.3.3 Observed Volumes, and Speeds - Another method of estimation with traffic volumes and speeds is the product limit method. The theory behind the product limit method according to Minderhoud *(1998)* is based on explicit division of flow observations. In the general approach of the product limit method, free-flow measurements are applied as measurements for additional information about road capacity value.

A simple example for understanding the product limit method is based on eight observations, using 15-min averaging intervals as shown above in table 2.2. During the 2-hr observation period, congestion upstream occurred, so there were some capacity observations at the bottleneck. The measured intensity values are expressed here in vehicles per hour. In the first column of Table 2.2 shown below, the averaging interval is indicated.

Table 2.2 Product Limit Method Calculation *(1998)*

1 Interval ©	2 q_i (Veh/h)	3 Set	4 Order *j*	5 $K_{q, qi\ c}$ ©	6 *G (q)*	7 *F (q)*
1. 15.30-45	3000	Q	2	-		
2. 15.45-00	2500	Q	1 lowest	-	1	0
3. 16.00-15	3500	C	3	6	5/6 = 0.83	0.17
4. 16.15-30	4000	Q	4	-		
5. 16.30-45	4000	C	6	3	5/6.3/4.2/3 =0.41	0.59
6. 16.45-00	4500	Q	7	-		
7. 17.00-15	4600	C	8 highest	1	5/6.3/4.2/3 .0/1 =0	1
8. 17.15-30	4100	C	5	4	5/6.3/4 =0.62	0.38
2 hours	Average Flow 3812	Total *l* = 8 © *in (Q)* = 4 *l in* © = 4				

Source: Minderhoud (*1998*)

The corresponding hourly intensity values are presented in the second column. It is assumed that speed data are used to categorize the observations into set $\{C\}$ or set $\{Q\}$, which is done in the third column. Furthermore, the rank of the intensity values is determined in the fourth column, after which the discrete functions *G (q) and F (q)* = 1 – *G (q)* were calculated. Function *F(q)* is defined as the probability that the capacity value q_c is higher than a given value *q*. The function *F(q)* is defined by 1 – *G(q) and* the general expression of the product limit method is given as:

$$G(q) = Probability\ (q_c > q)$$

$$G(q) = \prod_{qi} \left[\frac{k_{qi} - 1}{k_{qi}} \right] \qquad q_i \in \{C\} \qquad \text{Equation 2.4}$$

Where

K_{qi} = number of observation elements *l* in set $\{S\}$ with intensity q_i larger than or equal to q;

$\{C\}$ = set of observed congested flow intensities;

$\{Q\}$ = set of observed free-flow intensities;

$\{S\} = \{Q\} \cup \{C\}$ and $\{S\}$ is set of all observations l.

However, the usefulness of product limit method is questionable because there is no information about the quality (reliability, precision) of the estimated capacity value. In the speed / volume curve however, travel speed decreases as link volume increases paralleling the concept of levels of service. But in situations where traffic flow and vehicle speeds are constrained by pavement distress, capacity on such road section can be taken as vehicle per hour per lane because the influence of pavement distress on mixed traffic will render vehicle speed and maneuverability advantages of passenger cars insignificant. It may be added that in such situations the application of speed / flow relationship would give a good capacity estimate bearing in mind that the associated problems with speed / flow method of estimation, for example, defining the critical or optimum speed. In Greenshields' relationship (*1934*) theoretical estimate of the capacity (q_m) of a length of a road from a pair of observed data points has been shown to be:

$$q_m = K_j V_f \;/ 4 \qquad \text{Equation 2.5}$$

Where: $V_o = V_f / 2$, and $K_c = K_j / 2$

Note that: V_o = Optimum speed; V_f =Optimum speed;

K_c = Critical Density; K_j = Jam Density

As shown below in Table 2.3 the reference flow to capacity ratio is a measure of capacity condition according to HCM (*1994*), as flow approaches capacity traffic congestion will be experienced by road users.

Table 2.3 Reference Flow to Capacity

Critical Flow/Capacity Ratio X = RFC	Capacity Condition
$X \leq 0.85$	Under Capacity
$0.85 < X \leq 0.95$	Near Capacity
$0.95 < X \leq 1.00$	At Capacity
$X > 1.00$	Over Capacity

Source: Based on Table 9.14, HCM (*1994*)

2.3.4 Observed Volumes, Densities, and Speeds - According to Haight *et al (1961),* the relationship between flow and density is the fundamental relationship of traffic under free flow condition. The view was also shared by May (*1997*) that for the purpose of measuring quantity, the parameters, density and flow are important, because density, while speed and flow relationship describe the quality of service experienced by the traffic stream. But the drawback is that density would have to contend with the measurement of speed using the fundamental relationship of flow, speed and density. Density is often difficult to determine because one should observe a complete and uniform road section and count the total number of cars present at any moment. Notwithstanding, Van Arem and Ver der List (*1998*) explored the relationship between flow and density in a situation of free flow and concluded that it could be represented by a quadratic equation. In the flow (q) – density (k) relationships by Van Arem and Ver der List (*1998*), density was used as the control parameter and flow the objective function and could be written as:

$$q = \beta_o + \beta_1 k + \beta_2 k^2 \qquad \text{Equation 2.6}$$

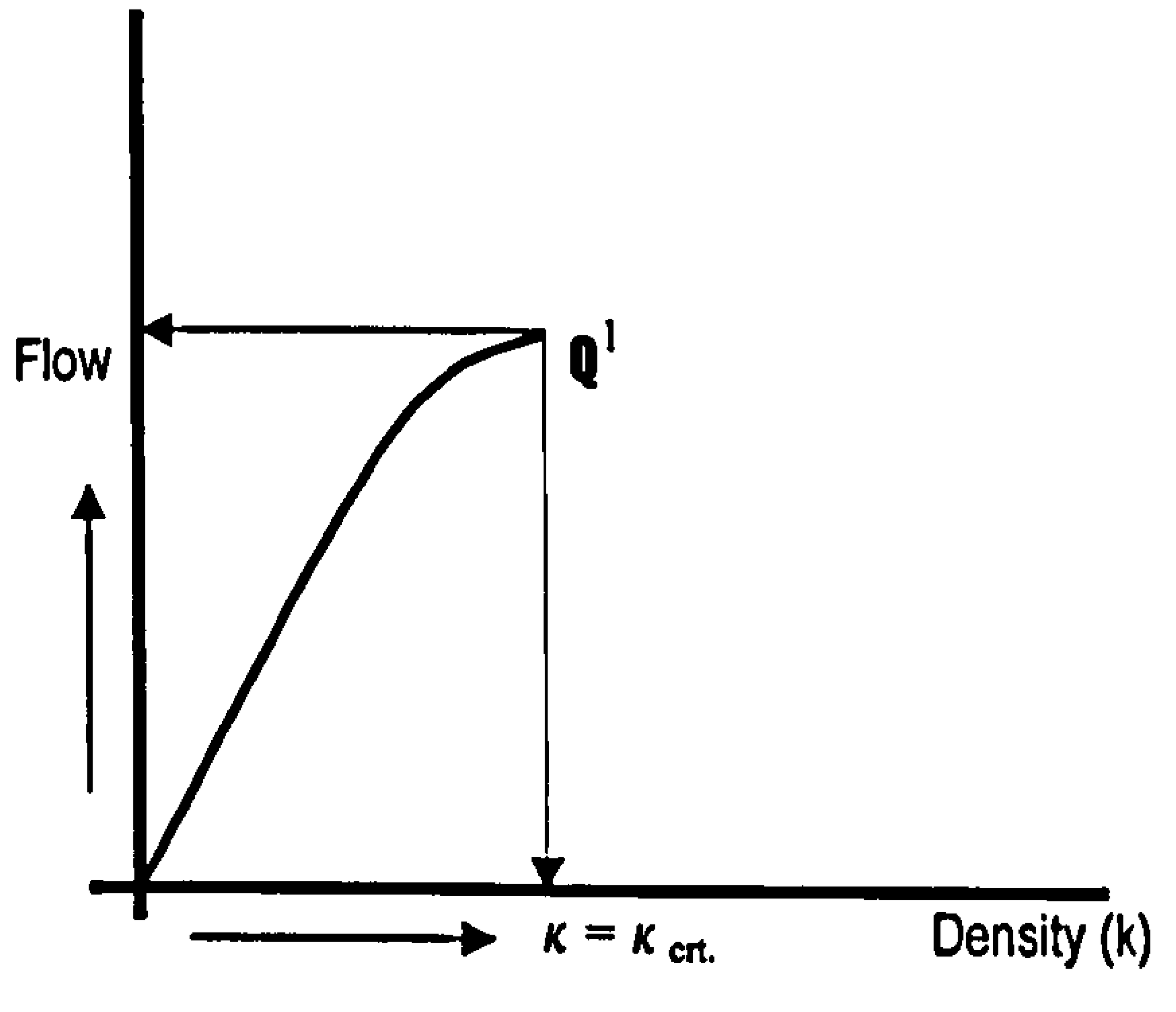
In theory, where the flow / density relationship has been used to compute roadway capacity, the critical density is reached at the apex points as shown in Figure 2.6 below. At point Q_1 the traffic is not free flowing and one would expect that to happen on road sections when capacity has been reached.

However, the capacity theory underlying the model dictates that concavity in the flow – density curve must be present for validity. Given the coefficients signs in equation (2.11), β_1 the sign must be positive and negative or zero at β_2 in order not to violate the concavity requirement of the flow-density curve. Thus, equation 2.6 can be re-written as;

$$q = -\beta_o + \beta_1 k - \beta_2 k^2 \qquad \text{Equation 2.7}$$

However, in the equation 2.12 above under a very low density condition, as density approaches zero ($k \rightarrow 0$), flow approaches zero ($q \rightarrow 0$) and speed approaches free-flow speed ($u \rightarrow u_f$). As flow increases, density increases while speed is decreasing, critical density is reached when flow becomes maximum as shown below in figure 2.6, further increases in density result in deceased flow until finally as jam density is reached, flow approaches zero. The draw back with this method lies with determining the critical density. It can be derived, estimated or assumed as appropriate, but how, it may be queried. It is quite possible to extrapolate mathematically till the maximum of the *q-k* function is reached but would such theoretical values so computed compare with the actuality of traffic operation. It may even be the case that such calculated capacities are unrealistically high and questionable. It can even be argued that capacities derived in such a way may have very little resemblance to traffic actuality. Since our interest is in estimating the capacity change due to pavement distress, the choice of precise value of critical density need not be very critical to the outcome of this study. By maximising flow critical density can be computed.

Figure 2.6 Flow / Density Relationship (using quadratic function)



2.4 ROAD SURFACING:

Broadly, roads can be classified into two groups; rural road system and the urban road system. The rural road system includes the following classes of roads; primary or trunk roads, including motorways and expressways, secondary roads, feeder roads and access roads, which radiate from feeder roads. Whereas the urban road system is structured to enhance road safety and basically includes; primary distributors, district distributors, local distributors and access roads which provides direct access to buildings and plots in a given environmental area. In road design three elements are important; the road geometry, the road pavement and the drainage system. The traditional approach in geometric design considers the layout plan, longitudinal section and the cross-section. The main objective of the drainage system is to ensure that surface water and sub surface water are removed from the road so that the road pavement is not adversely affected by it.

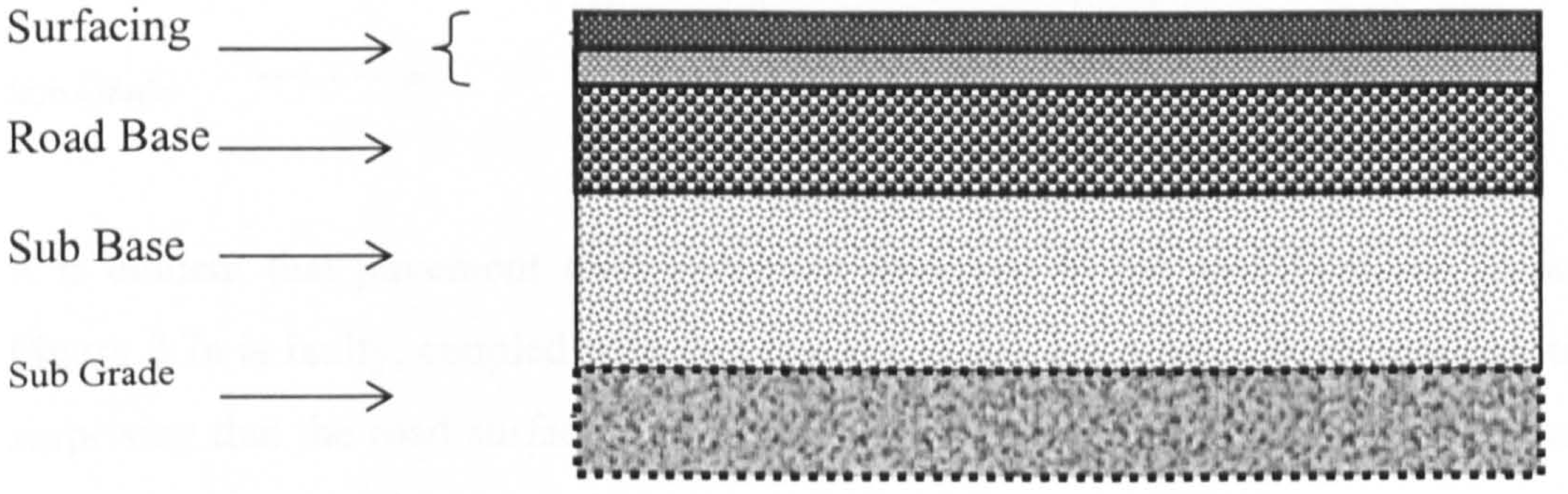
The flexible road pavement which is of interest to us consists of a series of structural layers generally as shown below in Figure 2.7, the naturally occurring soil immediately below the formation is generally referred to as the sub-grade. According to O'Flaherty (*2002*) this is the foundation layer, the structure that must eventually support all of the loads that come onto the pavement. The sub-base is a layer of relatively weak material and its thickness depends upon the projected intensity of traffic loadings and the strength of the sub-grade. The road-base is usually asphalt, and designed to absorb and redistribute loads such that deformation in the road pavement remains within acceptable limits. Road surfacing is made of the wearing layer and the base course.

2.4.1 Simplified Pavement Structure - The wearing course (uppermost layer) usually 40mm completes the flexible road pavement construction and is designed to withstand the direct effects of road traffic together with the action of weather and temperature conditions according to O'Flaherty (*2002*). It was further suggested that a requirement for base course is usually 60mm; therefore, high stability can be obtained by using mixes with a high stone and low void content. Also, the aggregate should preferably be crushed stone having a high impact resistance and the use of harder bitumen grades is beneficial for increased resistance to deformation and fatigue cracking. Theoretically, in a true flexible road the whole of the construction is in compression, the loads from traffic being so distributed by the construction that the load at formation level is not greater than the sub-grade can accommodate without permanent deformation according to Lister (*1977*).

Thus, the function of road surfacing is to enable good ride quality to be combined with the appropriate resistance to skidding and to resist crack propagation. And for this, texture and durability under traffic are required. Valkering (*1992*) suggested that in modern flexible road construction, the materials used are capable of some resistance to tension. This result in improved load-spreading properties and safely permits a reduction in the thickness of construction as compared with materials offering no resistance to tension. The works of a number of scholars, including, Heukelom, W and Klomp A.G (*1962*), Brown S.F, Pell, P.S and Stock,A.F

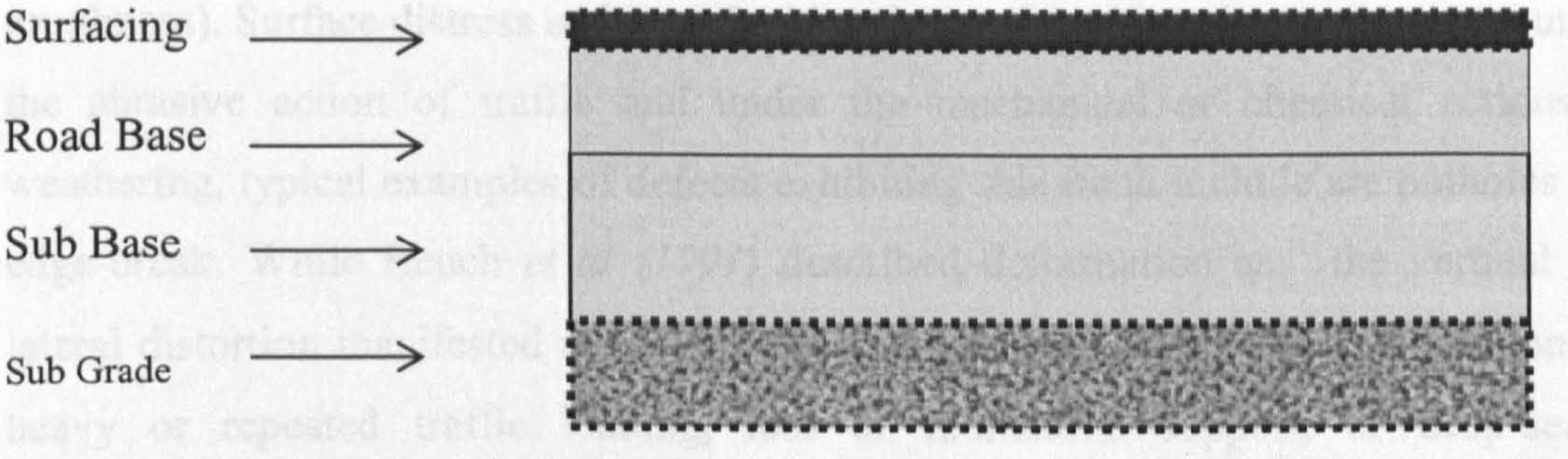
(*1977*),Lister,N.W, Powell,W.D and Goddard,R.T.N (*1982*), and McElvaney,J and Pell, S.P (*1974*) show factors that have applied pressure effects on the pavement.

Figure 2.7 Simplified Pavement Structure



2.4.2 Typical Constituency of Trunk Road Pavement In Nigeria – In developing countries it will be found quite often that the traffic mix may include fairly significant proportions of pedestrians, bicycles and animals competing for road space. It may also be found that the proportion of buses and lorries is quite high. Under such circumstances, the road pavement should be designed with wider and stronger shoulder. However, in Nigeria a typical low cost road pavement has 40mm sometimes smaller surfacing, 150mm and 250mm road base and sub-base respectively usually made up of laterite. Laterite is a red-colored clay-like kind of soil found in the tropics. It is an infertile soil, but bricks made out of dried or baked laterite make a good building material. Laterite is heavily leached tropical subsoil. When exposed and dried it sometimes is rock-like. It isn't a fertile soil. Laterite consists usually of aluminum oxyhydroxides with smaller amounts of iron oxyhydroxides and a little bit of a clay mineral called halloysite. Laterite needs the high temperatures and rainfall of the tropics to form. The water washes out the bases and the silicic acid, and enriches the soil with aluminum silicates, aluminum hydrosilicates, iron oxides and iron hydroxides. The iron in particular leads to the typical red colour.

Figure 2.7a Typical Constituency of Trunk Road Pavement In Nigeria



It is evident that pavement road pavement designed to the specifications shown in Figure 2.7a is faulty, coupled with fact that the drains are mostly dysfunctional its not surprising that the road surfacing fails few weeks after opening. Under traffic loading the various courses in a bituminous-bound pavement are subject to repeated stressing and the possibility of damage by fatigue cracking is usually considered to continually exist. When a wheel load passes over a flexible pavement, each course in the pavement responds in the same general way: an applied stress pulse is caused by the wheel mass whilst the resultant horizontal strain consists of resilient and permanent components. The permanent strain component, although tiny for a single-load application, is cumulative and becomes substantial after a great number of load applications. An excessive accumulation of these permanent strains from all layers can lead to fatigue cracking and to pavement failure according to O'Flaherty (*2002*).

2.5 ROAD PAVEMENT DISTRESS:

Road pavement does not fail suddenly. It is generally considered to begin to deteriorate after entering service and then gradually, to get worse as time progresses until a failure condition is reached. Bituminous surfacing may crack for a variety of reasons that include lack of good bond between the surface layer and the course underneath, excessive pavement deflection, expansion and contraction of the sub grade, shrinkage and often, in early stages the crack patterns can indicate the cause. In any case when the cracks have developed over a large area and become sufficiently wide and numerous to allow the entry of surface water or disturbance of the surface by traffic, the road deteriorates.

The World Bank predictive model HDM111 (1987) identified two categories of distress modes: surface (potholes, ravelling, cracking) and deformation (rutting and roughness). Surface distress is the gradual break-up of the bituminous pavement under the abrasive action of traffic and under the mechanical or chemical actions of weathering, typical examples of defects exhibiting this trend include are potholes and edge-break. While Beuch *et al (1991)* described deformation as ' the vertical and lateral distortion manifested at the bituminous pavement surface under conditions of heavy or repeated traffic loading, loss of foundation support, or deep-seated differential expansions and settlements'. This problem mainly occurs in the wearing course of a road and is principally caused by heavy goods vehicles (HGV). The problem is also aggravated by modern vehicle designs utilising higher tyre pressure, which increase point loading on the road.

Deformation development near the edge of a carriageway is very common on Nigeria roads and it is likely to be accelerated if the road-base is not carried through the shoulder and the shoulder does not have an impervious covering. Typical examples of road deformation include the followings, corrugations, undulation, shoving, transverse depressions, rut and depressions. HDM-4 (2000) defined road deterioration as a function of; original design, material types, construction quality, road geometry, pavement age, environmental conditions, maintenance policy pursed, traffic volume and axle loading. Cracking may be the result of fatigue in bituminous materials and it is assumed to originate from the bottom of the bound layers occurring in the pavement structure or the surfacing only. Flexible roads do not last very long in Nigeria and the extent to which hot climate can be called to account for poor road surfacing has yet to be established, but this is not the focus of this study. However typical examples of pavement disintegration are shown in Plates 1, 2, 3, 4, 5, and 6.

- **Plate 1** Typical Pothole (degradation of pavement structure)
- **Plate 2** Typical Edge Damage (degradation of pavement structure)
- **Plate 3** Typical Edge Subsidence and Rutting
- **Plate 4** Typical Rut and Depressions
- **Plate 5** Typical Shoving (defects in the pavement structure)
- **Plate 6** Typical Cracking

Plate 1

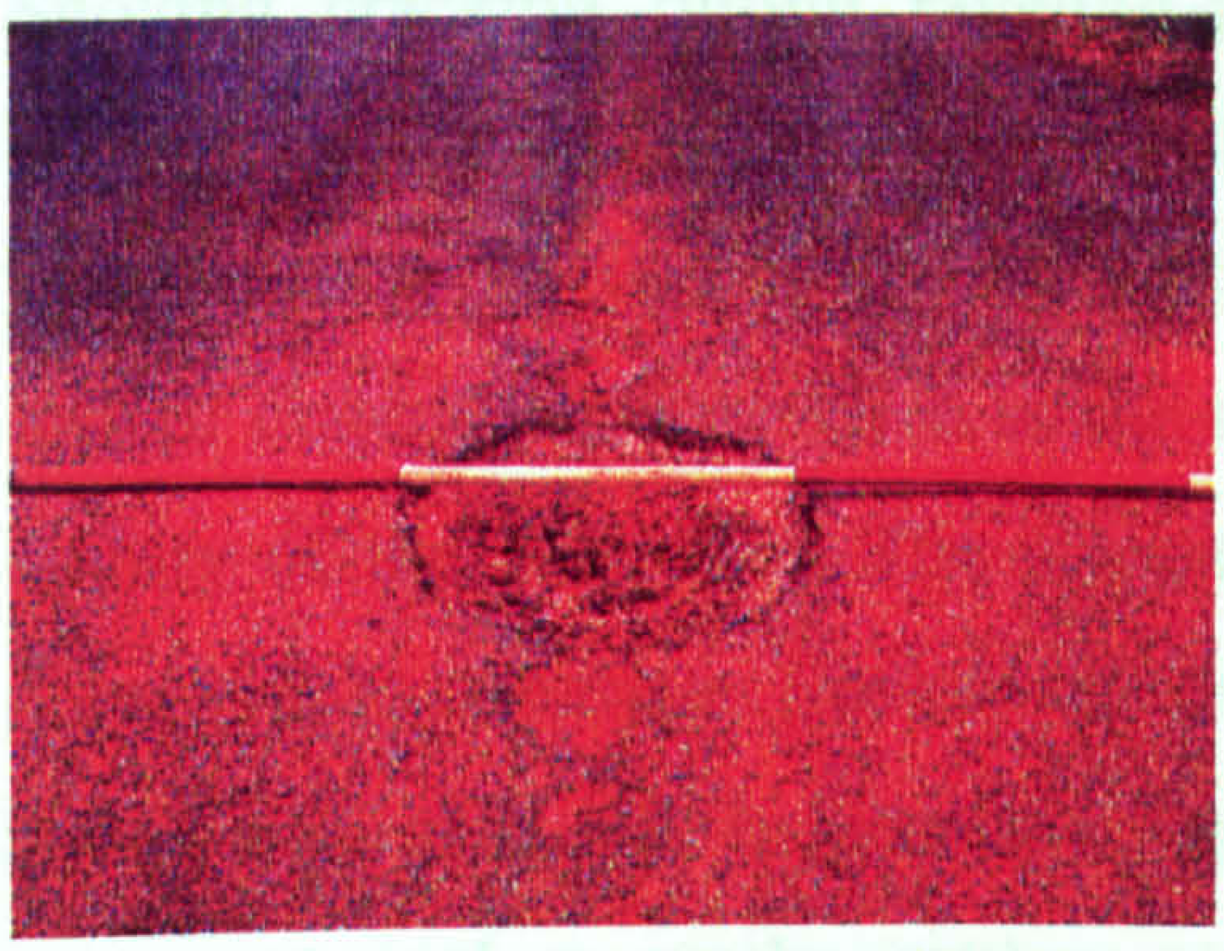


Plate 2

Plate 3

Plate 4

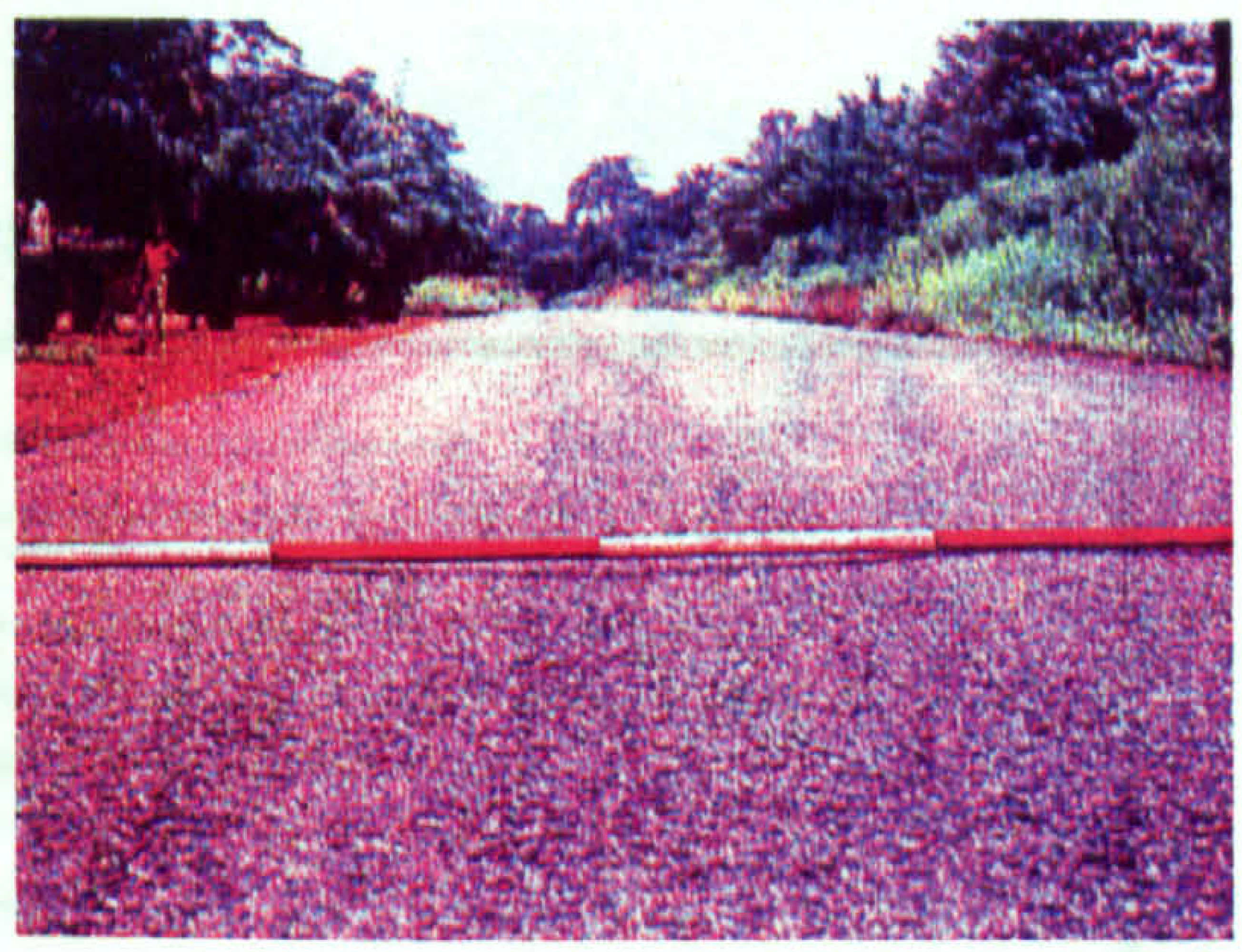


Plate 5

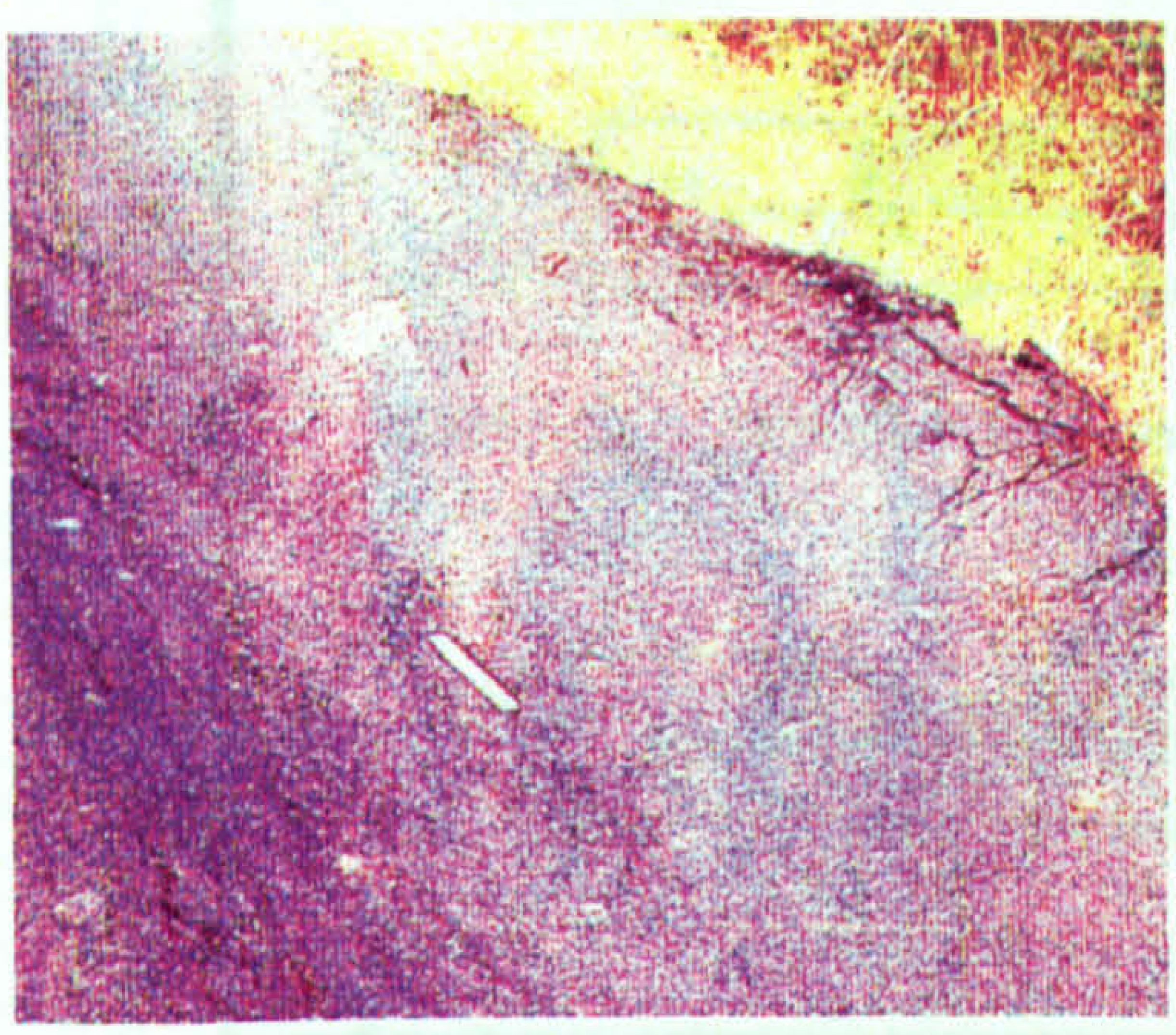
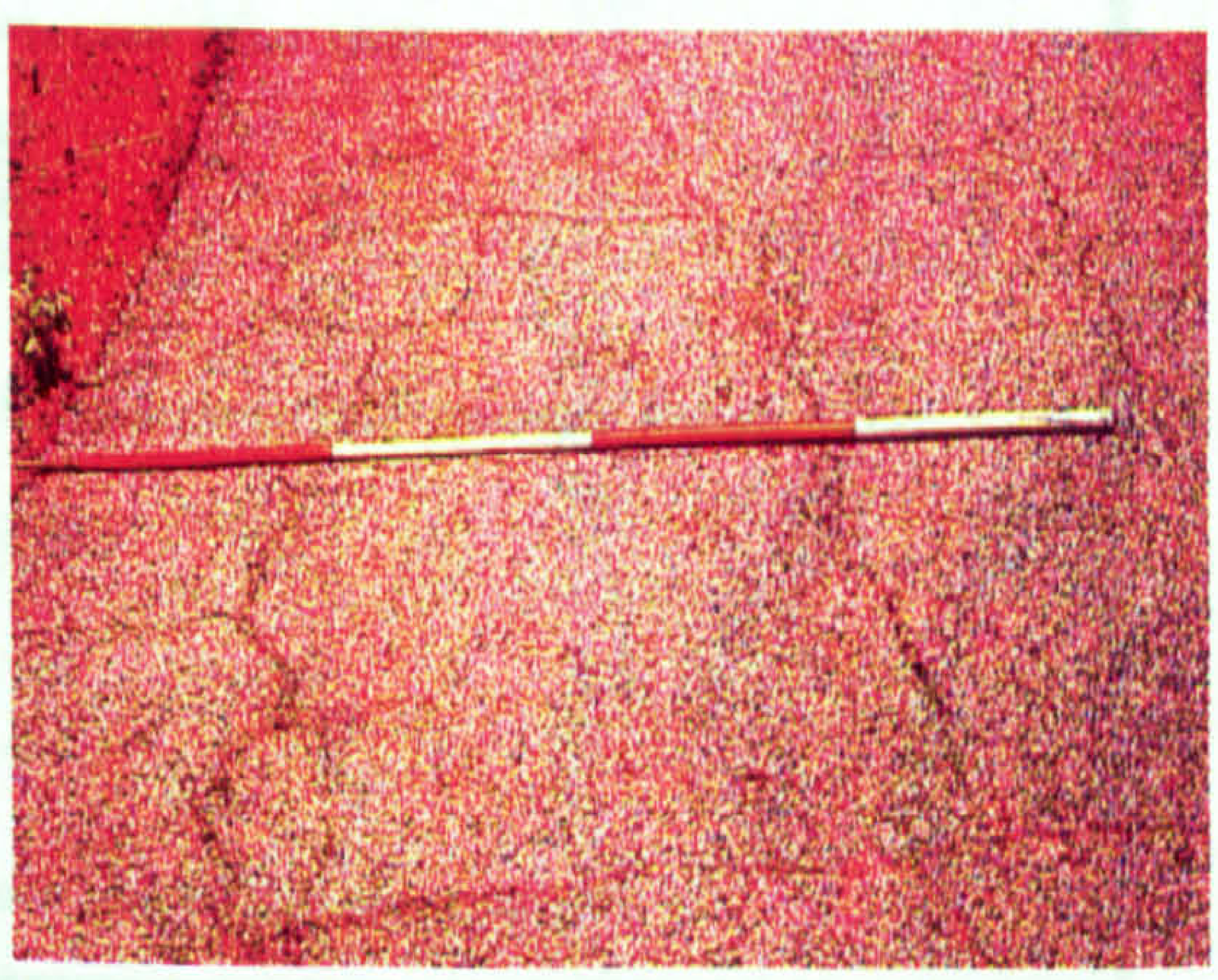
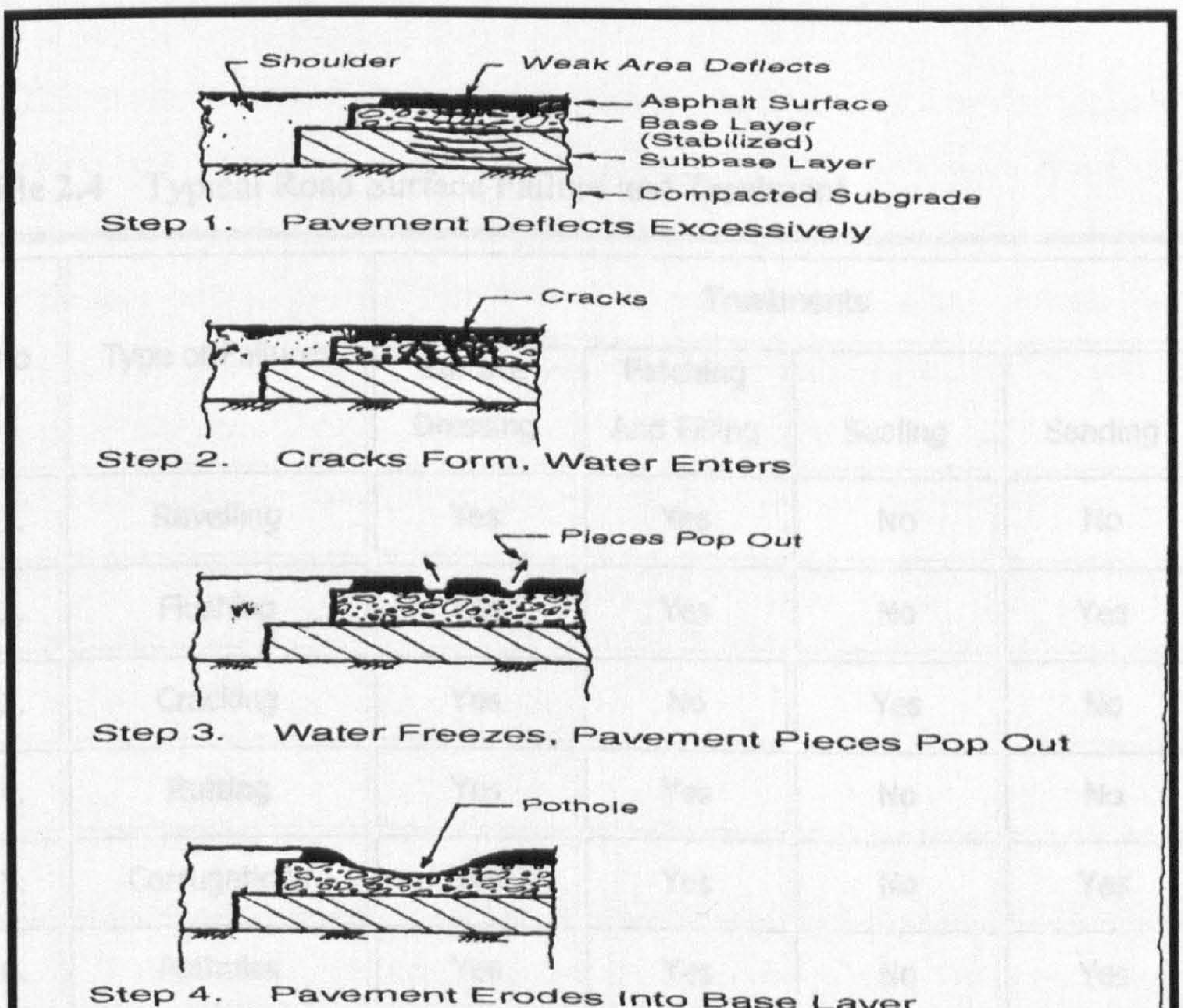


Plate 6



2.5.1 Potholes - Defects are usually manifested in form of cracking, rutting, raveling, potholes, roughness, edge break, surface texture and polished surface. Shoving, cracking, rutting, raveling and flushing may lead to break up of pavement. Specifically, pothole was defined in HDM111 as open cavity in road surface with at least 150mm diameter and at 25mm depth. Pothole may be defined as any localised loss of material or depression in the surface of a pavement that compromises the ride quality of the pavement. The process of forming a pothole when the base is weak according to American Society of Civil Engineers HITEC report (*1995*) is illustrated below in Figure 2.8. In general terms potholes may result from, deficiencies in the pavement, such as cracks, settlement in the utility cut, repair failure, overlay failure, poor construction and water is an important contributor to pothole formation mainly through loss of support caused by a saturated base.

Figure 2.8 Pothole Formations in Full-depth Asphalt Pavement



Source: CERF Report HITEC 95-1 Page 7

Pavement disintegration, deformation and cracking of road pavement are known form of treatable road defects. If the bituminous surfacing shows signs of weakness, it is essential to determine whether the fault is in the surface, the pavement or in the sub-grade before any extensive repairs or re-surfacing works are begun. It is recognised that the correct diagnosis of the cause is often difficult (especially at the early stages of distress) and it may be necessary to dig small inspection pits to examine the various layers and arrange laboratory tests of the materials.

In any case some of the defects associated with each type of road pavement failure with their expected remedial treatments are shown below in Table 2.4. The most commonly encountered pothole repair failures are lack of adhesion, dishing, pushing or shoving of the patching mix, loss of material through ravelling, delamination of the patching mix and drainage failures. A lack of adhesion between the patch material and the surface of the old pavement can lead to early failure when cracks form and water penetrates under the patch.

Table 2.4 Typical Road Surface Failure and Treatment

No	Type of Failures	Treatments			
		Surface Dressing	Patching And Filling	Sealing	Sanding
1.	Ravelling	Yes	Yes	No	No
2.	Flushing	Yes	Yes	No	Yes
3.	Cracking	Yes	No	Yes	No
4.	Rutting	Yes	Yes	No	No
5.	Corrugations	Yes	Yes	No	Yes
6.	Potholes	Yes	Yes	No	Yes

Source: O'Flaherty C.A (*2002*)

Dishing can be defined, as settlement of the surface, is the result of inadequate compaction of the repair mix. Shoving is the result of inadequate shearing resistance in the mix and can be the result of a poorly compacted mix, the bleeding of tack or liquid asphalt to the upper portion of the repair or a poorly designed mix. Raveling is a loss of mix from the surface of the repair. It results from insufficient cohesion within the mix and can be a mixture-related problem. Delamination is symptomatic of asphalt concrete overlays or thin patches that peel away from the old surface and is cause by poor adhesion between the old pavement and the patch. In general, the performance of a bituminous pavement deteriorates with rising temperature. This is due in part to the fact that the effective resilient moduli of bituminous-bound materials and hence the stresses generated in the pavement are temperature dependent, and in part because their resistance to deformation drops rapidly with increasing temperature.

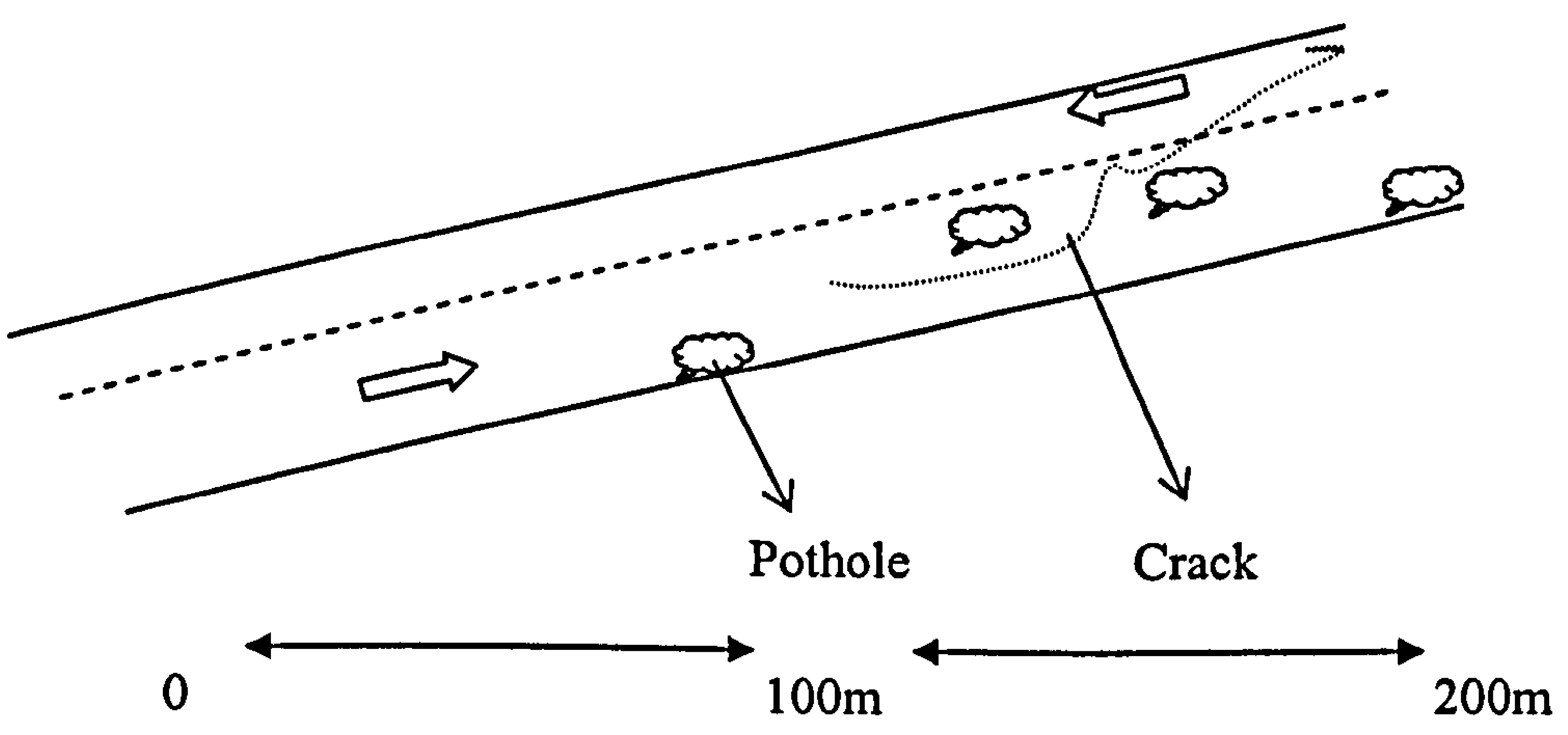
2.5.2 Pavement Distress Measurements – These are usually taken as percentage of affected area relative to road section with particular attention on sizes, numbers and depth. DTp road note advice 20/84 (1997) suggested that for validity carriageway lane must not be less that 2.5m, therefore potholes, ravelling, and edge damages with transverse widths greater than 500mm on a 6.1m carriageway (allowing 100mm for road markings) would have violated lane width tolerance level. Normally when inspecting a road section, the road is divided into subsections of 100 or 200 metres according to Thagesen (*1996*) with the road register marker posts used for reference. Then for each distress mode, the extent and severity of the defect are recorded supplemented by an assessment of their possible causes. This regime has been incorporated into this study by way of recording the numbers of potholes, area of distress, and the maximum depth of pothole.

The Federal Highway Authority in Nigeria –FHA *(1998)* has classified pavement distress severities into three categories, slight, moderate and severe. As shown below in figure 2.10 simple measurements are required for pavement distress as contained in most literature and they include: type of distress, length, width, depth, affected area, number (nos.), and the relative percentage of distress. Interestingly in Transport

Research laboratory overseas road note 1 *(1994)* on treatment selection rules for paved roads, the extent and level of pothole are conspicuously absent.

In Figure 2.9 above, note that the distribution of potholes is random and it may not necessary follow a particular pattern. According to Department of Transport's (DTp) advice note TA 20/84 (*1997*), the minimum width acceptable for traffic lane is 2.5m. Therefore, any pavement distress that will reduce the width of traffic lane irrespective of their arrangements will affect traffic operating capacity. In cases where it is desirable to have some form of measure that will alert the road providers of possible distress in order to maintain the road in an adequate condition then some form of pavement management model sometimes referred to, as level of serviceability would be required.

Figure 2.9 Hypothetical Road with Pavement Distress



In the HDM 111, predictive model developed by Watanatada *et al* (*1987*) the deterioration relationships ultimately manifest themselves in predicted surface roughness, which is the main determinant of the road user costs on a specific length of road. From the HDM 111 approach, number of potholes and depth of potholes were important variables. However, in this study, the concern is not just the condition of the pavement rather how it affects vehicles volumes and speeds. Following the DTp's advice it may be necessary to check for a 2.5m clearance from the traffic lane edge and centre. In sum area of distress is measurable as rectangular areas circumscribing manifest distress expressed as percentage of carriageway area and section length.

2.6 PAVEMENT DISTRESS AND ROAD CAPACITY RELATIONSHIP:

The break up of pavement by way of edge subsidence and potholes will effectively reduce the road carriageway width. Reduction in carriageway width and pavement with potholes will have significant influence on roadway capacity by reducing vehicle speed. Drivers may travel at lower speeds; keep shorter distances between vehicles ahead or may choose to travel on a different lane of the carriageway because of poor road surface and this may result into higher (user, maintenance, delay and safety, costs), increase in travel time, environmental degradation and indeed road user distress. Because of good surface conditions, drivers may travel at higher speeds given a certain traffic density, may keep shorter distances between vehicles ahead without lowering speed, or may choose a different lane of the carriageway (multi-lanes). If drivers cannot maintain their desired speed by overtaking slower moving vehicles then free flow conditions no longer exist and the highway will show signs of congestion.

There are no literatures on the relationship between pavement distress and roadway capacity loss. Traditionally, regression techniques are employed for the development of functions that relate road condition indices to the information recorded in the pavement management database and the partial coefficients estimated by method of least squares. The technique is that if fitting a hyper-plane through a set of points in such a way that the sum of the square normal distances from points on the hyper-plane is minimised. So, it can be assumed that as the level of pavement distress severity increases so will the level roadway capacity losses to a maximum of 100 percent. Modelling the relationship between pavement distress and roadway capacity loss by way of regression techniques is a useful tool.

The percentage of HGVs and the extent of distress are constraints on the exponential function; thus, Latorre *et al* (*1997*) suggested that a logistic function is capable of explaining constrained exponential function. However, logistic function shows a change of concavity at an inflection point. The theory underlying this model dictates that negative concavity in the curve must be present for validity. Whether such a function could be used to describe the relationship between pavement distress and roadway capacity loss is not exactly clear. What is clear is that a relationship exists between pavement distress and road capacity. Hypothetically, it can be suggested that there is a relationship between road condition and roadway capacity loss, where roadway capacity loss is the objective function and road condition is the control parameter as shown below in Figure 2.10 It is clear that when road conditions deteriorate the road capacity loss increases (provided the road is operating at capacity). In Figures 2.11 and 2.12 the influence of pavement distress on road capacity loss is illustrated where road capacity dropped from Q^1 to Q^2 .

Figure 2.10 Hypothetical Road Capacity loss v. Road condition

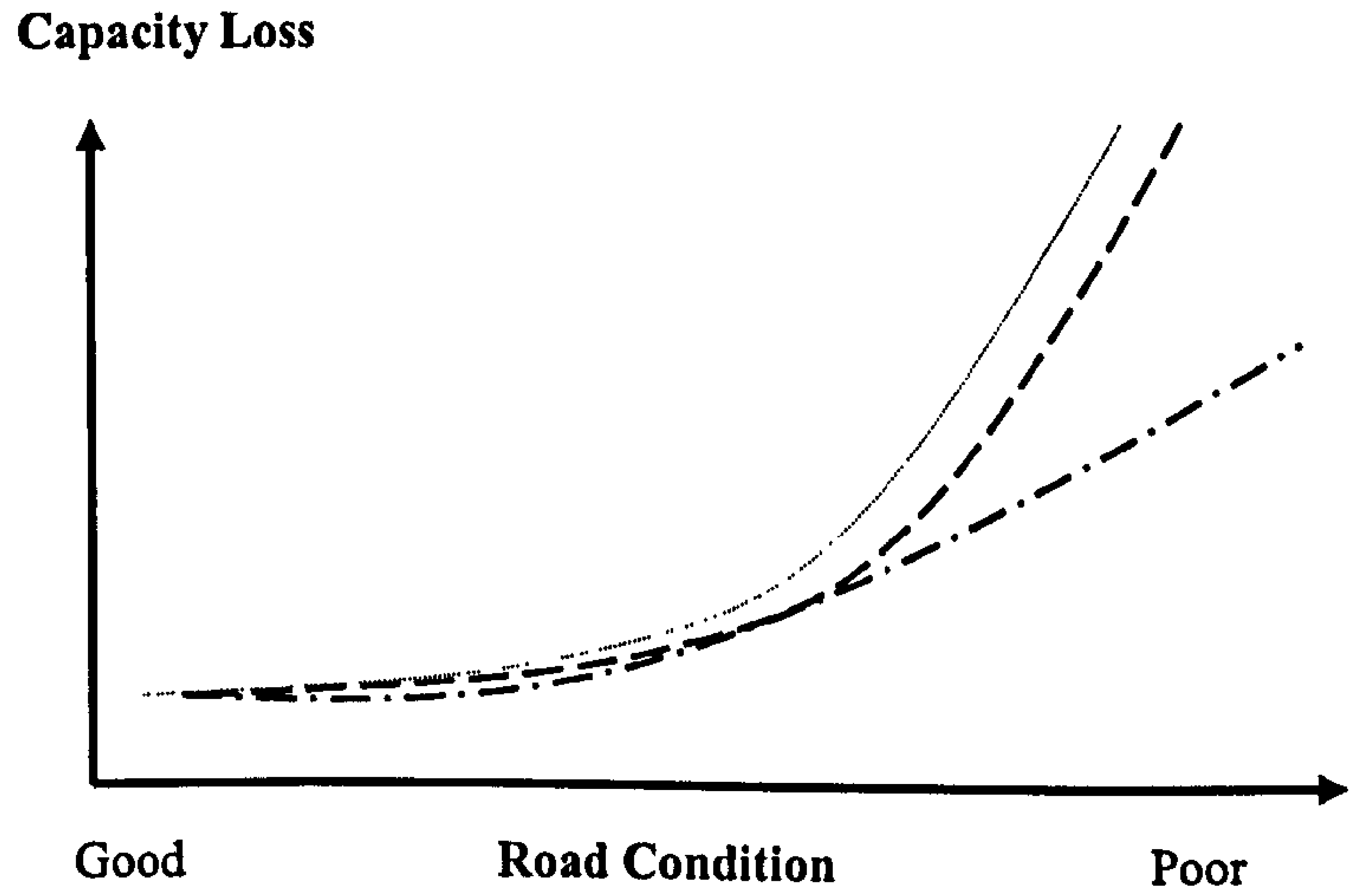


Figure 2.11 Influence of Pavement Distress on Flow / Density Relationship

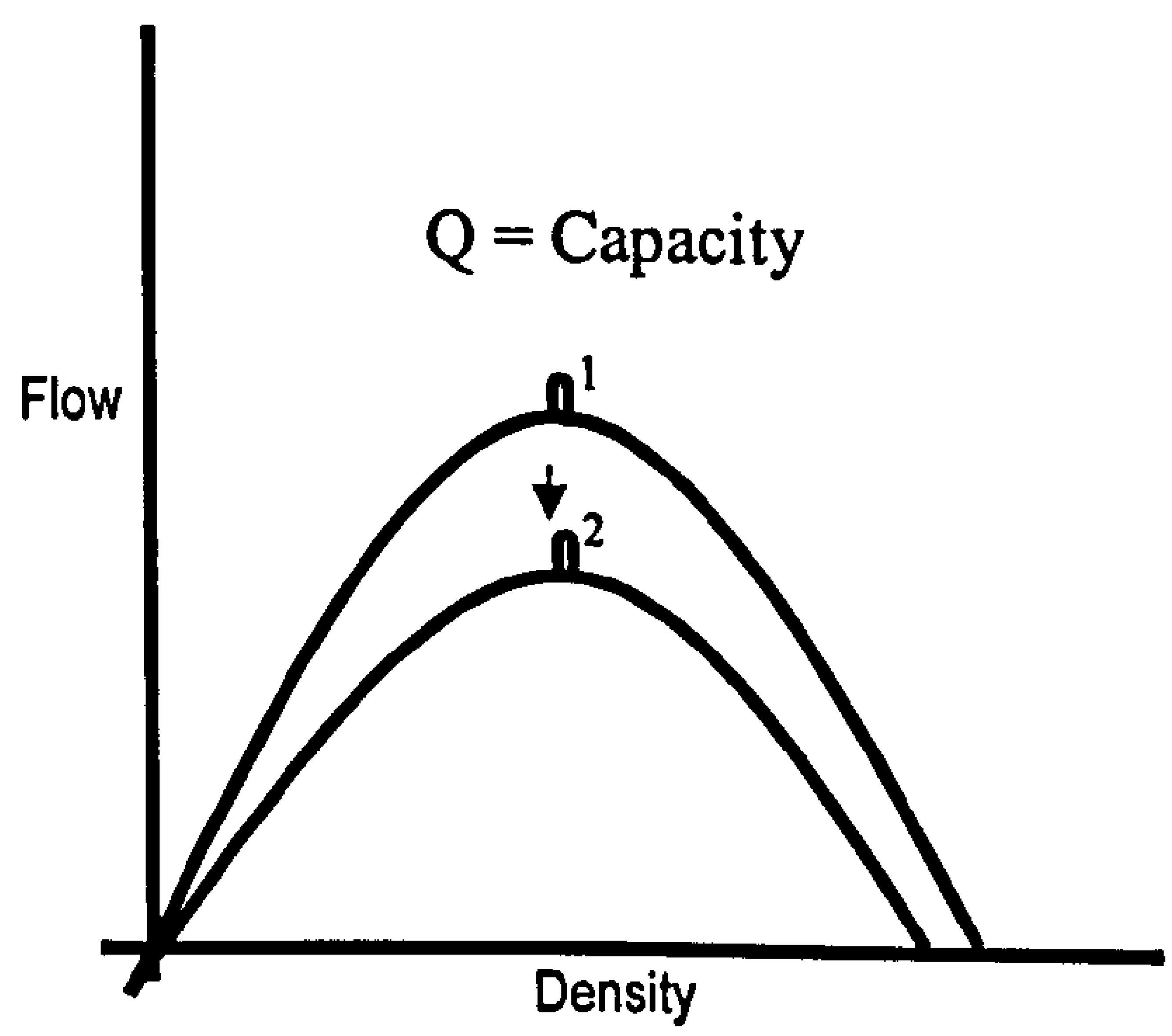
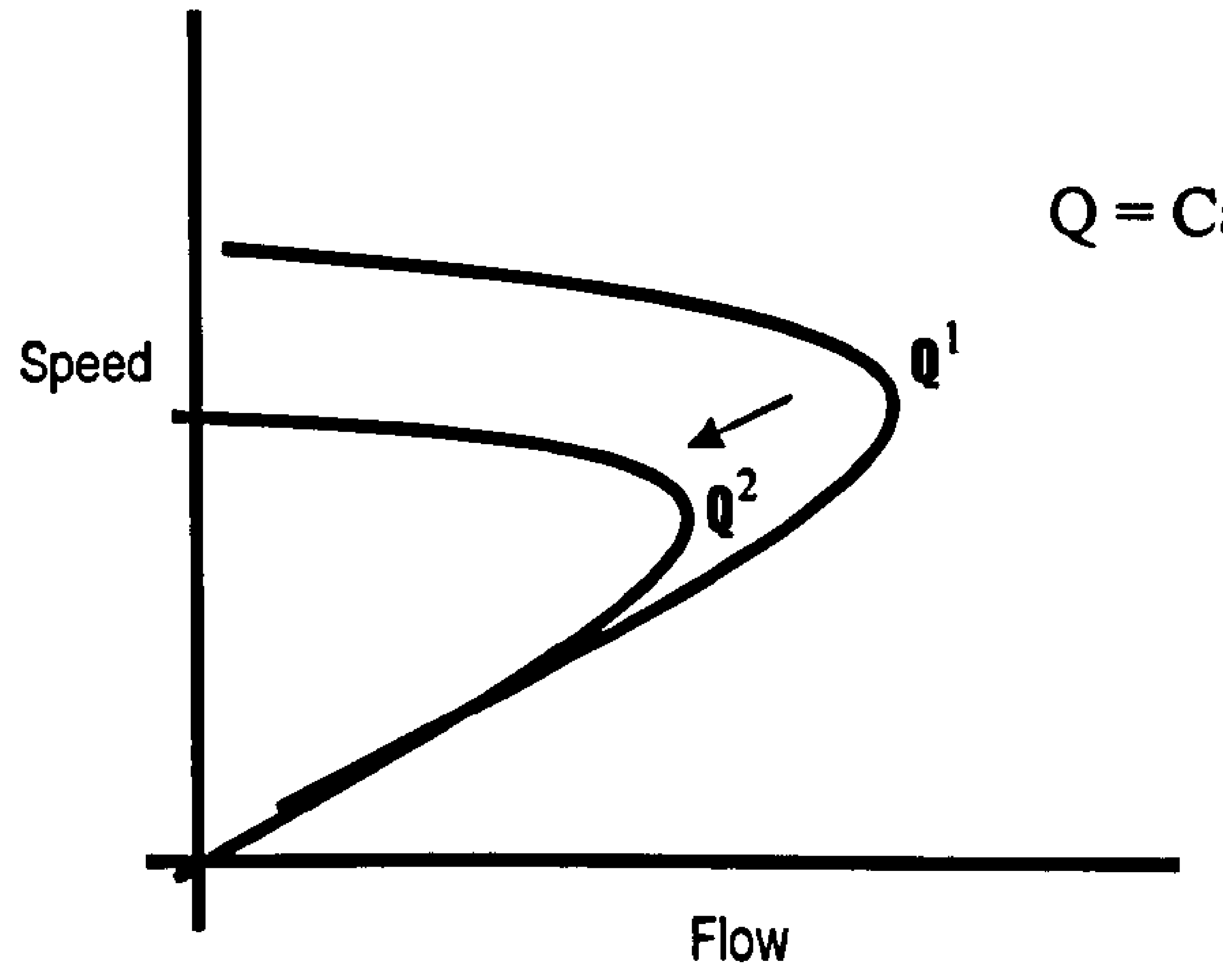


Figure 2.12 Influence of Pavement Distress on Speed / Flow Relationship



2.7 PCE VALUES FOR DISTRESSED ROAD SURFACE:

There are not many literatures on the relationship between pavement distress on level terrain and passenger car equivalent values. However, passenger car equivalent values on good level terrain used in Nigeria according to Federal Ministry of Works and Housing - FMWH (*1998*) are; Passenger Car (PCs) 1 PCE, Light Goods Vehicle (LGVs), 1.5 PCE, Heavy Goods Vehicle (HGVs) 2 PCE. These PCE values are based on HCM (*1994*) guidance without modifications to local environments and would have to be investigated even though used in this study. Passenger car equivalent values shown below in Table 2.4 are significant to roadway capacity estimation and their values are measures of vehicle performances relative to various types of terrain usually level, rolling and mountainous.

The Highway Capacity Manual defined six levels of service (A - F) for each road type with level A representing free flow, low volume, high speed, comfortable operating conditions while F represents forced flow, stop-start, uncomfortable conditions. Vehicle performances relative to various types of terrain as shown in Table 2.5 indicate that on level terrain the PCE values for the vehicle types in Table 2.5 decreased significantly. It can be suggested that under a pavement distressed level terrain condition, the PCE values for the same vehicle types will decrease further because of the sizes of these vehicles. Since the 1965 *HCM* numerous other techniques have been applied.

Table 2.5 Passenger Car Equivalency Values for Use on Two-lane roads

Vehicle Type	Level of Service	Type of terrain		
		Level	Rolling	Mountainous
Heavy commercial vehicles	A	2.0	4.0	7.0
	B and C	2.2	5.0	10.0
	D and E	2.0	5.0	12.0
Recreation vehicles	A	2.2	3.2	5.0
	B and C	2.5	3.9	5.2
	D and E	1.6	3.3	5.2
Buses	A	1.8	3.0	5.7
	B and C	2.0	3.4	6.0
	D and E	1.6	2.9	6.5

Source: HCM (*1994*)

PCE estimation methods can be summarised as; PCEs based on headways used by Cunaign (*1984*), PCEs based on delay used by Cunaign (*1984*), PCEs based on platoon formation used by Van Aerde and Yagar (*1984*), PCEs based on speed used by Van Aerde and Yagar (*1984*), PCEs based on vehicle-hours used by Sumner *et al* (*1984*) and PCEs based on travel time used by Keller and Saklas (*1984*).

In fact Elefteriadou *et al* (*1998*) in their work on development of PCE for highways suggested that of the techniques mentioned above, speed and delay were the most often used as basis for calculating PCEs on various highway types. Elefteriadou *et al* (*1998*) used speed for calculating PCEs because they claim that 'speed is a performance measure immediately experienced by all uses on each type of highway, and it provides a clear picture of how smoothly a facility is operating'. This approach was suggested by Roess *et al* (*1980*) on the ground that speed is the principal criterion for designation of levels of service.

Van Aerde and Yagar (*1984*) developed PCEs based on speed on the basis of relative rates of speed reduction related to each vehicle type. A multiple regression model was structured to estimate the free-speed and the speed-reduction coefficients for various percentile speeds (10, 50, and 90 percent): Percentile speed = free speed + C_1 (number of passenger cars) + C_2 (number of trucks) + C_3 (number of recreational vehicles) + C_4 (number of other vehicles + C_5 (number of opposing vehicles). Coefficients C_1 to

C_5 indicate the relative sizes of speed reductions due to the respective vehicle type or direction of travel. PCEs values were determined as:

$$\text{PCEs for vehicle type n} = C_n / C_l$$

The headway method is one of the several techniques for measuring PCEs. By using the headway method one is implying that the relative amount of space occupied by a vehicle in motion is the basis for calculating PCE values. Headway is the distance from rear bumper of the lead vehicle to the rear bumper of the following vehicle at appoint in time. It is also a measure of separation between vehicles, which may affect safety and the ease with which pedestrians and vehicles can cross the traffic stream. In any case the simplistic approach based on vehicle headways may be estimated as:

$$PCE_{ij} = H_{ij} / H_{pcj}$$

Where:

PCE_{ij} is the PCE of vehicle Type I under Conditions j, and H_{ij}, H_{pcj} is the average headway[1] for vehicle Type I and passenger car for Conditions j.

Note that: *according to HCM (1992) i,)*

- *Headway = Spacing (m/veh) / Speed (m/sec)*
- *Spacing (m/veh) = 1000m / Density (veh/km)*

2.8 SUMMARY OF LITERATURE REVIEW:

In summary, three key issues were discussed in this chapter namely; road capacity, road pavement distress and passenger car equivalent values. However, the principal issue is the extent of road capacity loss associated with pavement distress. Relevant literatures on pavement distress and roadway capacity were reviewed and interest was focused on capacity estimation methods, the measurement of pavement distress, and the influence of pavement distress on passenger car equivalent values. Although not considered a major part of the study, the relationship between pavement distress and road capacity was investigated. Highway Capacity Manual defines road capacity of a fixed facility as 'the maximum hourly rate at which vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period (usually 15 minutes) under prevailing roadway, traffic and control conditions'. Department of Transport - DTp advice note TA79/99 and Highway Capacity Manual (HCM) merely give guidelines and suggested that the validity of their estimated road capacities can usually be tested against that obtained by robust direct empirical results.

Although several capacity-estimation methods are based on appropriate theories concerning macroscopic traffic flow, the attempts to determine the capacity of a road by existing methods will generally result in a capacity value estimate. The validity of this value is hard to investigate because of the lack of a reference capacity value, which is supposed to be absolutely valid. Nevertheless the chosen method in this study using flow-density model by way of quadratic equation would be sufficient in determining road capacity loss. It follows that road capacity could be estimated by extrapolating free flow observations. Density could then be computed from the observed traffic volume, speed using the fundamental relationship. The number of potholes, depth of potholes, and areas of pavement distress are important variables when evaluating the extent of pavement distress; the variables can be related to road capacity loss by way of multiple regressions for the purpose of establishing a model equation that can describe the relationship.

Pavement surface distress measurements are usually taken in literatures as percentage of affected area relative to road section with particular attention on sizes, numbers and depth of potholes. DTp road note advice 20/84 (1997) suggested that for validity carriageway lane must not be less that 2.5m, therefore potholes, ravelling, and edge damages with transverse widths greater than 500mm on a 6.1m carriageway (allowing 100mm for road markings) would have violated lane width tolerance level. The effects of pavement distress on passenger car equivalent values in significant to road capacity estimation. Even though attempts have been made by many scholars to address the issues of passenger car equivalency and provide more realistic values for uninterrupted flow, there are no uniform values. So, by using a simplistic 'headway of vehicle type' approach we can at least point the PCE values for road section with pavement distress in a particular direction.

3

HIGHWAYS AND TRAFFIC IN NIGERIA

This chapter addresses issues relating to the historic background, design and performance of the road system in Nigeria with particular focus on the conditions of the road from the 1960s to date in general and specifically flexible pavement maintenance and their costs implications for road user, the environment and the economy of Nigeria.

3.1 ROAD DEVELOPMENT:

The need to provide a proper road system had long been recognised by the colonial government, especially as a means of ensuring reasonable contacts within and between human settlements, as well as providing the channels for the evacuation of produce, so as to boast external trade. Consequently, attention was focus on the provision of trunk A roads, the skeleton of Nigerian road network, on which other lower categories of roads (Trunk B, C and unclassified roads) were and are still being constructed.

The provision of roads in Nigeria is usually by governments (Federal, State and Local). Olugbenga (*1995*) presented the history of highway development in Nigeria. According to him, Nigeria has almost 3,200km of motorable roads before the First World War in 1914, and this increased to 4,750km by 1926. The then Public Works Department – PWD maintained all roads. The first bituminous surfaced road had tar as binder and was contrasted by way of direct labour.

The total length of road between 1914 and 1996 is shown below in Table 3.0. Lagos – Ibadan expressway is the first dual carriageway in Nigeria and was opened in 1978. The distribution of roads by category and region for 1953 is shown in Table 3.1, while the distribution among different tiers of government in 1996 is shown in Table 3.2. In Table 3.2, it can be seen that 67 percent of the paved roads belong t o the Federal highway network. This forms the primary axis of the Nigeria road system.

Table 3.0 Lengths of Roads between 1914 and 1996

Year	Bituminous Surface – km	Earth, Gravel Surface - km	Total - km
1914			3,200
1926			4,750
1934			6,040
1938			8,280
1939			9,480
1946			13,240
1953			45,993
1960	8,694	57,010	65,704
1962	11,053	60,818	71,871
1965	14,941	73,017	87,958
1968	15,200	73,280	88,480
1969	15,758	75,200	90,958
1972	18,109	77,266	95,375
1996	39,500	153,700	193,200

Source: Olugbenga (*1979, 1995*) and Fadaka (*1996*)

Table 3.1 Distribution of Roads by Category and Region in 1953

Category	Northern Region-km	Western Region - km	Eastern Region-km	Southern Cameroon - km	Total km
Trunk A	5,594	1,075	1,136	526	8,331*
Trunk B	6,771	1,661	858	422	9,712
LC Roads	15,410	2,138	10,213	189	27,950
Total	27,775	4,874	12,207	1,137	45,993

*Of this total, 1,782km had bituminous surfacing. Note that LC – Local councils

Source: Olugbenga (*1995*)

Table 3.2 Nigeria Road System 1996

Road Class	Road Length - Km			
	Paved	Unpaved	Total	%
Federal	26,500	5,600	32,100	16
State	10,400	20,100	30.500	16
Local	2,600	128,000	130,600	68
Total	36,500	153,700	193,200	100
%	20	80	100	

Source: Fadaka (*1996*)

During the colonial era, the responsibility of funding both the construction and the maintenance of trunk (A) roads fell totally on the central government. The roads then were functional and in excellent condition, road transportation services and indeed transportation system were running smoothly as could be expected from effective and efficient management operations provided by the colonial governments. After independence in 1960, the inability of the federal ministry of works to deal with and respond adequately to the vase needs of road network was obvious. It may be partly because of maintenance management vacuum left by the departing colonists and mainly because of the relative growth of the problem to population and transportation needs.

Most access links in Nigeria however, are unpaved roads with substantial proportion of the total movements made by non-motor operated vehicular traffic. Collector links have intermediate vehicular flow (ADT 300-1000 see Table 3.4) to and from rural areas, either direct to adjacent urban centres, or to the arterial network. The geometric standard is usually not high and road link can be paved or unpaved. Arterial roads are the main routes connecting state capitals, and other countries. The vehicular traffic (ADT) on them is usually greater than 400 vehicular traffic flows.

Today, the Nigerian population has grown from 55 million in 1960 to an estimated 118 million in 2001 making it one of the most densely populated countries in the world according to the Independent Electoral Commission (*2001*). The dependence on road transportation is near total with vehicle population up from 55,000 in 1970 to 1.5 million in 1998 according to Road Vision Committee (2000). Passenger car traffic grew at an annual rate of 3.5 per cent between 1998 and 2002, and is estimated to grow at 4.5 per cent between 2002 and 2007 (Federal Ministry of Works, Sheladia Inc and Yolas Network (*1998*). Commercial vehicle traffic growth rate is estimated at 3.5 per cent per annum for the period 1998-2003. Table 3.3 shows the summary of road network characteristics in Nigeria. These large increases in traffic flows have traffic capacity management, road maintenance, and also, environmental management consequences for the road system; The transition to higher level of vehicle ownership and consequently road use has become an increasing burden to governments in Nigeria.

Table 3.3 Summary of 51,800-km of Road Network Characteristics

OWNERSHIP			***SURFACING***		
Federal Government	28,600-km	55%	Paved	37,900-km	73%
State Governments	20,000-km	39%	Unpaved	13,900-km	27%
Local Governments	3,200-km	6%			
CONDITION			***TRAFFIC LEVELS***		
Good	4,400-km	9%	ADT > 1500	13,000-km	25.1%
Fair	20,800-km	40%	ADT 300-1500	23,250-km	44.9%
Poor	26,600-km	51%	ADT 30-300	15.550-km	30.0%

Source: (*FMWH 1998)*

Kent Falck-Jensen *(1995)* identified three distinct stages in road development levels as; i) provision of access, ii) provision of additional capacity and iii) increase of operational efficiency when approaching appropriate geometric design standards in developing countries. It can be argued that developing countries will not usually be at stage (iii), indeed most will be at the first stage with stage (iii) design standards often leading to uneconomical and technically inappropriate designs.

3.2 ROAD DESIGN AND CONSTRUCTION

A frequent justification for construction, rehabilitation and maintenance of roads is that improved transport infrastructure promotes development. This is most demonstrated by growing investment in transport infrastructure and the importance accorded road transportation is reflected by the usual allocation of a substantial portion of transportation sector budget to it (mostly the highest and between 50 and 65 percent on the average).

This budgetary allocation is usually for the construction, rehabilitation and maintenance of highways and associated infrastructure such as culverts, drains and bridges. According to Transport and Road Research Laboratory - TRRL in their Overseas Road Note 31 *(1987)* most design standards currently in use by developing countries are considerable higher than can be justified from an economic or safety point of view considering that traffic flow is generally low. In any case Federal Highways are generally designed to Federal Ministry of Works and Housing - FMWH specifications and it is required that highway design must be executed with the aid of AutoCAD or any other suitable software programs according to FMWH, (*1999*).

Modern pavement design is based on mechanistic and empirical/mechanistic procedures. These procedures rely mainly on classifications-based traffic volume counts collected on extended periods of time, and the fatigue or cumulative loading effects over design period. The CBR design procedure contained in the current edition of FMWH's Design Manual appears simplistic, too empirical and outdated considering it was published in 1973. Table 3.4 shows the typical design standards of Nigerian roads.

But defining the functions of link hierarchy is simplistic in theory, there are over laps of functions in practice and clear distinctions in some cases are not apparent on functional terms alone. And it is not unusual to find roads with dual functions relative to traffic conditions, road surface conditions, and ambient, social and economical conditions among others.

Table 3.4 Road Design Standards for Nigeria

Road Link	Class	Traffic Flow* (ADT)	Surface Type	Width (m)		Maximum Gradient %	Terrain / Design Speed (km/h)		
				Carriageway	Shoulder		M	R	L
Arterial Collect	A	5000 - 15000	Paved	6.5	2.5	8	85	100	120
	B	1000 -5000	Paved	6.5	1.0	8	70	85	100
Collect Access	C	400-1000	Paved	5.5	1.0	10	60	70	85
	D	100-400	Paved / Unpaved	5.0	1.0+	10	50	60	70
Access	E	20-100	Paved / Unpaved	3.0	1.5+	15	40	50	60
	F	< 20	Paved / Unpaved	2.5/3.0	Passing Places	15/20	N/A	N/A	N/A

Source: Overseas Road Note 6 (TRL)

* Two-way flows recommended as no more than one Design Class step in excess of first year Annual Daily Traffic (ADT): + for gravel roads the shoulders should not normally be gravelled except for class D if shoulder should damage occurs. Note that: M – mountainous; R – Rolling; L - Level

The major materials used in road construction in Nigeria are lateritic soils, gravel and bitumen. Nigeria has abundant deposit of laterite, which does not satisfy the requirement for base course materials as mention in Chapter 2 and also large a deposit of bitumen. Laterite when used for base course construction is often stabilized using Portland cement, however, cement is expensive and sparingly used. This should provoke discussion on an alternative stabilising agent for example bitumen and reduce dependence on Portland cement. Adedimila and Oti (1987) concluded that laterite can be stabilised with bitumen and the result will satisfy the specifications for use as a base course material. The government paid very little attention to the research work and merely recommended that further studied be conducted. The estimated bitumen deposit reserves are shown in Table 3.5

Table 3.5 Estimated Reserves for Major Bitumen Deposits Worldwide

Country	Bitumen Deposit	Estimated Reserve – metric tons
Canada	North Alberta Deposits	388×10^6
Malagasy	Bemolangu Deposits	246×10^6
Nigeria	South Western Nigeria Tar Sand Deposits	270×10^6 (minimum)
USA	Utah, Kentucky and California Deposits	351×10^6 (minimum) 773×10^6 (minimum)
Venezuela	Orincco - Guarico Deposits	281×10^6

Source: Adegoke (1980)

3.3 ROAD MAINTENANCE AND REHABILITATION

It must be mentioned that passenger cars dominate road transportation in Nigeria with a strong presence of commercial vehicles. This may be indicative of commercial vehicles influence on roads in Nigeria and one would have to investigate whether this factor is taken into account at the design stage. A good part of the existing road network extending over an estimated mileage of 155,000 km is in poor condition with only 9 per cent of the 58,000 km of paved roads categorised as 'in good condition' according to Sheladia *et al.* (*1998*). The take over of about 16,000km of selected state roads by the federal government in 1974 meant the addition of extra road improvement and maintenance responsibility. The principal concern of the federal government at the time was to find a lasting solution to the growing problem of inadequate road maintenance. Thus, a field organisation for maintaining all federal roads by direct labour was set up by the federal ministry of works in 1974. It was short-lived.

In 1995, at the height of concern for the deplorable state of Nigeria roads, the government at the time announced plans to set up road camps along federal highways in order to accelerate response to road rehabilitation and maintenance, only to scrap the initiative as unworkable a few weeks later. A year later, the government established the Petroleum Trust Fund (PTF) for the same purpose of road maintenance and rehabilitation, indicated that about $266.67 million was available for the project according to Adesoji *(1997)*, only to scrap it later as being too over ambitious.

In year 2000, the government signalled interest in the highway and traffic problems by announcing plans and policies on highway construction, highway maintenance and rehabilitation, highlighting the followings:

- Rehabilitation and maintenance of roads to ensure usability all year round
- Provision of modern services such as telephone, rest stations, 24-hour rescue services and medical facilities on federal highways
- Extension of all highways (dual-lanes) leading into the federal capital city
- Formation of Nigeria Road Board (NRB) for purpose of maintaining standard
- Establishment of Road Fund (RF) with contribution from sources like highway toll, vehicle taxes, trucks, Weigh Bridge and parking fees, also petroleum tax element.

Unfortunately the programmes and initiatives had the familiar promises and failures, and it is therefore not surprising that sustainability of road system has become so elusive and very difficult for subsequent governments to achieve in Nigeria. The expenditure on road networks between 1962 and 1985 was about $1.6 billion; in 1998 a total of $441 million was committed for investment in the development of road networks according to the Federal Ministry of Works and Housing - FMWH, (*2000*). Despite all these investments in road building, road rehabilitation and expansion programmes, road conditions in Nigeria have remained poor with rapid rate of road surface deterioration. Investment loss due to poor road conditions in 1998 was estimated to be $ 1 billion a year with an additional vehicle operating costs of about (US $625 million) a year (Federal Ministry of Works and Housing (*2000*).

In a study carried out by the Federal Ministry of Works and Housing (*1998*), it was estimated that the requirement of funds for the 51,800-km road network is over 1.7 billion US dollar for periodic/major maintenance and 0.56 billion US dollar for recurrent -maintenance over ten year period (1999-2008) as shown in Table 3.6, Figure 3.1 and Figure 3.2

Table 3.6 Projected Annual Resource Requirements x N000000 (1999-2008) by FMWH

Year	Periodic/Major Maintenance			Routine Maintenance		
	Owner			Owner		
	Federal	State	Local	Federal	State	Local
1999	18,704.67	8,187.73	692.91	3,345.20	2,380.12	435.77
2000	20,334.45	16,486.14	1,472.66	3,179.10	2,323.44	429.28
2001	25,528.99	12,750.07	730.59	3,122.93	2,279.83	428.10
2002	6,883.20	2,779.26	82.40	2,897.81	2,210.20	420.86
2003	14,092.36	5,564.25	60.80	2,905.35	2,251.16	422.86
2004	7,444.00	2,750.94	88.57	2,874.39	2,205.65	421.92
2005	7,295.94	4,070.23	596.70	2,861.28	2,209.25	422.37
2006	4,441.84	3,737.41	229.16	2,861.53	2,208.21	422.85
2007	1,055.99	834.47	78.41	2,879.48	2,235.35	423.68
2008	1,832.50	1,442.72	270.78	2,920.56	2,251.17	435.64
TOTAL	107,614.04	58,603.23	4,302.98	29,847.62	22,554.39	4,263.32

Source: FMWH (September 1998 Report on Road Network Rehabilitation and Maintenance Study)

Urban roads will require about $ 0.4 billion (at $20,000 / kilometre) and rural roads about $0.14 billion (at $2,000 per kilometre). The total requirement of funds is estimated to be US3.5 billion. But in highway design, as in the design of any facility, there are always trade-offs between the initial costs and future costs. Usually, the engineer has either the option of high initial cost and lower maintenance cost, or lower-initial cost and higher maintenance cost. And for the road user, lower future cost would need to be paid for by higher initial costs. But the most important thing is for the potential trade-offs to be balanced as part of any highway design.

In highway design, constraints on the type of maintenance are real problems. The constraints may be as a result of several factors. For instance, future maintenance budgets may be limited, the performance of maintenance agency may be affected by dearth of equipment, materials, or there may be an administrative or political decision to make low maintenance a goal.

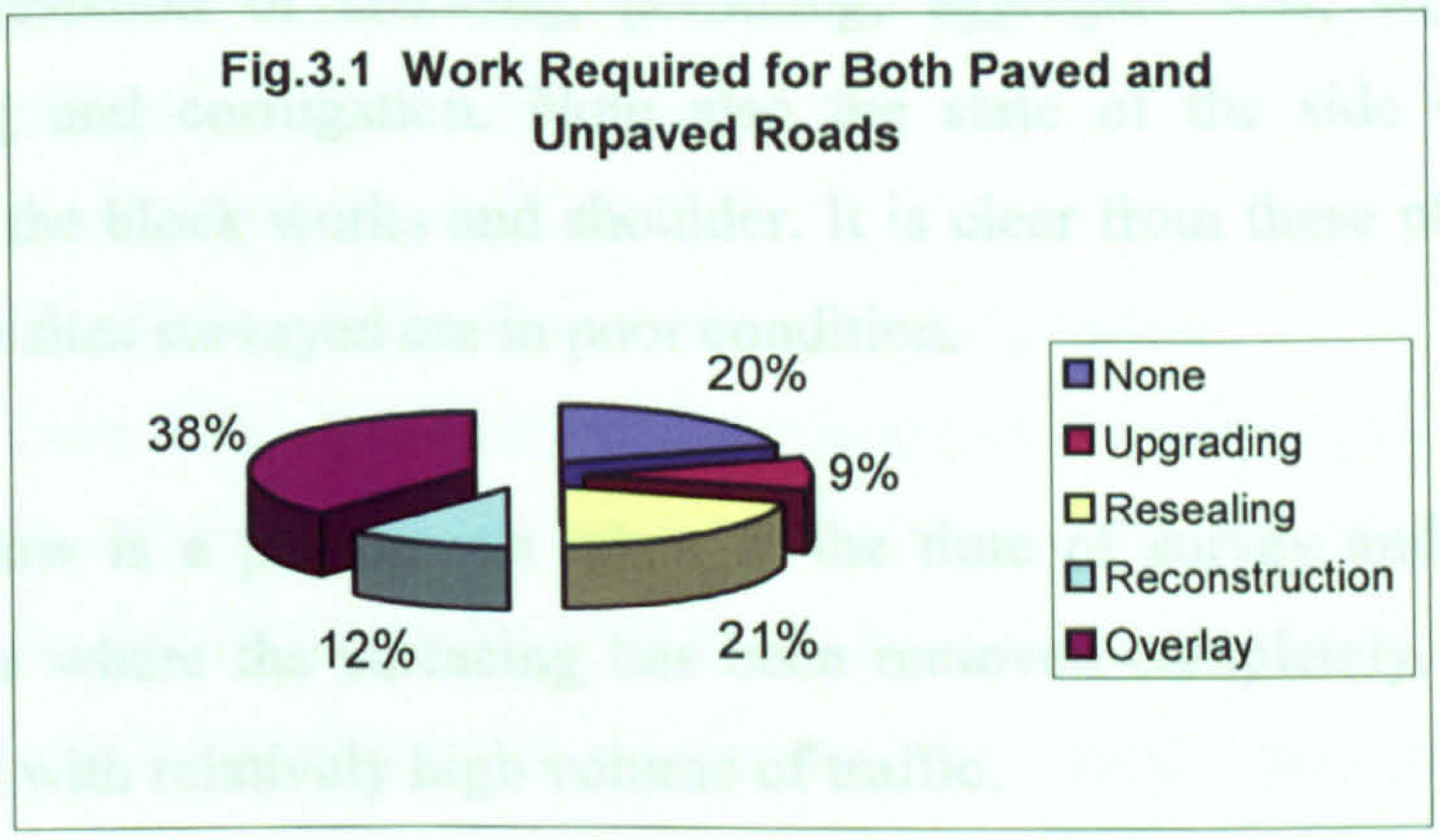


Fig.3.1 Work Required for Both Paved and Unpaved Roads

Source: FMWH (September 1998 Report)

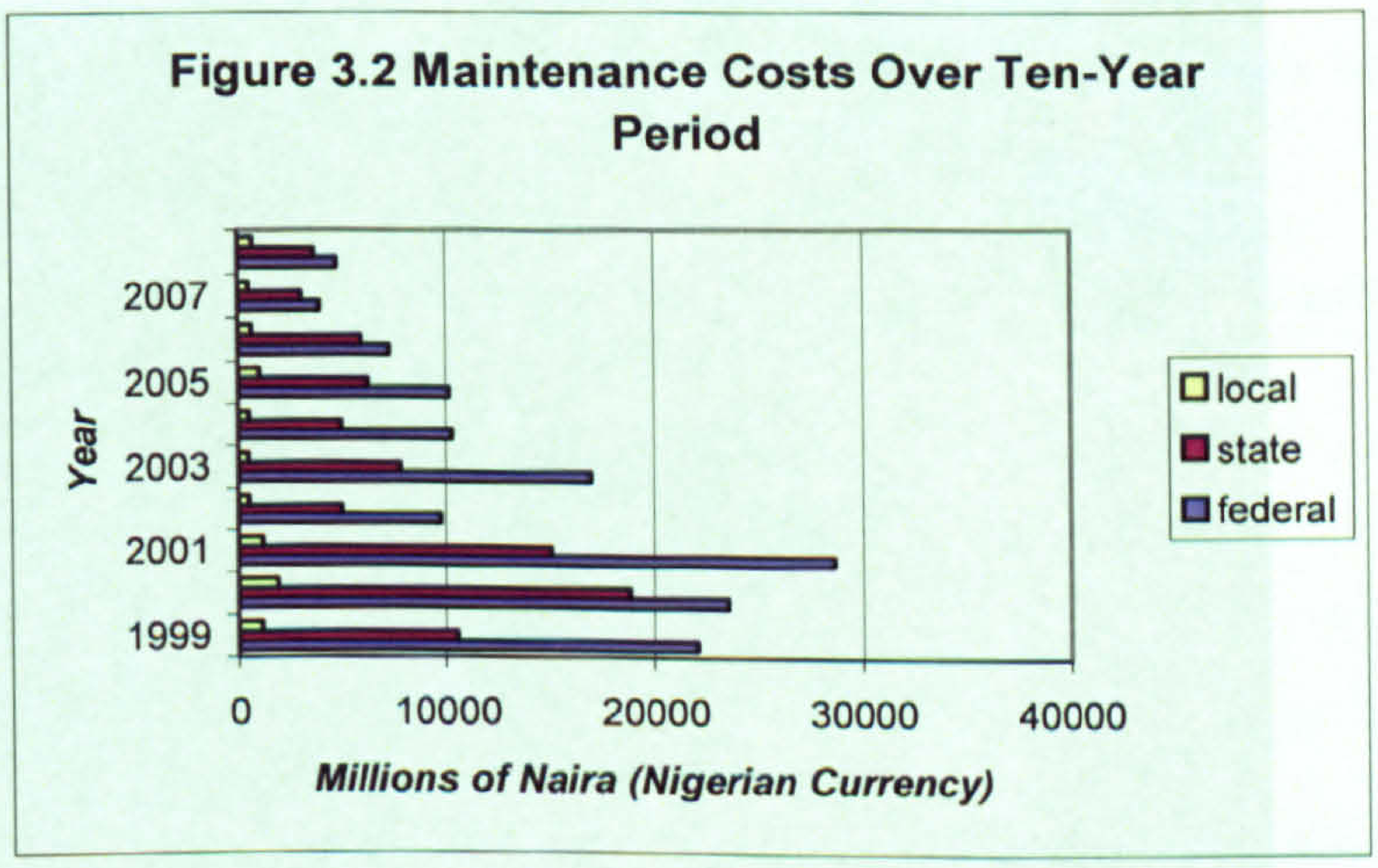


Figure 3.2 Maintenance Costs Over Ten-Year Period

Source: FMWH (September 1998 Report)

Note: $1 = 85 Naira (1998 Prices)

3.4 SURVEY OF ROAD CONDITIONS

At the moment there is a growing disquiet amongst road users with regards to the poor conditions of the roads and it is clear that the governments is finding it even more difficult to cope with increasing demand for road use. In any case, the extent and description of the problem have yet to be established as more meaningful research efforts are required in tackling the root causation of the problems at both the aggregate and decomposed levels. Note the general unevenness of the roads and extreme manifestation of cracking, potholing, aggregate loss, edge subsidence, scaling, rutting and corrugation. Note also the state of the side drains and the unevenness of the block works and shoulder. It is clear from these photographs that the roads at the sites surveyed are in poor condition.

Figure 3.3 below is a photograph taken at the time of survey and it shows road surface distress where the surfacing has been removed completely. This road is a connector road with relatively high volume of traffic.

Figure 3.3 Typical Road Distress.

From the foregoing it is clear that:

1. Government effort seems unstructured and uncoordinated as there are:
   - No optimised data bank or tracking system
   - Possible duplication of efforts
   - Conflicting maintenance management practice;
   - Very little cross-functional development has been taking place;
   - No effective mechanism for decision making (zero database)
   - At the moment it is difficult if not impossible to locate reliable, comprehensive and updated documents on road inspection, maintenance, traffic counts and history, age and construction information and the absence of optimised road database.

2. Government efforts appear minimal in creating an innovative environment, as there are no forum for promoting road maintenance awareness and no defined effective road management system in place.

3 The existing road management system may be focusing inwardly rather than outwardly by:
   - Having no apparent visible measures of performance
   - Having no visible pooling of intelligence data
   - Not using expertise efficiently and sufficiently

Road services had been impressive in the past in Nigeria but the condition of the road at the present time remains generally poor, and it can be argued that the poor condition of roads can be partly attributable to lack of effective road maintenance system. But this has yet to be put to the test, as other factors, like poor design, badly executed contracts, inadequate funding, poor highway and traffic management are also capable of giving rise to dysfunctional road system.

3.5 SUMMARY

Several reform initiatives have been put forward for tackling the problem associated with the road system in Nigeria, including private sector management involvement, the establishment of road camps, Build-Transfer-Operate (BOT) arrangements, Road Vision 2000 and Road Management Initiatives (RMI) by the World Bank. Despite all these initiatives, the condition of the road system in Nigeria remains generally poor.

It is obvious that the financial obligation or burden on the federal government if it has to be solely responsible for the Road Recovery Programme (RRP) is enormous. At the same time it must be pointed out that the governments do not seem to have problem raising the required fund, but why it may be queried has Nigeria a major oil producing country with huge deposit of bitumen and oil output of about 2.4million barrels a day fallen into such a trap. The answer to this can be found in the prevalence of resource management and planning systems in the country that are not properly integrated. However, the extent to which the absence of planned management and planning systems can be called to account for poor state of the Nigerian roads has yet to be established.

According to the Federal Highway Toll Plaza Management Committee, the first tollgate on a federal highway was at the Lagos end of the Ibadan Expressway in 1978. Since then, the numbers of tollgate have increased steadily to 28 by 1996. Before 1996, however, the collection of toll revenue and management of the existing toll gates were the responsibility of the FMWH. But a lot of revenue leakage was discovered in 1996, and this prompted a series of traffic surveys in order to determine the expected earnings from the tollgates. Because of the continuous extremely poor financial performance and unabated revenue leakage at the tollgates, all exiting tollgates were contracted out to private sector operators.

At the moment 25 private operators are charged with the responsibility of collecting tolls and are expected to pay a specific, agreed amount to the Federal Government with the first week of every month. All accruing tollgate revenues were set aside for road maintenance and rehabilitation. Since the take over of the tollgate by the private sector, there has been tremendous improvement in the revenue generated at the tollgate. The relevance of tollgate financing to this study lies in the fact that private sector involvement in the realisation of road management objectives cannot be overlooked.

At the moment road problems have reached a bottleneck in Nigeria making transportation of people and goods almost impossible to operate profitably throughout the country. Road improvements usually lead to lower operating costs for vehicles. But how and when are very difficult to tell in the light of socio-political and economic instability prevalent in the country.

According to Aghion and Howitt (*1998*), sustainable growth derives from growth in productivity and technological progress. But technological progress, which stimulates growth, involves continuous development activities, including training, adaptive, innovative or research and development activities in order to make the application of acquired technology relevant. This involves learning.

4

DATA COLLECTION

In Chapter 1.2 we set out the objectives of this study and in Chapter 1.3 we mentioned that the method of study is empirical based, with observations and sample surveys taken at various locations in Nigeria. Within the purview of the study objectives, the area of pavement distress, vehicle volumes and speeds are important. However, the locations to be investigated must be representative of population for validity of sample survey and also the selected roads must have sections with and without pavement distress. Three types of vehicles were distinguished: private car, light goods vehicles, and heavy goods vehicles.

Chapter four aims to set out the analytical and empirical background for the sites discussed in Chapters Five, and analysed Six, Seven. The estimation of roadway capacity and the computation of critical density for free flow traffic conditions where capacity seldom occurs are central to the study.

It has been hypothesised that, 'pavement distress produces capacity loss and increases travel time loss'. In order to determine the influence of pavement distress on roadway capacity data is needed: i) to establish the extent of pavement distress per survey road length, ii) for vehicle speeds and traffic flows on road section with and without the influence of pavement distress.

To that effect the survey data (see table 4.1 below) and information collected are both qualitative and quantitative. Direct measurements were obtained at 12 selected sites, and supplemented with records from the Ministries of Works, the Nigerian Building and Road Research Institute and the Nigerian Institute of Transport Technology.

TABLE 4.1 EXAMPLE OF A SURVEY SUMMARY SHEET

ROAD NAME **STATE** **DATE**

START TIME FINISH TIME

Carriageway + side-drain

WITHOUT-DISTRESS

SECTION A

AVERAGE SPEED m/sec

SPEED km/h

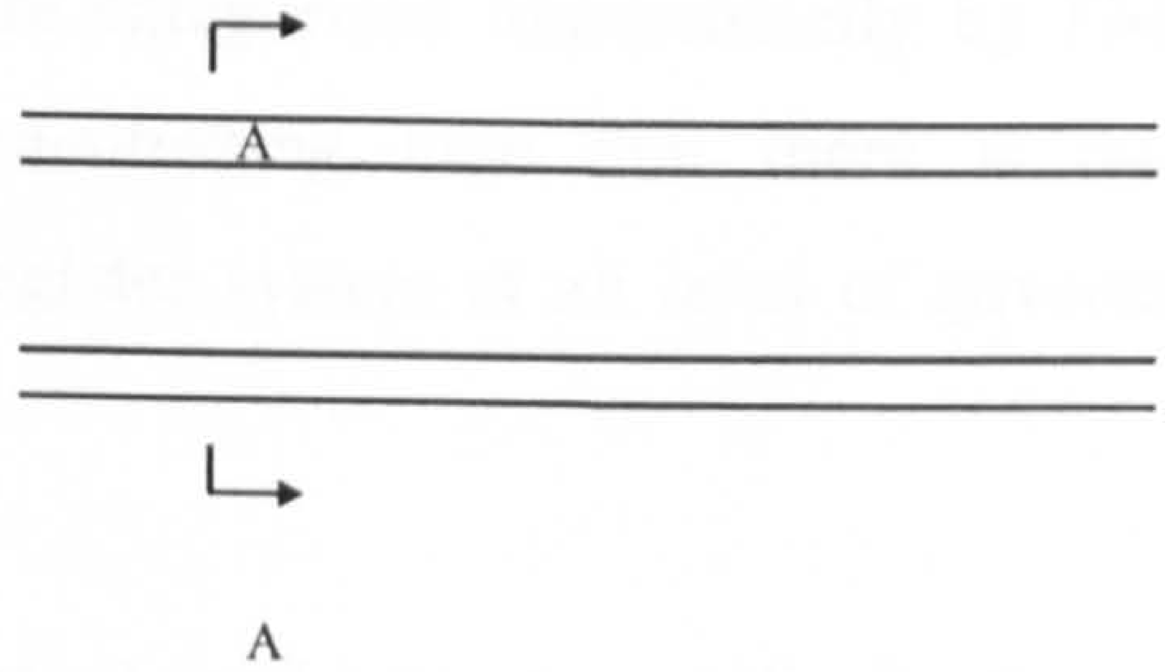
VOLUME VEHS/HR

PASSENGER CARS

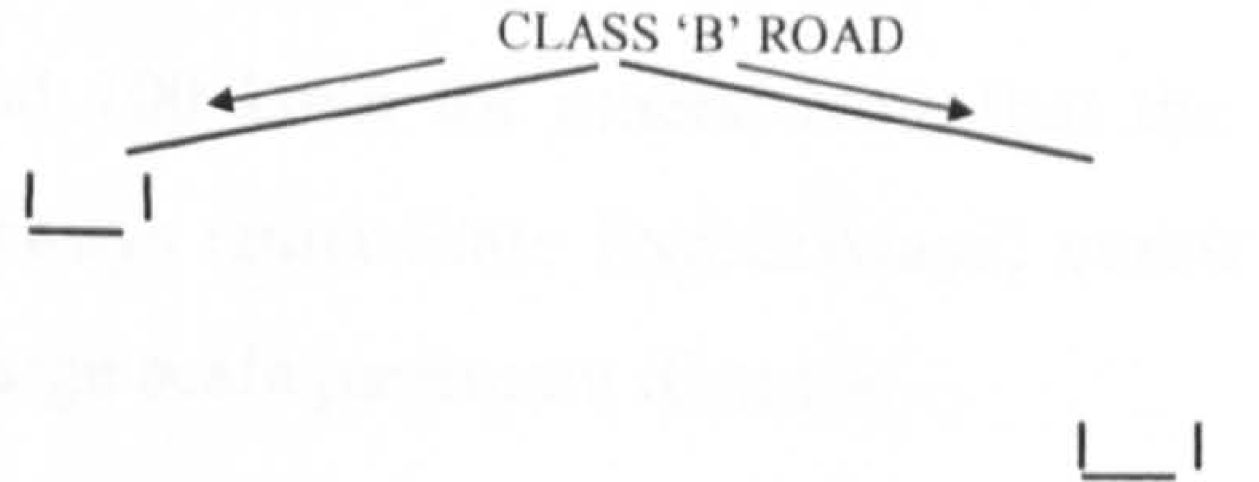
COMMERCIAL VEHICLES

% LIGHT GOODS VEHCILE

% HEAVY GOODS VEHICLE



TYPICAL CARRIAGEWAY WIDTH 7.3 M



SIDE DRAIN SIDE DRAIN

Pavement: Flexible **Terrain:** Normal

DISTRESSED SECTION CHAINAGE (m)

WITH -DISTRESSED
SECTION B

SPEED m/sec

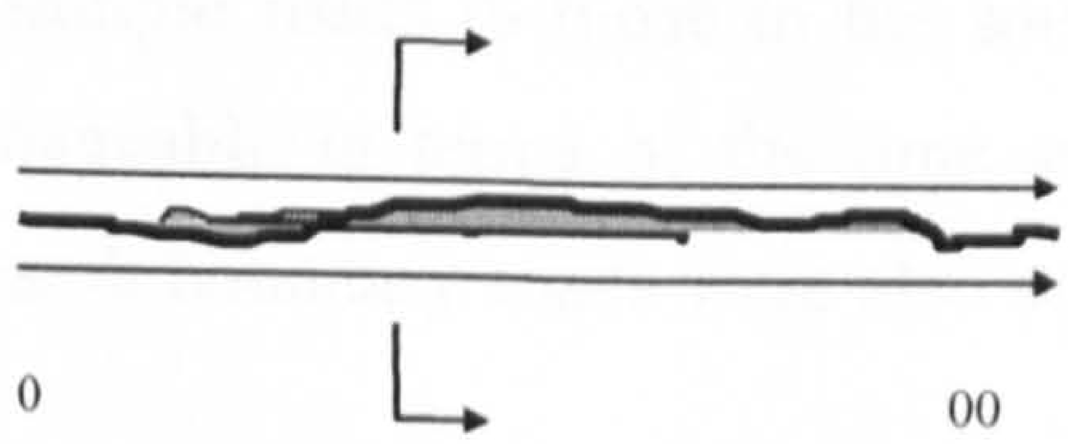
SPEED km/h

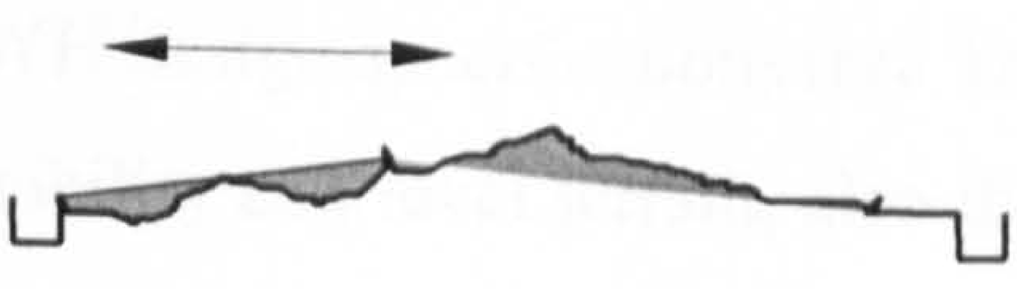
VOLUME VEHS/HR

PASSENGER CARS

COMMERCIAL VEHICLES

% RSD





SECTION A-A

1. POTHOLE S SURFACE: AREA M²
2. POTHOLES SURFACE: MAX. DEPTH M
3. POTHOLES Nos.

COMMENTS

4.1 CRITERIA FOR SITE SELECTION

Generally there are two road systems (rural and urban) in Nigeria. The rural road system includes primary, secondary, feeder and access roads while the urban road system is structured to enhance road safety and basically includes primary, district, local distributors and also access roads. Roads are categorised hierarchically by FMWH as; arterial, collector and access. It worth mentioning here that there is no known comprehensive, updated and reliable road register system at all level of governments at the time of survey.

In any case the study is concerned with the rural road system, specifically the secondary roads because of its function as provider of access to most parts of the country the secondary roads are the focus of this study. The speed limit on two-lane road according to FMWH is 60 km/h for goods vehicle and 100 km/h for others. Note that the primary roads are usually dual carriageway motorways (Inter-State Expressways) constructed to design standards and not too affected by large scale pavement distress.

According to the Federal Ministry of Works and Housing September Report *(1998)* on road assessment for maintenance needs, over 70 per cent of the national road surfaces that are in poor condition are located in the southern region of the country. Since the majority of the roads with distress are located in this region, the research boundary is confined to this area. Circumscribing the sample roads to those in the southern region was also thought to make the survey manageable in terms of the time and resources available to the researcher. Within the research boundary roads were also selected based on the following criteria:

- Road Geometry ≥ class 'B' road FMWH design specifications (see Table 3.6 page 58 for classification details), clear visibility and level terrain, also the absence of traffic signals influence on road link
- Road Link ≥ 500m to allow for survey length > 210m, surface distress length (variable) and transition length = 160m after surface distress. The link should be free both ways of influence from road junction, roundabout, petrol station, broken

down or parked vehicle, police check point and other roadway/traffic conditions that could cast doubt on data collected.

- Road must exhibit visible multiple surface distresses that are capable of impairing traffic movements outside other traffic conditions like on street parking, goods vehicles, traffic signals and also sections that are free from distress and not too far out of range for meaningful speed-flow measurements

On the basis of the criteria set out above the sites shown below in Table 4.2 were selected for sample surveys. Road code and site names are presented and assessed in the subsequent section

Table 4.2 Summary of Selected Sites

No	Code	Name
01	OG011	Aiyetoro Road Abeokuta, OGUN STATE
02	OG012	Oba Simolade Road Shagamu OGUN STATE
03	OY018	Awolowo Avenue (Bodija), Ibadan OYO STATE
04	OY019	Oyo Road (Mokola) Ibadan OYO STATE
05	OG010	Lantoro Road Abeokuta, OGUN STATE
06	EK009	Ajilosun Street, Ado-Ekiti EKITI STATE
07	ED008	Upper Siluko Road Benin EDO STATE
08	ED007	Upper Sakponba Road Benin EDO STATE
09	ED006	Ogida Road Benin EDO STATE
10	DL005	Warri / Sapele Road Warri, DELTA STATE
11	DL004	Refinery Road (16) Warri DELTA STATE
12	AN001	Enugu / Onitsha Road Onitsha ANAMBRA STATE

Source: Survey Data

4.2 ASSESSMENT OF SELECTED SITES

The surveyed sites are single-carriageway lanes type 'B'. All road links were coded for convenience referencing in alphabetical orders. The data for each day were screened for bad weather, incidents, equipment malfunctioning or usual traffic operation and general recording errors. Study crew would not normally check their own-recorded data at the close operation. In order to accomplish the objectives this study as set out in chapter1 the scope of works carried out is summarised as follows:

- Obtaining and using, after updating as required appropriate data available in the 1998 federal trunk road safety study report, 1998 Federal ministry of Works and Housing report and other relevant road data.
- Locating and identifying secondary road links with ADT > 500 vehicles per hour, sectioning road length into three parts:
- Estimating running speed and traffic volumes for sectioned lengths.

On the basis of that only periods (0600-1900 hrs) with relatively high volume of traffic (>500 per hour) and free flowing at speed (>65km/h) were used.

4.2.1 Site OG011 - Aiyetoro Road Abeokuta, OGUN STATE - Aiyetoro Road is a single 6.5m carriageway with 1.0m shoulder, class 'B' paved road (≥ class B required) with 1,000 – 5000 annual daily traffic. Design life for the road pavement is 15 years with a design speed of 85 km/h (≥ 65km/h required) on level terrain.

The road link has a 238m section -A (upstream) without pavement distress which is greater than 210m (see Figure 4.1) and a section B (downstream) with pavement distress length of 27.7m.

DTp road note advice 20/84 (1997) suggested that for validity carriageway lane must not be less that 2.5m, therefore potholes, ravelling, and edge damages with transverse widths greater than 500mm (0.5m) on a 6.1m carriageway (allowing 100mm for road markings)

Therefore, the OG011 road section with 14 nos. potholes, each with an open cavity in road surface with at least 150mm diameter and at 25mm depth and affected area of $108.5m^2$ would have violated carriageway lane width tolerance level.

For the purpose high volume of traffic (>500 per hour) and free flowing at speed (>65km/h) survey must be conducted during the day between 0800 and 0900hrs and in the evening between 1700hrs and 1900 hrs. The period with greater of the volume should be used.

4.2.2 Site OG012 - Oba Simolade Road Shagamu OGUN STATE - Oba Simolade Road is a single 6.5m carriageway with 1.0m shoulder, class 'B' paved road (≥ class B required) with 1,000 – 5000 annual daily traffic. Design life for the road pavement is 15 years with a design speed of 85 km/h (≥ 65km/h required) on level terrain.

The road link has a 246m section -A (upstream) without pavement distress which is greater than 210m (see Figure 4.1) and a section B (downstream) with pavement distress length of 35.2m.

DTp road note advice 20/84 (1997) suggested that for validity carriageway lane must not be less that 2.5m, therefore potholes, ravelling, and edge damages with transverse widths greater than 500mm (0.5m) on a 6.1m carriageway (allowing 100mm for road markings)

Therefore, the OG012 road section with 10 nos. potholes, each with an open cavity in road surface with at least 150mm diameter and at 25mm depth and affected area of $128.5m^2$ would have violated carriageway lane width tolerance level.

For the purpose high volume of traffic (>500 per hour) and free flowing at speed (>65km/h) survey must be conducted during the day between 0700 and 0900hrs and in the evening between 1600hrs and 1900 hrs. The period with greater of the volume should be used.

4.2.3 Site OY018 - Awolowo Avenue (Bodija), Ibadan OYO STATE - Awolowo Avenue Road is a single 6.5m carriageway with 1.0m shoulder, class 'B' paved road (≥ class B required) with 1,000 – 5000 annual daily traffic. Design life for the road pavement is 15 years with a design speed of 85 km/h (≥ 65km/h required) on level terrain.

The road link has a 238m section -A (upstream) without pavement distress which is greater than 210m (see Figure 4.1) and a section B (downstream) with pavement distress length of 27.3m.

DTp road note advice 20/84 (1997) suggested that for validity carriageway lane must not be less that 2.5m, therefore potholes, ravelling, and edge damages with transverse widths greater than 500mm (0.5m) on a 6.1m carriageway (allowing 100mm for road markings)

Therefore, the OY018 road section with 16 nos. potholes, each with an open cavity in road surface with at least 150mm diameter and at 25mm depth and affected area of 99.5m^2 would have violated carriageway lane width tolerance level.

For the purpose high volume of traffic (>500 per hour) and free flowing at speed (>65km/h) survey must be conducted during the day between 0700 and 0900hrs and in the evening between 1600hrs and 1900 hrs. The period with greater of the volume should be used.

4.2.4 Site OY019 - Oyo Road (Mokola) Ibadan OYO STATE - Oyo Road (Mokola) Road is a single 6.5m carriageway with 1.0m shoulder, class 'B' paved road (≥ class B required) with 1,000 – 5000 annual daily traffic. Design life for the road pavement is 15 years with a design speed of 85 km/h (≥ 65km/h required) on level terrain.

The road link has a 265m section -A (upstream) without pavement distress which is greater than 210m (see Figure 4.1) and a section B (downstream) with pavement distress length of 54.4m.

DTp road note advice 20/84 (1997) suggested that for validity carriageway lane must not be less that 2.5m, therefore potholes, ravelling, and edge damages with transverse widths greater than 500mm (0.5m) on a 6.1m carriageway (allowing 100mm for road markings)

Therefore, the OY019 road section with 13 nos. potholes, each with an open cavity in road surface with at least 150mm diameter and at 25mm depth and affected area of 198.5m^2 would have violated carriageway lane width tolerance level.

For the purpose high volume of traffic (>500 per hour) and free flowing at speed (>65km/h) survey must be conducted during the day between 0700 and 0900hrs and in the evening between 1600hrs and 1900 hrs. The period with greater of the volume should be used.

4.2.5 Site OG010 - Lantoro Road Abeokuta, OGUN STATE - R Lantoro oad is a single 6.5m carriageway with 1.0m shoulder, class 'B' paved road (≥ class B required) with 1,000 – 5000 annual daily traffic. Design life for the road pavement is 15 years with a design speed of 85 km/h (≥ 65km/h required) on level terrain.

The road link has a 257m section -A (upstream) without pavement distress which is greater than 210m (see Figure 4.1) and a section B (downstream) with pavement distress length of 46.4m.

DTp road note advice 20/84 (1997) suggested that for validity carriageway lane must not be less that 2.5m, therefore potholes, ravelling, and edge damages with transverse widths greater than 500mm (0.5m) on a 6.1m carriageway (allowing 100mm for road markings)

Therefore, the OG010 road section with 12 nos. potholes, each with an open cavity in road surface with at least 150mm diameter and at 25mm depth and affected area of 169.3m^2 would have violated carriageway lane width tolerance level.

For the purpose high volume of traffic (>500 per hour) and free flowing at speed (>65km/h) survey must be conducted during the day between 0700 and 0900hrs and in the evening between 1600hrs and 1900 hrs. The period with greater of the volume should be used.

4.2.6 Site EK009 - Ajilosun Street, Ado-Ekiti EKITI STATE - Ajilosun Street, is a single 6.5m carriageway with 1.0m shoulder, class 'B' paved road (≥ class B required) with 1,000 – 5000 annual daily traffic. Design life for the road pavement is 15 years with a design speed of 85 km/h (≥ 65km/h required) on level terrain.

The road link has a 275m section -A (upstream) without pavement distress which is greater than 210m (see Figure 4.1) and a section B (downstream) with pavement distress length of 64.4m.

DTp road note advice 20/84 (1997) suggested that for validity carriageway lane must not be less that 2.5m, therefore potholes, ravelling, and edge damages with transverse widths greater than 500mm (0.5m) on a 6.1m carriageway (allowing 100mm for road markings)

Therefore, the EK009 road section with 15 nos. potholes, each with an open cavity in road surface with at least 150mm diameter and at 25mm depth and affected area of 235.1m^2 would have violated carriageway lane width tolerance level.

For the purpose high volume of traffic (>500 per hour) and free flowing at speed (>65km/h) survey must be conducted during the day between 0800 and 0900hrs and in the evening between 1700hrs and 1900 hrs. The period with greater of the volume should be used.

4.2.7 Site ED008- Upper Siluko Road Benin EDO STATE. - Upper Siluko Road is a single 6.5m carriageway with 1.0m shoulder, class 'B' paved road (≥ class B required) with 1,000 – 5000 annual daily traffic. Design life for the road pavement is 15 years with a design speed of 85 km/h (≥ 65km/h required) on level terrain.

The road link has a 250m section -A (upstream) without pavement distress which is greater than 210m (see Figure 4.1) and a section B (downstream) with pavement distress length of 40m.

DTp road note advice 20/84 (1997) suggested that for validity carriageway lane must not be less that 2.5m, therefore potholes, ravelling, and edge damages with transverse widths greater than 500mm (0.5m) on a 6.1m carriageway (allowing 100mm for road markings)

Therefore, the ED008 road section with 17 nos. potholes, each with an open cavity in road surface with at least 150mm diameter and at 25mm depth and affected area of 148.2m^2 would have violated carriageway lane width tolerance level.

For the purpose high volume of traffic (>500 per hour) and free flowing at speed (>65km/h) survey must be conducted during the day between 0700 and 0900hrs and in the evening between 1600hrs and 1900 hrs. The period with greater of the volume should be used.

4.2.8 Site ED007- Upper Sakponba Road Benin EDO STATE - Aiyetoro Road is a single 6.5m carriageway with 1.0m shoulder, class 'B' paved road (≥ class B required) with 1,000 – 5000 annual daily traffic. Design life for the road pavement is 15 years with a design speed of 85 km/h (≥ 65km/h required) on level terrain.

The road link has a 246m section -A (upstream) without pavement distress which is greater than 210m (see Figure 4.1) and a section B (downstream) with pavement distress length of 53.4m.

DTp road note advice 20/84 (1997) suggested that for validity carriageway lane must not be less that 2.5m, therefore potholes, ravelling, and edge damages with transverse widths greater than 500mm (0.5m) on a 6.1m carriageway (allowing 100mm for road markings)

Therefore, the ED007 road section with 11 nos. potholes, each with an open cavity in road surface with at least 150mm diameter and at 25mm depth and affected area of 194.9m^2 would have violated carriageway lane width tolerance level.

For the purpose high volume of traffic (>500 per hour) and free flowing at speed (>65km/h) survey must be conducted during the day between 0800 and 0900hrs and in the evening between 1700hrs and 1900 hrs. The period with greater of the volume should be used.

4.2.9 Site ED006 - Ogida Road Benin EDO STATE - Ogida Road is a single 6.5m carriageway with 1.0m shoulder, class 'B' paved road (≥ class B required) with 1,000 – 5000 annual daily traffic. Design life for the road pavement is 15 years with a design speed of 85 km/h (≥ 65km/h required) on level terrain.

The road link has a 282m section -A (upstream) without pavement distress which is greater than 210m (see Figure 4.1) and a section B (downstream) with pavement distress length of 71.9m.

DTp road note advice 20/84 (1997) suggested that for validity carriageway lane must not be less that 2.5m, therefore potholes, ravelling, and edge damages with transverse widths greater than 500mm (0.5m) on a 6.1m carriageway (allowing 100mm for road markings)

Therefore, the ED006 road section with 9 nos. potholes, each with an open cavity in road surface with at least 150mm diameter and at 25mm depth and affected area of 262.4m^2 would have violated carriageway lane width tolerance level.

For the purpose high volume of traffic (>500 per hour) and free flowing at speed (>65km/h) survey must be conducted during the day between 0800 and 0900hrs and in the evening between 1700hrs and 1900 hrs. The period with greater of the volume should be used.

4.2.10 Site DL005 - Warri / Sapele Road Warri, DELTA STATE – Warri / Sapele Road is a single 6.5m carriageway with 1.0m shoulder, class 'B' paved road (≥ class B required) with 1,000 – 5000 annual daily traffic. Design life for the road pavement is 15 years with a design speed of 85 km/h (≥ 65km/h required) on level terrain.

The road link has a 259m section -A (upstream) without pavement distress which is greater than 210m (see Figure 4.1) and a section B (downstream) with pavement distress length of 48.4m.

DTp road note advice 20/84 (1997) suggested that for validity carriageway lane must not be less that 2.5m, therefore potholes, ravelling, and edge damages with transverse widths greater than 500mm (0.5m) on a 6.1m carriageway (allowing 100mm for road markings)

Therefore, the DL005 road section with 7 nos. potholes, each with an open cavity in road surface with at least 150mm diameter and at 25mm depth and affected area of 178.2m^2 would have violated carriageway lane width tolerance level.

For the purpose high volume of traffic (>500 per hour) and free flowing at speed (>65km/h) survey must be conducted during the day between 0800 and 0900hrs and in the evening between 1700hrs and 1900 hrs. The period with greater of the volume should be used.

4.2.11 Site DL004 – Refinery Road Warri DELTA STATE Refinery Road is a single 6.5m carriageway with 1.0m shoulder, class 'B' paved road (≥ class B required) with 1,000 – 5000 annual daily traffic. Design life for the road pavement is 15 years with a design speed of 85 km/h (≥ 65km/h required) on level terrain.

The road link has a 255m section -A (upstream) without pavement distress which is greater than 210m (see Figure 4.1) and a section B (downstream) with pavement distress length of 48.4m.

DTp road note advice 20/84 (1997) suggested that for validity carriageway lane must not be less that 2.5m, therefore potholes, ravelling, and edge damages with transverse widths greater than 500mm (0.5m) on a 6.1m carriageway (allowing 100mm for road markings)

Therefore, the DL004 road section with 13 nos. potholes, each with an open cavity in road surface with at least 150mm diameter and at 25mm depth and affected area of 162.3m^2 would have violated carriageway lane width tolerance level.

For the purpose high volume of traffic (>500 per hour) and free flowing at speed (>65km/h) survey must be conducted during the day between 0700 and 0900hrs and in the evening between 1600hrs and 1900 hrs. The period with greater of the volume should be used.

4.2.12 Site AN001- Enugu / Onitsha Road Onitsha ANAMBRA STATE - Aiyetoro Road is a single 6.5m carriageway with 1.0m shoulder, class 'B' paved road (≥ class B required) with 1,000 – 5000 annual daily traffic. Design life for the road pavement is 15 years with a design speed of 85 km/h (≥ 65km/h required) on level terrain.

The road link has a 297m section -A (upstream) without pavement distress which is greater than 210m (see Figure 4.1) and a section B (downstream) with pavement distress length of 86.3m.

DTp road note advice 20/84 (1997) suggested that for validity carriageway lane must not be less that 2.5m, therefore potholes, ravelling, and edge damages with transverse widths greater than 500mm (0.5m) on a 6.1m carriageway (allowing 100mm for road markings)

Therefore, the AN001 road section with 15 nos. potholes, each with an open cavity in road surface with at least 150mm diameter and at 25mm depth and affected area of 315.1m^2 would have violated carriageway lane width tolerance level.

For the purpose high volume of traffic (>500 per hour) and free flowing at speed (>65km/h) survey must be conducted during the day between 0700 and 0900hrs and in the evening between 1600hrs and 1900 hrs. The period with greater of the volume should be used.

4.3 THE SURVEY METHODS

4.3.1 Road Coding - The classification of roads applied in this study is based on FMWH road coding system. The range of roadways to be included in the sample was limited only to those meeting certain criteria that include straight link with and without pavement distress sections, two- lane motorway and others that have been mentioned earlier. The method adopted to assign the road code is explained as illustrated.

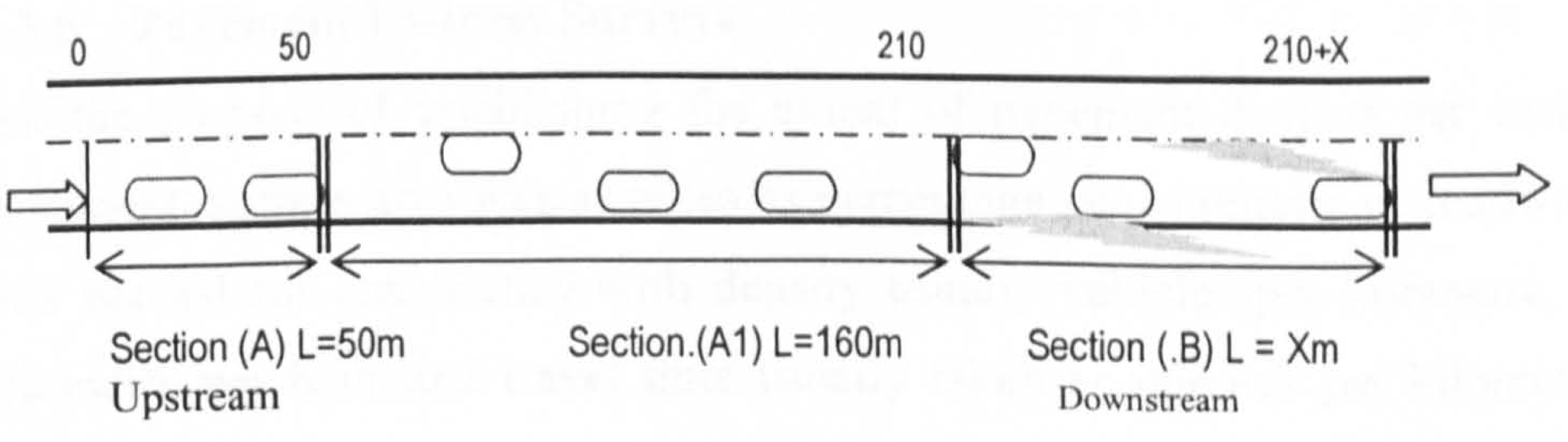
For example AN001 indicates a road in Anambra State (AN) and is owned by the Federal Government (code 0) that is first in serial number (01). In addition to existing available information from reports and other documentation, the Ministry of Works and Housing made available a list of requested roads and their classifications.

4.3.2 The Survey Team and Equipments - The team was made up of a team leader, and eight men (two men per section (one each for speed and vehicle count, a video recorder man and a multi-purpose man). Team members were trained in equipment handling, public relations, and data recording. Tally sheets; work sheets; a packet of pen (red, blue, and black); tape measure and markers; 10 pieces of stopwatch; 10 pairs of walking-talkie; 2 numbers of video camera; 12 road cones; and a survey bus.

4.3.3 The Set Up of Typical Survey Site - The first step was to identify those roads that carry traffic of at least 500 vehicles per hour and prepare an inventory. After identifying the road, link codes were assigned to the roads based on the initials of the states to help locate the road in the road system. The set up is illustrated below in figure 4.1 Study sites were divided into three sections with section **A** as the upstream end and section **B** the downstream end, while section **A1** was the transition part allowing for possible congestion flow upstream of the distressed section. Section A1 was set at 160m from the baseline of section A and B as recommended by the Highway Manual Special Report 209 (*1992*).

The upstream end is the section without Distress while the down stream end is the section with Distress. Two average capacity (Q) values for sections A and B were estimated. These values are then compared. Data on the peak and off peak periods collected at the initial stage were used to establish the observation time period in order to eliminate the effect of peak period on capacity because the primary focus is an uninterrupted flow on the road link. Data relating to rainfall were used to exclude rainy periods. Thus the influence of rain on capacity was eliminated and surveys were conducted during daylight to eliminate the effect of darkness.

Figure 4.1 Set up of Typical Survey Site



4.3.4 Traffic Volume Surveys

Traffic volume is defined as the total number of vehicles passing a point on a lane during a specified interval time and flow is the equivalent hourly rate at which vehicles pass over a given section of a lane during a given interval less than one hour. Strictly speaking volume is in vehicles per time period per carriageway, while flow usually but not always take into account the influence of different types of vehicles and is expressed in passenger car units (pcu). Any factors seriously affecting the flow of the vehicles in any period, for example like, roadwork, accidents, and bad weather were be recorded on the sheet relating to the period.

4.3.5 Vehicle Speed Surveys

The observers located at strategic positions along the designated route collected data relating to vehicle running speeds were by way of timing vehicle in motion over a defined length (50m and 160m). Running speed manual measurements were supplemented with automatic digital video camera. Video cameras were positioned at stations for the duration of the survey to provide added information on volume and composition of traffic. It can be mentioned in passing that there was a sharp difference in the attitude of heavy goods vehicle drivers on road section with surfacing distress. HGV motorists pay very little attention to pavement distress as observed at surveyed sites. It may be argued that because of change in drivers attitude relative to pavement distress, and to some extent the need by heavy goods vehicle (HGV) operators to make profit, a description that depict passenger car equivalency value for HGV as substantially higher than one unit on distressed level terrain is somehow distorted.

4.3.6 Pavement Distress Surveys

For the purpose of establishing the extent of pavement distress per carriageway lane, pavement distress area was as taken as percentage per kilometre of roadway length. This was needed for consistency with density usually vehicles per kilometre, speed usually kilometre per hour and travel time usually taken as minutes per kilometre. Pavement Distress Measurements are usually taken as percentage of affected area relative to road section with particular attention on sizes, numbers and depth. *DTp* road note advice 20/84 (*1997*) suggested that for validity carriageway lane must not be less that 2.5m, therefore potholes, ravelling, and edge damages with transverse widths greater than 500mm on a 6.1m carriageway (allowing 100mm for road markings) would have violated lane width tolerance level. Specifically, pothole was defined in HDM111 as open cavity in road surface with at least 150mm diameter and at 25mm depth.

4.4 ASSESSMENT OF SAMPLE DATA AND ANALYTICAL METHODS

Data and analytical technique to be used in the study were assessed by way of preliminary studies. The main purposes of the preliminary studies are to assess the analytical technique to be used later on in Chapter 7 and also test the usefulness of data against the chosen estimation method. It was intended as both equipment and procedural method familiarisation exercise for the study crew.

Also, it served as an early warning for possible equipment and procedural method setbacks that might affect the real survey and capacity loss analysis model. The empirical results from the preliminary studies offered the study an opportunity to test the capacity loss model for reliability. Application of the roadway capacity loss model is illustrated below and the experienced gained at these preliminary investigations proved invaluable when the sample surveys at the 12 selected sites were conducted.

4.4.1 Assessment of Sample Data - Pavement distress, vehicle volume and speeds surveys were conducted for one week (17-21) in April 2000 at selected site - DL002. Note that the selected site is not part of the surveyed sites in the study. Vehicle volume and speeds observations were aggregated into 5-min, 15-min and 60-min intervals over one hour duration in order to investigate the effect on computed flows of time intervals. As show below in Table 4.3

Table 4.3 Flow Profile

Count Period	Vehicles	Volume 5 min	Flow 15min	Flow 60min
Col 1	Col 2	Col 3	Col 4	Col 4
0800	52	52		52
0805	58	58		58
0810	60	60	170	60
0815	53	53		53
0820	44	44		44
0825	56	56	153	56
0830	55	55		55
0835	40	40		40
0840	45	45	140	45
0845	52	52		52
0850	38	38		38
0855	40	40	130	40
vph		60 x 12 = 720	170 x 4 = 680	593

Note that '*vph*' denotes vehicles per hour and that conversion to pcu units has not been used at this stage since it is mere a demonstration of time intervals.

When applying 5-min interval, the maximum number of vehicles per period is multiplied by 12. Where 12 = 60/5, the maximum flow = 720 vehicles per hour. When applying 15-min interval the maximum number of vehicles per period is multiply by 4. Where 4 = 60/15, the maximum flow = 680 vehicles per hour. When applying 60-min interval the maximum number of vehicles per period = the total number of vehicles per period, therefore the maximum flow = 593 vehicles per hour

From the illustrations above, the highest figure of maximum flow is attainable from 5min interval; hence the five-minute interval was used in this study.

Table 4.4 ROAD CODE DL002 –Esisi Road Warri, DELTA State

DATE: 16 April 2000		Road code: DL002				Carriageway lane width: Lane (W) 3.65m								Depth 40cm		
						PD: Length 55m:				PD Area 145.8m²				% PD 4%		
														%CV 46.6		
Period 5 MIN Interval	Time	ROAD SECTION A (without PD)							ROAD SECTION B (with PD)							
		(VOLUME VEHICLES)				AVERAGE SPEED KM/H			(VOLUME VEHICLES)				AVERAGE SPEED KM/H			
XX		PC	LGV	HGV	Total	PC	LGH	HGV	PC	LGH	HGV	TOTAL	PC	LGH	HGV	
01	0800	19	20	01	40	95	60	50	14	15	01	30	35	35	35	
02	0805	18	19	01	38	85	60	50	13	14	01	28	35	35	35	
03	0810	17	20	01	38	90	62	50	18	19	01	38	35	35	35	
04	0815	28	28	02	58	85	55	50	23	24	02	48	32	32	32	
05	0820	25	26	02	53	86	55	50	16	16	02	33	32	32	32	
06	0825	35	15	01	35	78	60	50	23	23	01	47	32	32	32	
07	0830	36	20	01	49	88	60	50	18	18	01	37	33	33	33	
08	0835	25	24	02	53	92	60	45	25	25	02	52	35	35	35	
09	0840	32	27	01	66	85	60	45	22	23	01	46	35	35	35	
10	0845	28	09	01	38	80	60	45	18	19	01	38	35	35	35	
11	0850	29	15	01	45	83	60	45	22	23	01	46	35	35	35	
12	0855	24	25	00	49	91	55	45	17	20	00	37	35	35	35	
Duration = 1hr		300	248	14	562				230	235	14	480				

Source: Survey Data **Note:** PD is pavement Distress

The sample surveys for Road DL002 are shown above in Table 4.4. Esisi Road is a single 6.5m carriageway with 1.0m shoulder, class 'B' paved road (≥ class B required) with 1,000 – 5000 annual daily traffic. Design life for the road pavement is 15 years with a design speed of 85 km/h (≥ 65km/h required) on level terrain. The road link has a 265m section (upstream) without pavement distress which is greater than 210m (see Figure 4.1) and a section (downstream) with pavement distress length of 55m. DTp road note advice 20/84 (1997) suggested that for validity carriageway lane must not be less that 2.5m, therefore potholes, ravelling, and edge damages with transverse widths greater than 500mm (0.5m) on a 6.1m carriageway (allowing 100mm for road markings), therefore the OG011 road section with 145.8m^2 pavement distress area, would have violated carriageway lane width tolerance level.

4.4.2 Assessment of Analytical Methods –We assume that speed; flow and density relationships for the section A and B would be the same if it were not for the pavement distress. However, the pavement distresses on section B affect speed (v), flow (q) and density (k) relationship for section B. The roadway capacity models used here were adapted from studies in recent literature (Van Arem *et al (1994),* Minderhoud *et* al *(1998*), and Akcelik *(1991)* of the form:

$$q = -\beta_o + \beta_1 k - \beta_2 k^2 \quad \text{Equation 4.1}$$

Step 1 – Compute Flows, Speeds and Densities for Road Sections - In the empirical results shown in table 4.4 volumes of vehicles were converted into pcu units in order to harmonise the traffic flows by plugging in the pcu values (PC = 1, LGV = 1.5 and HGV = 2 pcu). The Nigerian PCU values are used in the preliminary analysis bearing in mind the effect of pavement distress on roadway capacity. The PCUs are the only available values and there are no sufficient data to test the accuracy of the values at this stage.

Table 4.4 also shows total volume difference of 82 vehicles, this large difference could have occurred from human counting or timing error. Since our estimate is based only on a sample of the population of vehicle volume it would be appropriate to be more guarded in our estimation by adding an 'error term' or interval estimate as shown in table 4.5b. 95% confidence level was chosen and the formula for the error term is 1.96std. /√n where std. is the standard deviation and n is 12 time intervals. Since this is a preliminary analysis the Nigerian pcu values are used; volumes were converted to flow per time interval by way of a multiplier (x12) and densities were calculated using the fundamental speed, flow and density relations: $q = uk$ as shown in Tables 4.5a and 4.6a as shown below, and Tables 4.5b and 4.6b contain the computation of the 95% confidence interval estimations.

Table 4.5a Estimated Flows, Speeds, and Density at Road DL002 – Section A

	1	2	3	4	5	6	7	8
Period	PC	LGV	HGV	Volume	Volume	Flow	Speed	Density
5 min	Pcu	Pcu	Pcu	Veh	Pcu/period	Pcu/hr	Km/hr	Veh/km
1st	19	30.0	02	40	51.0	612	95	6.44
2nd	18	28.5	02	38	48.5	582	85	6.85
3rd	17	30.0	02	38	49.0	588	90	6.53
4th	28	42.0	04	58	74.0	888	85	10.45
5th	25	39.0	04	53	68.0	816	86	9.49
6th	35	22.5	02	35	59.5	714	78	9.15
7th	36	30.0	02	49	68.0	816	88	9.27
8th	25	36.0	04	53	65.0	780	92	8.48
9th	32	40.5	02	66	74.5	894	85	10.52
10th	28	13.5	02	38	43.5	522	80	6.53
11th	29	22.5	02	45	53.5	642	83	7.73
12th	24	37.5	00	49	61.5	738	91	8.11
Duration -1hr						(716± 71)	(87± 3)	

Note: conversion factor from volume to pcu: PC =1, LGV = 1.5 and HGV = 2.0

Flow per period = column 5 x 12; Density per period = col. 6 / col. 7

Table 4.5b Section A Test Statistics

612	374544	95	9025
582	338724	85	7225
588	345744	90	8100
888	788544	85	7225
816	665856	86	7396
714	509796	78	6084
816	665856	88	7744
780	608400	92	8464
894	799236	85	7225
522	272484	80	6400
642	412164	83	6889
738	544644	91	8281
8592	6325992	1038	90058
Mean =	716	Mean =	87
	6151872		89787
	15829.091		24.636364
Std.=	125.81	Std.=	4.96
Error	71.19	Error	2.81
Section A	Flow	Section A	Speed

Table 4.6a Estimated Flows, Speeds, and Density at Road DL002 – Section B								
	1	2	3	4	5	6	7	8
Period	PC	LGV	HGV	Volume	Volume	Flow	Speed	Density
5 min	Pcu	Pcu	Pcu	Veh	Pcu/period	Pcu/hr	Km/hr	Veh/km
1st	14	22.5	02	30	38.5	462	35	13.20
2nd	13	21.0	02	28	36.0	432	35	12.34
3rd	18	28.5	02	38	48.5	582	35	16.63
4th	23	36.0	04	48	63.0	758	32	23.63
5th	16	24.0	04	33	44.0	528	32	16.50
6th	23	34.5	02	47	59.5	714	32	22.31
7th	18	27.0	02	37	47.0	564	32	17.63
8th	25	37.5	04	52	66.5	798	32	24.94
9th	22	34.5	02	46	58.5	702	33	21.27
10th	18	28.5	02	38	48.5	582	35	16.63
11th	22	34.5	02	46	58.5	702	35	20.06
12th	17	30.0	00	37	47.0	564	35	16.11
Duration -1hr						(616± 66)	(34± 1)	

Note: conversion factor from volume to pcu: PC =1, LGV = 1.5 and HGV = 2.0

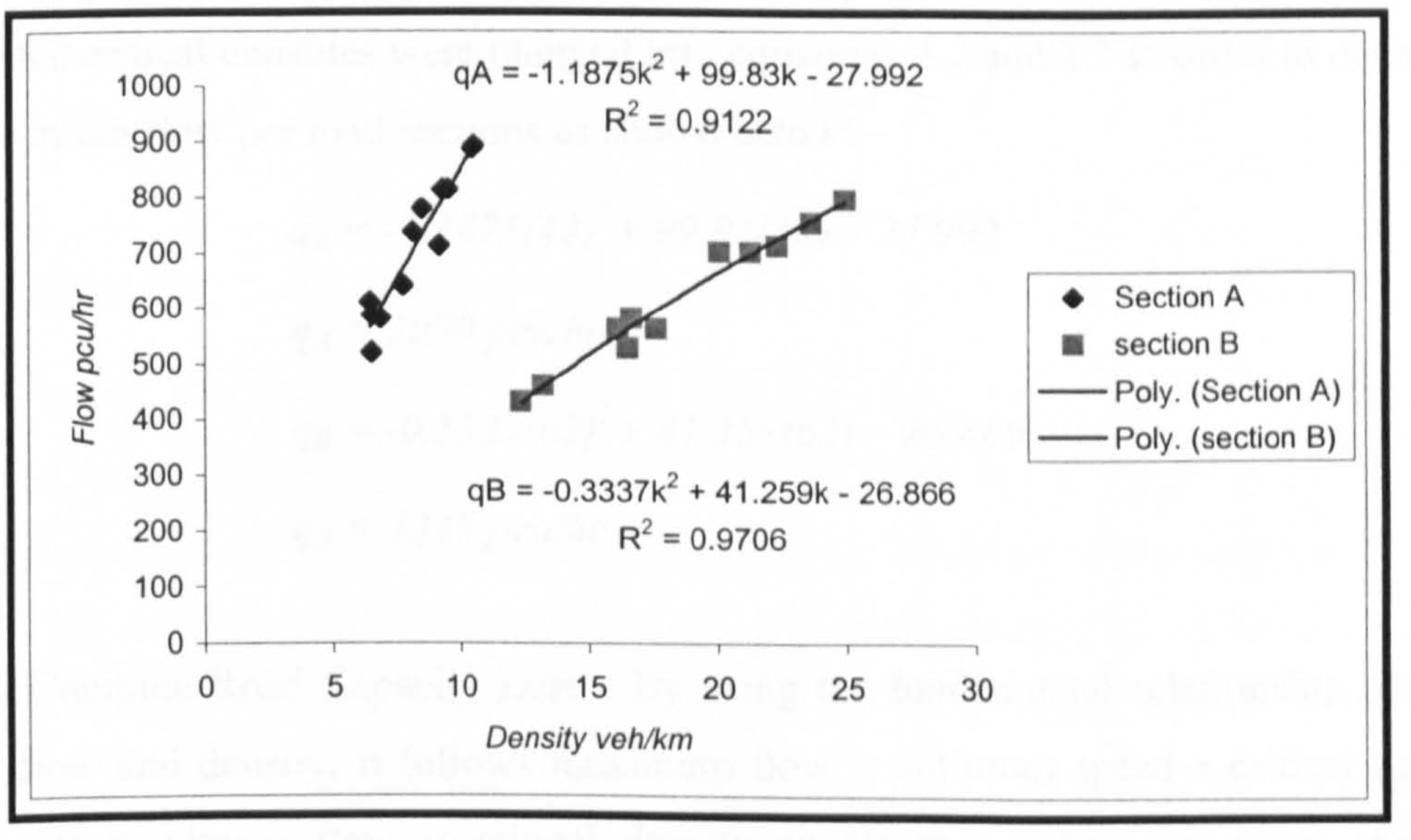
Flow per period = column 5 x 12; Density per period = col. 6 / col. 7

Table 4.6b Section B 95% Confidence Intervals Estimation

462	213444	35	1225
432	186624	35	1225
582	338724	35	1225
758	574564	32	1024
528	278784	32	1024
714	509796	32	1024
564	318096	32	1024
798	636804	32	1024
702	492804	33	1089
582	338724	35	1225
702	492804	35	1225
564	318096	35	1225
7388	4699264	403	13559
Mean =	616	Mean =	34
	4548545.3		13534.083
	13701.697		2.265152
Std.=	117.05	Std.=	1.51
Error	66.23	Error	0.85
Section B	Flow	Section B	Speed

Step 2 - Plug Computed Flows and Densities in Tables 4.5a and 4.6a into Equation 4.1 with the following results as shown in figure 4.2

Figure 4.2 Flows / Densities Curves for Road DL002



Source: survey

Step 3 – Derive Model Equations for Road Sections - By plugging the figures for flow and density into equation 4.1, the model coefficients as shown above in figure 4.2 for both road sections were determined as:

$$q_A = -1.1875k^2 + 99.83k - 27.992 \quad \text{Equation 4.2}$$

$$q_B = -0.3337k^2 + 41.259k - 26.866 \quad \text{Equation 4.3}$$

Step 4 – Differentiate Derived Model Equations to Compute Critical Densities - By differentiating q with respect to κ; for a maximum value of q: $\partial q / \partial \kappa = 0$.

Critical densities (κ_{crt}) for Sections A and B were established as:

Section A $\quad \partial q / \partial \kappa = -2.375k + 99.83;$

And $\quad -2.375k + 99.83 = 0$

Critical density - $\kappa_{crt} = 42 \ veh \ (km^{-1})$

Section B $\partial q / \partial \kappa = -0.6674k + 41.259;$

And $-0.6674k + 41.259 = 0$

Critical density - $\kappa_{crt} = 62\ veh\ (km^{-1})$

Step 5 Plug Derived Critical Densities into Model Equations to Estimate Road Capacity - Computed critical densities were plugged into equations 4.2 and 4.3 in order to determine the maximum flow per road sections as shown below:

$$q_A = -1.1875(42)^2 + 99.83(42) - 27.992$$

$$q_A = 2070\ pcu/hr$$

$$q_B = -0.3337(62)^2 + 41.259(62) - 26.866$$

$$q_B = 1248\ pcu/hr$$

Step 6 Compute Road Capacity Loss - By using the fundamental relationship between speed, flow and density, it follows maximum flow = optimum speed *x* critical density. Where the maximum flow at critical density equals the roadway capacity, then the roadway capacity for section A = *2070 pcu/hr (critical density = 42veh/km);* and section B = *1248 pcu/h (critical density = 62veh/km);* Optimum speed if required would be 49km/h for section A and 20 km/h for section B.

Roadway capacity loss is the difference between the computed capacities; 2070 - 1248 = 822pcu/hr. Percentage of Roadway capacity loss = 822 / 2070 = 39.71% However, these are preliminary results that require further investigations. Analysis from the preliminary studies suggests a distinctive pattern of determinant of capacity loss – high speed – section A, and low speed – section B. But, one is not completely sure of such speed pattern till the isolated empirical result is compared against findings from unrelated sample survey data. Before collecting unrelated sample data for the study, there is the need to assess the selected sites for the purpose of ensuring that they meet the established criteria set out earlier in this chapter. Even though the Nigerian passenger equivalency values of PC =, LGV – 1.5 and HGV = 2.0 were used earlier to compute roadway capacities for road section with and without pavement distress, it can be argued that such computed road capacity loss would give a distorted picture of actuality. Also, the extent to which observed HGV vehicles are driven at an above average speed on distressed level terrain compared to passenger cars would give rise to claim that HGV pce value of 2.0 unit is not realistic, it can be argued. However, in the absence of other authentic Nigerian PCE values, the aforementioned values were relied upon for the roadway capacity loss estimation.

4.5 SUMMARY

Data collection and sample survey methodology have been discussed so far and overall, the data obtained from the survey of road links is regarded as reasonable and reliable for at least three reasons: Firstly, it is obvious that if the objective of this study as stated in chapter one is to be achieved, only roadways with and without pavement distress on a stretch of at least 500 metres could be surveyed as earlier mentioned in this chapter. Secondly, information on the physical features of the road obtained from the ministries was checked against actual measurements and found to be correct and reliable. Thirdly, the crew had trial runs in April 2000 before the actual survey therefore it is reasonable to presume that they understood the concept and importance of data reliability.

Simple measurements are required for pavement distress include: type of distress, length, width, depth, affected area, number (nos.), and the relative percentage of distress. The terms used to describe pavement distress variables are summarized below.

Type of Distress - Three types of pavement distress were observed and measured, namely potholes (nos./section, depth, surface area involved in m^2), edge damage (length (m) and width (m) and cracking (surface area involved in m^2). The extent of edge damage was given as >29% and the level as >150mm erosion from the original edge according to Transport Research laboratory overseas road note 1 (*1987*).

Length of Distress - It is usually measured as Length (m) of pavement distress (potholes, cracking, and edge damage) per road section. This is needed because of the relevance of pavement distress vertical implications especially with respect to travel time over affected section.

Width of Distress -It is usually measured as Width (m) of pavement distress (potholes, cracking, and edge damage) per road section. This is needed because of the relevance of horizontal pavement distress implications, especially with respect to lane width reduction in affected section.

Depth of Distress It is usually measured as Maximum depth (mm) of pothole per road section. This is needed because of the relevance of pavement distress depression implications especially with respect to loss travel time at affected section.

Relative Area of Distress Area of distress (m^2) was taken as sum of rectangular areas circumscribing manifest distress, expressed as percentage of carriageway area and section length. Thus, relative area of distress (a) is length x width of distress per road section relative to lane width - w (A/W), where the lane width is same for all road section then area of distress divide by 1.

Number of Pothole – The number of potholes per distressed area section was taken where open cavity in road surface is at least 150mm diameter and 25mm depth. Hence one pothole with 150mm would cover an area of about $0.176m^2$. As mentioned earlier that the minimum desirable carriageway lane width is 2.5m according to DTp. Advice note 20/84(*1997*), note that the maximum number of potholes (17) was recorded at site ED008 covering distress area of 2.992 m^2 and the minimum number (07) recorded at site DL005 covering distress area of 1.232 m^2. By implication the minimum recorded number of potholes would reduce effective carriageway width of 3.1m by 1.23m to 1.87m. Surely the number of potholes would be a useful parameter when describing the relationship between pavement distress and roadway capacity loss.

Relative Percentage Pavement Distress - Percentage of pavement distress (PD) per km per lane = $\frac{l \times W \times 100}{3050}$ Where, 3050 denotes effective carriageway lane width, l denotes road length, w denotes pavement distress width.

By virtue of the isolated nature of the data on which the preliminary investigation were based, the results of the roadway capacity loss analysis conducted, at best could be described as broadly suggestive. Consequently, the data in this chapter begs a number of questions about the influence of pavement distress on roadway capacity loss. The questions include;

- To what extent has pavement distress affected roadway capacity loss?
- What are the effects of pavement distress on passenger car equivalent values? and
- What is the relationship between roadway capacity loss and pavement distress?

In the next Chapter, results from sample surveyed at 12 sites will be investigated and used in Chapters 6 and 7 for road capacity loss estimations.

5

SAMPLE SURVEYS

This chapter will present the results from survey data that would be analysed in subsequent chapter. We shall restrict ourselves to the data colleted from the selected sites for the purpose of roadway analysis. The tabulated results in this chapter will show the followings; road code, total surveyed road length, maximum depth of pavement distress, total affected area of pavement distress and their relative percentage to the total surveyed area, percentage of commercial vehicles, date of survey, time intervals, start time, finish time, average vehicle speeds per time interval and also per surveyed sites and sections, volume and type of vehicles for both the affected area and the control area.

Take note that even though the time intervals for both sections are same, the actual start time at section B (downstream) commenced when first vehicle counted at section A (upstream) passed the screen line at section B (downstream). This is required to prevent vehicle volume loss at section B and also that the extent of pavement distress was taken as percentage of affected area per kilometre per carriageway.

The survey that took nine months to complete was conducted in Nigeria between August 2000 and April 2001. The survey aimed to collect data to show under daylight and dry weather conditions, road pavement distress would influence roadway capacity loss. Data was collected both manually and also automatically during daylight and dry weather condition for one hour with five-minute intervals per survey day. Summary of Sites, Road Code, Time and Survey Date are shown below in Table 5.0

Table 5.0 Summary of Sites, Road Codes, Time and Survey Date

No	Date	Time	Code	Name
01	28-09-00	1700-1800	OG011	Aiyetoro Road Abeokuta, OGUN STATE
02	28-09-00	0800-0900	OG012	Oba Simolade Road Shagamu OGUN STATE
03	03-10-00	1700-1800	OY018	Awolowo Avenue (Bodija), Ibadan OYO STATE
04	05-10-00	0800-0900	OY019	Oyo Road (Mokola) Ibadan OYO STATE
05	09-10-00	0800-0900	OG010	Lantoro Road Abeokuta, OGUN STATE
06	16-10-00	1700-1800	EK009	Ajilosun Street, Ado-Ekiti EKITI STATE
07	11-12-00	0800-0900	ED008	Upper Siluko Road Benin EDO STATE
08	08-12-00	1700-1800	ED007	Upper Sakponba Road Benin EDO STATE
09	08-12-00	0800-0900	ED006	Ogida Road Benin EDO STATE
10	07-12-00	1700-1800	DL005	Warri / Sapele Road Warri, DELTA STATE
11	07-12-00	0800-0900	DL004	Refinery Road (16) Warri DELTA STATE
12	05-12-00	1700-1800	AN001	Enugu / Onitsha Road Onitsha ANAMBRA STATE

Source: Survey Data

5.1 EMPIRICAL RESULTS FROM SURVEYED SITES

The tables presented in sections 5.1, 5.12 are classified into two distinct divisions. The samples on section A (upstream), is confined to road without pavement distress while the section B (downstream) contains data on roads with pavement distress. Vehicle count at section B commenced with the passing at Section B screen line of the first counted vehicle at Section A so as to avoid lost of vehicle at section B.

Volume of traffic fluctuates widely with time and the nature of variation depends on the type of the highway. Peak volume on Mondays-Fridays was counted early in the morning and late in the evening mainly due to commuter travels. The peaking pattern is not generally evident on weekends and lowest recording can be expected on Sundays.

5.1.1 Site AN001- As shown below in Table 5.1, 666 vehicles were observed at section A of which, 57.9 per cent were commercial vehicles (CVs). From a total of 387 CVs recorded at section A, 45 percent were light goods vehicle (LGV) and the remainder 12.9 heavy goods vehicle. Passenger cars (PC) constituted only 42.1 per cent of the total volume suggesting a high road influence of commercial vehicles. Large volume of commercial vehicles could suggest an active public transportation on this road, as most of the LGVs are mini buses. In spite of the condition of the road, 301 commercial vehicles out of 387 were recorded at section B compared to 218 passenger cars out of 280 for the same period. However, 58 per cent of CVs was recorded at section B while 42 per cent was recorded at the same section suggesting a lower traffic rate of passenger cars. This is indicated by the significant drop in passenger car vehicle speed from 90 kph to 44 kph compared to light good vehicle (24kph) and HGV 10kph. The road surface distress length was measured as 58.9m with a maximum depth of 350mm though varying from 50mm to 350mm. The total pavement distress affected area was 215.1 m^2 and that equates to 8.6% PD/km/ln.

Table 5.1 ROAD CODE AN001 – Enugu/Onitsha Road Onitsha, ANAMBRA State

DATE: 5 Dec. 2000		Road code: AN001				Surveyed Area: Lane (W) 3.65m * (L) 297m PD: Nos.15. Length 86.3m Area 315.1 m^2							Depth 35cm %PD/km/ln 8.6 %CV 58.1		
Period 5 MIN Interval	Time	ROAD SECTION A (without PD)							ROAD SECTION B (with PD)						
		(VOLUME VEHICLES)				AVERAGE SPEED KM/H			(VOLUME VEHICLES)				AVERAGE SPEED KM/H		
XX		PC	LGH	HGV	Total	PC	LGH	HGV	PC	LGH	HGV	Total	PC	LGH	HGV
01	1700	27	29	08	65	90	68	58	22	23	07	52	44	44	44
02	1705	24	26	07	57	90	68	58	17	18	05	41	44	44	44
03	1710	17	18	05	41	86	62	52	13	14	04	32	47	47	47
04	1715	23	24	07	54	86	58	58	20	21	06	47	45	45	45
05	1720	31	33	10	74	85	60	60	18	19	06	43	45	45	45
06	1725	17	18	05	40	95	69	49	18	20	06	44	45	45	45
07	1730	19	21	06	46	95	65	45	19	20	06	46	45	45	45
08	1735	22	24	07	53	90	65	55	19	21	06	46	47	47	47
09	1740	26	27	08	61	90	65	55	21	23	07	50	47	47	47
10	1745	17	18	05	41	90	65	55	15	16	05	35	47	47	47
11	1750	24	26	07	57	90	65	55	18	19	06	43	47	47	47
12	1755	32	35	10	77	90	70	55	17	18	05	41	47	47	47
Duration 1hr	=	280	300	86	666				218	234	67	519			

Source: Survey

5.1.2 Site DL004 -As shown below in Table 5.2, 502 vehicles were observed at section A of which 16.9 per cent were commercial vehicles (CVs) compared to 413 vehicles recorded at Section B. Passenger cars (PC) constituted only 82.1 per cent of the total volume suggesting high road influence of passenger cars. One can suggest that the large percentage of PCs may be indicative of low percentage of pavement because in spite of the condition of the road (4.4%/km/ln). 70 commercial vehicles out of 80 were recorded at section B compared to 343 passenger cars out of 417 for the same period.

There was a significant drop in PCs vehicle speed generally from 80kph to about 42pkh (38kph) compared to LGV (23kph) and HGV (3pkh). The speed drops suggest that PCs are the most affected by pavement distress. Pavement distress length was measured as 44.5m with a maximum depth of 220mm though varying from 50mm to 220mm. The affected pavement distress area was 162.3m ^{2} and that was the smallest recorded pavement distress area from the surveyed sites.

Table 5.2 ROAD CODE DL004 –Refinery Road Warri, DELTA State

DATE: 7 Dec 2000	Road code: DL004	Surveyed Area: Lane (W) 3.65m * (L) 255m PD: Nos.13 Length 44.5m Area 162.3m²	Depth 22cm %PD/km/ln 4.4 %CV 16.9

Period 5 MIN Interval	Time	ROAD SECTION A (without PD) (VOLUME VEHICLES)				AVERAGE SPEED KM/H			ROAD SECTION B (with PD) (VOLUME VEHICLES)				AVERAGE SPEED KM/H		
XX		PC	LGH	HGV	Total	PC	LGH	HGV	PC	LGH	HGV	Total	PC	LGH	HGV
01	0800	34	04	02	40	79	65	45	25	03	02	30	42	42	42
02	0805	31	04	02	37	80	65	45	22	03	02	27	42	42	42
03	0810	35	05	03	43	83	65	45	28	04	02	34	42	42	42
04	0815	43	06	03	52	81	65	45	35	05	03	42	40	40	40
05	0820	35	05	03	45	77	65	45	29	04	02	35	40	40	40
06	0825	35	05	03	45	88	65	45	29	04	02	35	40	40	40
07	0830	29	04	02	37	88	65	45	22	03	02	27	40	40	40
08	0835	46	06	03	55	89	65	45	37	05	03	45	40	40	40
09	0840	30	04	02	36	65	65	45	22	03	02	26	43	43	43
10	0845	30	04	02	36	73	65	45	30	04	02	36	42	42	42
11	0850	32	04	02	38	74	65	45	32	04	02	38	42	42	42
12	0855	32	04	02	38	73	65	45	32	04	02	38	42	42	42
Duration = 1hr		417	55	30	502				343	45	25	413			

Source: Survey

5.1.3 Site DL005 - As shown below in Table 5.3, 490 vehicles were observed at section A of which 4.9 per cent were commercial vehicles (CVs) compared to 468 vehicles recorded at Section B. Passenger cars (PC) constituted only 95 per cent of the total volume suggesting high road influence of passenger cars. One can suggest that the large percentage of PCs may be indicative of low percentage of pavement because in spite of the condition of the road (4.9%/km/ln). 23 commercial vehicles out of 24 were recorded at section B compared to 445 passenger cars out of 466 for the same period.

There was a significant drop in PCs vehicle speed generally from 80kph to about 39pkh (41kph) compared to LGV (21kph) and HGV (16pkh). Again the speed drops suggest that PCs are the most affected by pavement distress. Pavement distress length was measured as 48.8m with a maximum depth of 300mm though varying from 50mm to 300mm. The affected pavement distress area was 178.2m ^{2} and that was the second smallest recorded pavement distress area from the surveyed sites.

Table 5.3 ROAD CODE DL005 – Warri / Sapele Road Warri, DELTA State

DATE: 7 Dec 2000	Road code: DL005	Surveyed Area: Lane (W) 3.65m * (L) 259m PD: Nos.07 Length 48.8m: Area 178.2m^2	Depth 2cm %PD/km/ln 4.9 %CV 4.9

Period 5 MIN Interval	Time	ROAD SECTION A (without PD)							ROAD SECTION B (with PD)						
		(VOLUME VEHICLES)				AVERAGE SPEED KM/H			(VOLUME VEHICLES)				AVERAGE SPEED KM/H		
XX		PC	LGH	HGV	Total	PC	LGH	HGV	PC	LGH	HGV	Total	PC	LGH	HGV
01	1700	33	01	01	35	82	60	55	31	01	01	33	39	39	39
02	1705	48	02	01	51	82	60	55	38	02	01	42	39	39	39
03	1710	46	02	00	48	80	60	55	40	02	00	40	39	39	39
04	1715	32	01	01	34	89	60	55	40	01	01	42	40	40	40
05	1720	36	02	00	38	78	60	55	29	02	00	31	39	39	39
06	1725	33	01	01	35	86	60	55	36	01	01	38	38	38	38
07	1730	44	02	00	48	79	60	55	35	02	00	37	37	37	37
08	1735	37	02	00	39	79	60	55	48	02	00	50	38	38	38
09	1740	30	01	01	32	80	60	55	31	01	01	33	39	39	39
10	1745	43	02	00	45	81	60	55	31	01	00	32	39	39	39
11	1750	38	02	00	40	83	60	55	36	02	00	38	39	39	39
12	1755	45	02	00	47	83	60	55	36	02	00	38	39	39	39
Duration = 1hr		466	20	4	490				445	19	4	468			

Source: Survey

5.1.4 Site ED006 - As shown below in Table 5.4, 674 vehicles were observed at section A of which 55 per cent were commercial vehicles (CVs). From a total of 391 CVs recorded at section A, 357 were light goods vehicle (LGV) and the remainder 34 heavy goods vehicle. Passenger cars (PC) constituted only 45per cent of the total volume suggesting large presence of commercial vehicles. Large volume of commercial vehicles could suggest an active public transportation on this road, as most of the LGVs are mini buses.

In spite of the condition of the road with 7.2percent PD /km/ln, 313commercial vehicles out of 357 were recorded at section B compared to 249 passenger cars out of 283 for the same period. There was significant drop in passenger car vehicle speed from 80 kph to 55 kph (25kph) compared to light good vehicle (10kph) and HGV 5kph. The road pavement distress length was measured as 71.9m with a maximum depth of 300mm though varying from 50mm to 300mm. The total pavement distress affected area was 262.4m^2.

Table 5.4 ROAD CODE ED006 –Ogida Road Benin EDO State

DATE: 8 Dec 2000		Road code: ED006				Surveyed Area: Lane (W) 3.65m * (L) 282m PD: Nos.09 Length 71.9m: Area 262.4m²							Depth 30cm %PD/km/ln 7.2 %CV 55		
Period 5 MIN Interval	Time	ROAD SECTION A (without PD)							ROAD SECTION B (with PD)						
		(VOLUME VEHICLES)				AVERAGE SPEED KM/H			(VOLUME VEHICLES)				AVERAGE SPEED KM/H		
XX		PC	LGH	HGV	Total	PC	LGH	HGV	PC	LGH	HGV	Total	PC	LGH	HGV
01	0800	21	27	03	51	79	65	55	20	25	02	47	55	55	55
02	0805	24	30	03	57	74	65	55	17	22	02	41	50	50	50
03	0810	26	32	03	61	86	65	55	26	33	03	62	50	50	50
04	0815	27	34	03	65	79	60	55	24	30	03	57	45	45	45
05	0820	27	34	03	65	80	60	55	18	23	02	43	45	45	45
06	0825	21	27	03	50	85	65	55	24	30	03	57	46	46	46
07	0830	28	36	03	67	86	65	55	19	24	02	46	46	46	46
08	0835	23	29	03	54	86	60	55	24	30	03	56	48	48	48
09	0840	30	38	04	71	83	60	55	23	29	03	54	50	50	50
10	0845	26	32	03	61	86	60	55	21	27	03	50	50	50	50
11	0850	15	19	02	35	86	65	55	15	20	02	37	50	50	50
12	0855	16	20	02	37	85	65	55	17	21	02	40	50	50	50
Duration = 1hr		283	357	34	674				249	313	30	590			

Source: Survey

5.1.5 Site ED007 - As shown below in Table 5.5, 536 vehicles were observed at section A of which 58 per cent were commercial vehicles (CVs). From a total of 309 CVs recorded at section A, 282 were light goods vehicle (LGV) and the remainder 27 heavy goods vehicle. Passenger cars (PC) constituted only 42per cent of the total volume suggesting large presence of commercial vehicles. Large volume of commercial vehicles could suggest an active public transportation on this road, as most of the LGVs are mini buses.

In spite of the condition of the road with 5.3percent PD /km/ln, 246commercial vehicles out of 306 were recorded at section B compared to 179 passenger cars out of 227 for the same period. There was significant drop in passenger car vehicle speed from 80 kph to 40 kph (40kph) compared to light good vehicle (20kph) and that of HGV is insignificant. The road pavement distress length was measured as 53.4m with a maximum depth of 150mm though varying from 50mm to 150mm. The total pavement distress affected area was 194.9m^2.

Table 5.5 ROAD CODE ED007 –Upper Sakponba Road Benin EDO State

DATE: 8 Dec 2000	Road code: ED007	Surveyed Area: Lane (W) 3.65m * (L) 264m PD: Nos.11 Length 53.4m: Area 194.9m^2	Depth 15cm % PD/km/ln 5.3 %CV 58

Period 5 MIN Interval	Time	ROAD SECTION A (without PD)							ROAD SECTION B (with PD)						
		(VOLUME VEHICLES)				AVERAGE SPEED KM/H			(VOLUME VEHICLES)				AVERAGE SPEED KM/H		
XX		PC	LGH	HGV	Total	PC	LGH	HGV	PC	LGH	HGV	Total	PC	LGH	HGV
01	1700	22	24	02	48	77	60	40	16	20	02	38	40	40	40
02	1705	12	15	01	28	71	60	40	11	13	02	26	40	40	40
03	1710	21	27	03	51	92	60	40	13	17	02	32	40	40	40
04	1715	24	30	03	57	87	66	45	16	21	02	39	45	45	45
05	1720	14	17	02	33	83	66	45	13	16	02	31	45	45	45
06	1725	21	27	03	51	76	66	45	20	25	02	47	40	40	40
07	1730	16	21	02	39	84	60	45	10	12	01	23	44	44	44
08	1735	18	23	02	43	86	60	55	16	21	02	39	44	44	44
09	1740	16	21	02	39	80	60	50	12	15	01	28	44	44	44
10	1745	18	23	02	43	77	66	50	21	26	02	49	39	39	39
11	1750	19	24	02	46	70	66	50	16	21	02	39	39	39	39
12	1755	24	31	03	58	80	66	50	15	19	02	35	39	39	39
Duration = 1hr		227	282	27	536				179	225	21	425			

Source: Survey

5.1.6 Site ED008 -As shown below in Table 5.6, 529 vehicles were observed at section A of which 56 per cent were commercial vehicles (CVs). From a total of 296 CVs recorded at section A, 51 percent were light goods vehicle (LGV) and the remainder 5 percent heavy goods vehicle. Passenger cars (PC) constituted only 44 per cent of the total volume suggesting a high road influence of commercial vehicles. Large volume of commercial vehicles could suggest an active public transportation on this road, as most of the LGVs are mini buses. In spite of the condition of the road, 220 commercial vehicles out of 296 were recorded at section B compared to 173 passenger cars out of 233 for the same period. However, 55 per cent of CVs was recorded at section B while 44 per cent was recorded at the same section suggesting a lower traffic rate of passenger cars. This is indicated by the significant drop in passenger car vehicle speed from 82 kph to 40 kph (42kph) compared to light good vehicle (24kph) and HGV (6kph). The road pavement distress length was measured as 40m with a maximum depth of 200mm though varying from 50mm to 200mm. The total pavement distress affected area was 148.2m^2.

Table 5.6 ROAD CODE ED008 – Upper Siliko Road Benin, EDO State

DATE: 11 Dec 2000		Road code: ED008				Surveyed Area: Lane (W) 3.65m * (L) 250m PD: Nos.17 Length 40m: Area 148.2m²							Depth 20cm %PD/km/ln 4.1 %CV 56		
Period 5 MIN Interval	Time	ROAD SECTION A (without PD)							ROAD SECTION B (with PD)						
		(VOLUME VEHICLES)				AVERAGE SPEED KM/H			(VOLUME VEHICLES)				AVERAGE SPEED KM/H		
XX		PC	LGH	HGV	Total	PC	LGH	HGV	PC	LGH	HGV	Total	PC	LGH	HGV
01	0800	21	23	02	46	78	64	46	16	18	02	36	36	36	36
02	0805	20	23	02	45	75	67	46	15	18	02	35	39	39	39
03	0810	22	24	02	48	78	64	46	12	14	01	28	40	40	40
04	0815	15	17	02	34	87	66	46	15	17	02	33	40	40	40
05	0820	22	27	03	52	85	59	48	09	11	01	21	42	42	42
06	0825	18	20	02	40	75	60	48	16	19	02	37	42	42	42
07	0830	21	24	02	47	75	56	48	19	22	02	43	40	40	40
08	0835	12	14	01	28	75	59	48	08	10	01	19	42	42	42
09	0840	20	23	02	46	75	59	50	17	19	02	38	42	42	42
10	0845	24	28	03	55	75	59	50	17	20	02	39	39	39	39
11	0850	22	25	02	49	75	53	50	13	15	01	29	29	29	40
12	0855	17	20	02	39	78	53	50	15	18	02	35	35	35	39
Duration = 1hr		233	270	26	529				173	200	20	393			

Source: Survey

5.1.7 Site EK009 -As shown below in Table 5.7, 613 vehicles were observed at section A of which 55 per cent were commercial vehicles (CVs). From a total of 337 CVs recorded at section A, 52 percent were light goods vehicle (LGV) and the remainder 3 percent heavy goods vehicle. Passenger cars (PC) constituted only 45 per cent of the total volume suggesting a high road influence of commercial vehicles. Large volume of commercial vehicles could suggest an active public transportation on this road, as most of the LGVs are mini buses. In spite of the condition of the road with pavement distress as 6.4%/km/ln, 300 commercial vehicles out of 337 were recorded at section B compared to 246 passenger cars out of 276 for the same period. However, 55 per cent of CVs was recorded at section B while 45 per cent was recorded at the same section suggesting a lower traffic rate of passenger cars. This is indicated by the significant drop in passenger car vehicle speed from 85 kph to 36 kph (49kph) compared to light good vehicle (24kph) and HGV (19kph). The road pavement distress length was measured as 64.4m with a maximum depth of 200mm though varying from 50mm to 200mm. The total pavement distress affected area was 235m^2.

Table 5.7 ROAD CODE EK009 – Ajilosun Street Ado-Ekiti EKITI State

DATE: 16 Oct 2000	Road code: EK009	Surveyed Area: Lane (W) 3.65m * (L) 275m PD: Nos.15. Length 64.4m: Area 235.1m²	Depth 20cm % PD/km/ln 6.4 %CV 55

Period 5 MIN Interval	Time	ROAD SECTION A (without PD) (VOLUME VEHICLES)				AVERAGE SPEED KM/H			ROAD SECTION B (with PD) (VOLUME VEHICLES)				AVERAGE SPEED KM/H		
XX		PC	LGH	HGV	Total	PC	LGH	HGV	PC	LGH	HGV	Total	PC	LGH	HGV
01	1700	25	29	02	55	89	58	55	23	26	02	50	35	35	35
02	1705	27	31	02	59	82	58	56	22	25	01	48	35	35	35
03	1710	29	34	02	65	82	56	50	22	25	01	49	35	35	35
04	1715	23	26	02	50	85	60	55	24	28	02	53	36	36	36
05	1720	18	21	01	40	82	60	55	17	20	01	38	39	39	39
06	1725	19	22	01	43	82	55	56	14	16	01	30	39	39	39
07	1730	31	35	02	69	85	57	56	27	31	02	59	36	36	36
08	1735	24	28	02	53	84	55	56	25	29	02	55	36	36	36
09	1740	18	21	01	40	86	55	55	14	16	01	31	36	36	36
10	1745	19	22	01	42	90	57	55	19	22	01	43	36	36	36
11	1750	20	23	01	44	90	60	55	19	22	01	42	40	40	40
12	1755	24	28	02	54	90	60	55	22	25	01	49	40	40	40
Duration = 1hr		276	319	18	614				246	284	16	547			

Source: Survey

5.1.8 Site OG010 - As shown below in Table 5.8, 640 vehicles were observed at section A of which 7 per cent were commercial vehicles (CVs). From a total of 45 CVs recorded at section A, 26 were light goods vehicle (LGV) and the remainder 19 heavy goods vehicle. Passenger cars (PC) constituted only 93 per cent of the total volume. In spite of the condition of the road pavement at 4.6 percent per km per lane, 38 commercial vehicles out of 45 were recorded at section B compared to 500 passenger cars out of 593 for the same period suggesting a high traffic rate of passenger cars suggesting that passenger cars are likely to be more affected by pavement distress than commercial vehicles. This is indicated by the significant drop in passenger car vehicle speed from 95 kph to 45 kph (50 kph) compared to light good vehicle (30kph) and HGV 15kph. The road pavement distress length was measured as 46.4m with a maximum depth of 200mm though varying from 50mm to 200mm. The total pavement distress affected area was 169.3m^2.

Table 5.8 ROAD CODE OG010 –Lantoro Road Abeokuta OGUN State

DATE: 9 Oct 2000	Road code: OG010	Surveyed Area: Lane (W) 3.65m * (L) 257m PD: Nos.12 Length 46.4m: Area 169.3m^2	Depth 20cm % PD/km/ln 4.6 %CV 7

Period 5 MIN Interval	Time	ROAD SECTION A (without PD) (VOLUME VEHICLES)				AVERAGE SPEED KM/H			ROAD SECTION B (with PD) (VOLUME VEHICLES)				AVERAGE SPEED KM/H		
XX		PC	LGH	HGV	Total	PC	LGH	HGV	PC	LGH	HGV	Total	PC	LGH	HGV
01	0800	50	02	02	54	95	78	60	43	02	01	46	45	45	45
02	0805	50	02	02	54	92	78	62	47	02	02	51	45	45	45
03	0810	52	02	02	56	95	75	67	37	02	01	40	44	44	44
04	0815	53	02	02	57	99	72	69	45	02	01	48	48	48	48
05	0820	55	02	02	59	95	76	65	48	02	02	52	44	44	44
06	0825	51	02	02	55	93	70	65	56	02	02	60	44	44	44
07	0830	51	02	02	55	93	70	64	42	02	01	45	45	45	45
08	0835	53	02	02	57	95	70	64	47	02	02	50	45	45	45
09	0840	55	02	02	59	97	70	66	37	02	01	40	48	48	48
10	0845	41	02	01	44	91	75	66	33	01	01	35	48	48	48
11	0850	40	03	00	43	90	75	66	37	02	01	40	46	46	46
12	0855	44	03	00	47	90	75	66	29	01	01	31	46	46	46
Duration = 1hr		595	26	19	640				500	22	16	538			

Source: Survey

5.1.9 Site OG011 - As shown below in Table 5.9, 511 vehicles were observed at section A of which, 38 per cent were commercial vehicles (CVs). From a total of 194 CVs recorded at section A, 143 were light goods vehicle (LGV) and the remainder 51 heavy goods vehicle. Passenger cars (PC) constituted 62 per cent of the total volume suggesting a high road influence of commercial vehicles. Large volume of commercial vehicles could suggest an active public transportation on this road, as most of the LGVs are mini buses. In spite of the condition of the road pavement at 3 percent /km/ln, 167 commercial vehicles out of 194 were recorded at section B compared to 255 passenger cars out of 317 for the same period. However, 51 heavy good vehicles for one hour surveyed duration highlight the significance of this road for haulage activities with effect on flow rate attributable to lower vehicle speed. Significant drop in passenger car vehicle speed 77 kph to 39kph (38kph) compared to light good vehicle (19kph) and HGV (16kph) suggest the influence of pavement distress. The road pavement distress length was measured as 27.7m with a maximum depth of 300mm though varying from 50mm to 300mm. The total pavement distress affected area was 108.5m^2.

Table 5.9 ROAD CODE OG011 –Aiyetoro Road Abeokuta, OGUN State

DATE: 28 Sep 2000		Road code: OG011				Surveyed Area: Lane (W) 3.65m * (L) 238m PD: Nos.14 Length 27.7m: Area 108.5.m²							Depth 30cm % PD/km/ln 3 %CV 38		
Period 5 MIN Interval	Time	ROAD SECTION A (without PD)							ROAD SECTION B (with PD)						
		(VOLUME VEHICLES)				AVERAGE SPEED KM/H			(VOLUME VEHICLES)				AVERAGE SPEED KM/H		
XX		PC	LGH	HGV	Total	PC	LGH	HGV	PC	LGH	HGV	Total	PC	LGH	HGV
01	1700	23	10	04	37	79	58	55	19	08	03	30	39	39	39
02	1705	32	14	05	51	80	58	55	19	08	03	30	39	39	39
03	1710	25	11	04	40	80	58	55	18	08	03	29	39	39	39
04	1715	29	13	05	46	85	56	50	25	11	04	40	38	38	38
05	1720	34	15	06	55	79	56	50	25	11	04	41	38	38	38
06	1725	43	20	07	70	83	56	50	28	13	05	45	38	38	38
07	1730	22	10	04	35	82	63	50	18	08	03	29	38	38	38
08	1735	25	11	04	41	79	63	50	19	09	03	31	39	39	39
09	1740	21	10	03	34	87	60	50	19	09	03	31	39	39	39
10	1745	24	11	04	39	77	60	50	24	11	04	38	39	39	39
11	1750	17	8	03	28	77	60	52	24	11	04	39	38	38	38
12	1755	22	10	04	35	77	60	52	18	08	03	29	38	38	38
Duration = 1hr		317	143	51	511				255	115	42	412			

Source: Survey

5.1.10 Site OG012 - As shown below in Table 5.10, 527vehicles were observed at section A of which 28 per cent were commercial vehicles (CVs). Passenger cars (PC) constituted 72 per cent of the total volume suggesting high road use by passenger cars and also the importance of this route for private road transport.

In spite of the condition of the road pavement at 3.5 per cent per km per lane, 144 commercial vehicles out of 148 were recorded at section B compared to 287 passenger cars out of 379 for the same period thus suggesting that the presence of road pavement distress on this road has minimal impact on CVs. This is indicated by the significant drop in passenger car vehicle speed from 85 kph to 38 kph (47kph) compared to light good vehicle (26kph) and HGV (7kph). The road pavement distress length was measured as 35.2m with a maximum depth of 300mm though varying from 50mm to 300mm. The total pavement distress affected area was 128.5m^2.

Table 5.10 ROAD CODE OG012 – Oba Simolade Street, Shagamu OGUN State

DATE: 28 Sep 2000	Road code: OG012	Surveyed Area: Lane (W) 3.65m * (L) 246m PD: Nos.10 Length 35.2m: Area 128.5m²	Depth 30cm % PD/km/ln 3.5 %CV 28

Period 5 MIN Interval	Time	ROAD SECTION A (without PD) (VOLUME VEHICLES)				AVERAGE SPEED KM/H			ROAD SECTION B (with PD) (VOLUME VEHICLES)				AVERAGE SPEED KM/H		
XX		PC	LGH	HGV	Total	PC	LGH	HGV	PC	LGH	HGV	Total	PC	LGH	HGV
01	0800	33	06	06	46	86	64	45	27	06	06	39	38	38	38
02	0805	37	06	07	51	86	64	45	22	06	07	35	38	38	38
03	0810	36	06	07	50	86	64	45	18	06	07	31	38	38	38
04	0815	35	06	07	48	90	60	45	27	06	07	40	38	38	38
05	0820	37	06	07	52	90	60	45	24	06	07	37	38	38	38
06	0825	43	05	08	60	85	60	50	20	08	08	36	39	39	39
07	0830	29	08	06	40	85	60	50	27	06	06	39	36	36	36
08	0835	30	08	06	41	90	60	50	19	06	06	31	38	38	38
09	0840	25	08	05	35	95	60	50	18	05	05	28	39	39	39
10	0845	29	06	06	40	85	62	45	29	06	06	41	37	37	37
11	0850	15	03	03	21	85	62	45	23	03	03	29	38	38	38
12	0855	31	06	06	43	85	62	45	33	06	06	45	37	37	37
Duration = 1hr		379	74	74	527				287	70	74	431			

Source: Survey

5.1.11 Site OY018 - As shown below in Table 5.11, 618 vehicles were observed at section A of which 25 per cent were commercial vehicles (CVs). From a total of 154 CVs recorded at section A, 105 were light goods vehicle (LGV) and the remainder 49 heavy goods vehicle. Passenger cars (PC) constituted 75 per cent of the total volume suggesting a high road influence of commercial vehicles. Large volume of commercial vehicles could suggest an active public transportation on this road. 17 percent of the commercial vehicles were LGVs indicating a relative importance of this route to commuters

In spite of the condition of the road pavement at 2.7 percent per km per lane, 141 commercial vehicles out of 154 were recorded at section B compared to 425 passenger cars out of 464 for the same period. There was significant drop in passenger car vehicle speed from 84 kph to 48 kph (36kph) compared to light good vehicle (16kph) and HGV (8kph). The road pavement distress length was measured as 27.3m with a maximum depth of 150mm though varying from 50mm to 150mm. The total pavement distress affected area was 99.5m^2.

Table 5.11 ROAD CODE OY018 –Awolowo Avenue Ibadan OYO State

DATE: 3 Oct 2000	Road code: OY018	Surveyed Area: Lane (W) 3.65m * (L) 238m PD: Nos.16 Length 27.3m: Area 99.5m^2	Depth 15cm % PD/km/ln 2.7 %CV 25

Period 5 MIN Interval	Time	ROAD SECTION A (without PD) (VOLUME VEHICLES)				AVERAGE SPEED KM/H			ROAD SECTION B (with PD) (VOLUME VEHICLES)				AVERAGE SPEED KM/H		
XX		PC	LGH	HGV	Total	PC	LGH	HGV	PC	LGH	HGV	Total	PC	LGH	HGV
01	1700	42	10	04	56	85	64	56	35	08	04	46	48	48	48
02	1705	38	09	04	51	85	64	56	38	09	04	51	48	48	48
03	1710	46	10	05	61	80	64	56	43	10	05	57	49	49	49
04	1715	38	09	04	50	85	72	56	30	07	03	40	49	49	49
05	1720	37	08	04	49	92	69	58	33	07	04	44	47	47	47
06	1725	40	09	04	53	85	69	58	36	08	04	48	46	46	46
07	1730	39	09	04	52	85	69	58	37	08	04	49	46	46	46
08	1735	38	09	04	51	85	69	55	35	08	04	46	46	46	46
09	1740	41	09	04	54	83	72	55	38	09	04	51	48	48	48
10	1745	37	08	04	49	85	72	55	33	07	04	44	49	49	49
11	1750	35	08	04	47	82	69	58	37	08	04	49	48	48	48
12	1755	34	08	04	45	83	69	58	32	07	03	42	48	48	48
Duration = 1hr		464	105	49	618				425	96	45	567			

Source: Survey

5.1.12 Site OY019 - As shown below in Table 5.12, 714vehicles were observed at section A of which 39 per cent were commercial vehicles (CVs) compared to 626 at section B. From a total of 278 CVs recorded at section A, 221 were light goods vehicle (LGV) and the remainder 57 heavy good vehicles. Passenger cars (PC) constituted 61 per cent of the total volume suggesting a high road influence of commercial vehicles. Large volume of commercial vehicles could suggest an active public transportation on this road, as most of the LGVs are mini buses. In spite of the condition of the road pavement at 5.4 percent per km per lane, 244 commercial vehicles out of 278 were recorded at section B compared to 381 passenger cars out of 436 for the same period. There was significant drop in passenger car vehicle speed from an average of 76 kph to 36 kph (40kph) compared to light good vehicle (26kph) and HGV (12kph). The road pavement distress length was measured as 54.4m with a maximum depth of 200mm though varying from 50mm to 200mm. The total pavement distress affected area was 198.5m^2.

Table 5.12 ROAD CODE OY019 –Oyo Road Ibadan OYO State

DATE: 5 OCT 2000		Road code: OY019				Surveyed Area: Lane (W) 3.65m * (L) 265m PD: Nos.13 Length 54.4m: Area 1 98.5m²							Depth 20cm % PD/km/ln 5.4 %CV 39		
Period 5 MIN Interval	Time	ROAD SECTION A (without PD)							ROAD SECTION B (with PD)						
		(VOLUME VEHICLES)				AVERAGE SPEED KM/H			(VOLUME VEHICLES)				AVERAGE SPEED KM/H		
XX		PC	LGH	HGV	Total	PC	LGH	HGV	PC	LGH	HGV	Total	PC	LGH	HGV
01	0800	29	15	04	47	80	62	48	38	19	05	62	36	36	36
02	0805	34	17	04	55	75	62	48	40	20	95	65	36	36	36
03	0810	34	19	04	55	79	62	48	36	18	05	59	38	38	38
04	0815	37	18	05	60	86	60	48	29	15	04	48	38	38	38
05	0820	35	16	05	51	86	60	46	30	15	04	49	37	37	37
06	0825	31	21	04	68	86	60	46	32	16	04	52	36	36	36
07	0830	41	22	05	70	81	62	46	32	16	04	53	38	38	38
08	0835	43	20	04	64	81	62	45	34	17	04	55	38	38	38
09	0840	39	20	06	65	79	62	45	26	13	03	43	39	39	39
10	0845	40	20	05	65	76	62	45	28	14	04	46	38	38	38
11	0850	40	20	05	65	76	62	45	27	14	04	46	37	37	39
12	0855	43	17	04	56	76	62	45	29	15	04	48	37	37	39
Duration = 1hr		436	221	57	714				381	194	50	625			

Source: Survey

5.2 PHOTOGRAPHS SHOWING PAVEMENT DISTRESS

5.2 PHOTOGRAPHS SHOWING PAVEMENT DISTRESS – Photographs were taken at surveyed sites and shown below in Plates 01 to 24.

Plate 01

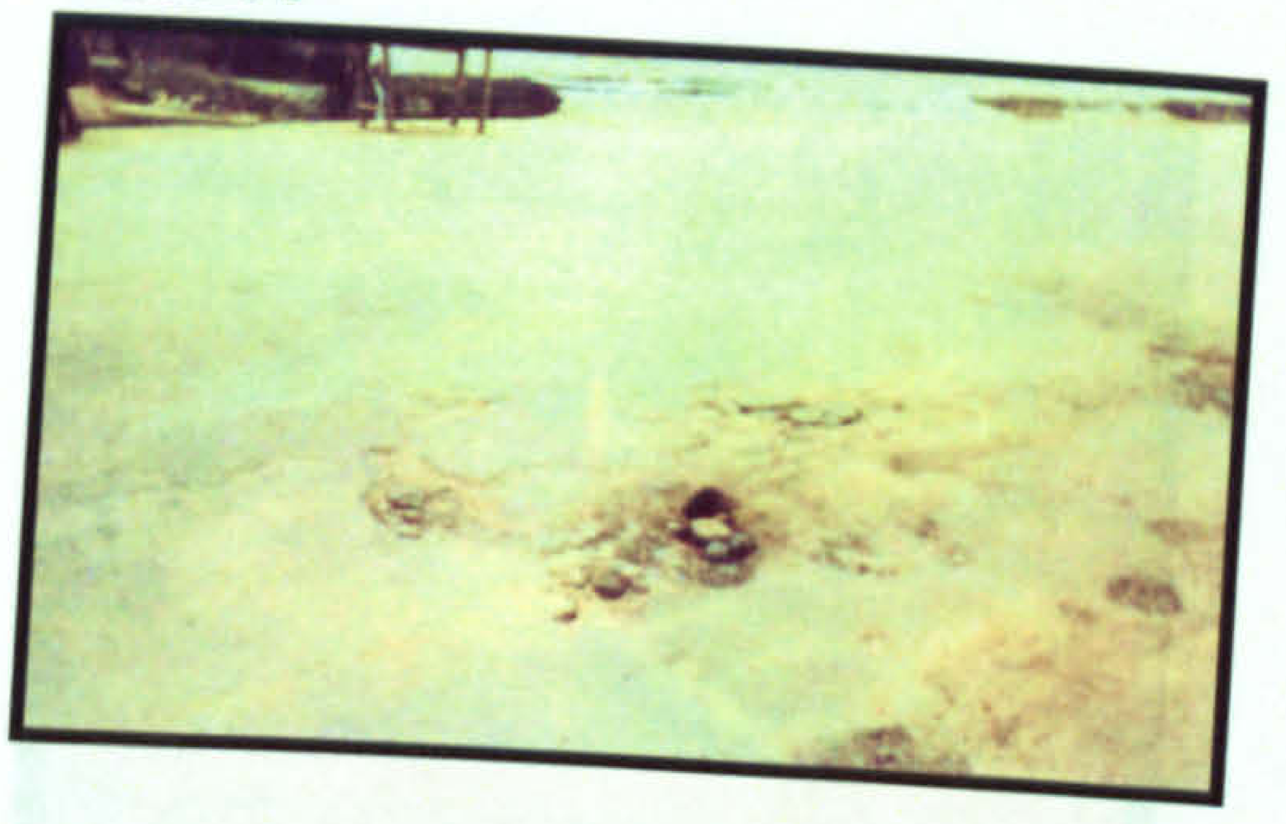


Plate 02

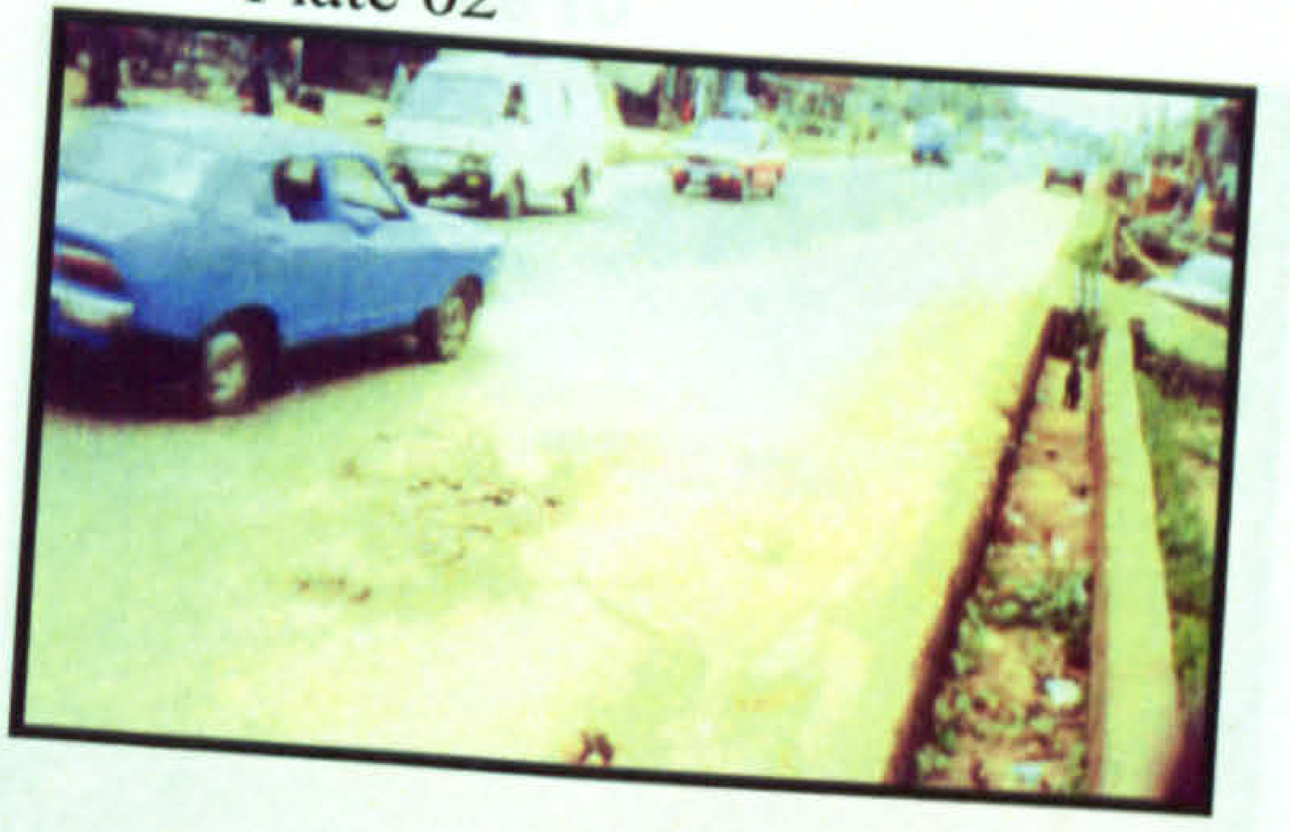


Plate 03

Plate 04

Plate 05

Plate 06

Plate 07

Plate 08

Plate 09

Plate 10

Plate 11

Plate 12

Plate 13

Plate 14

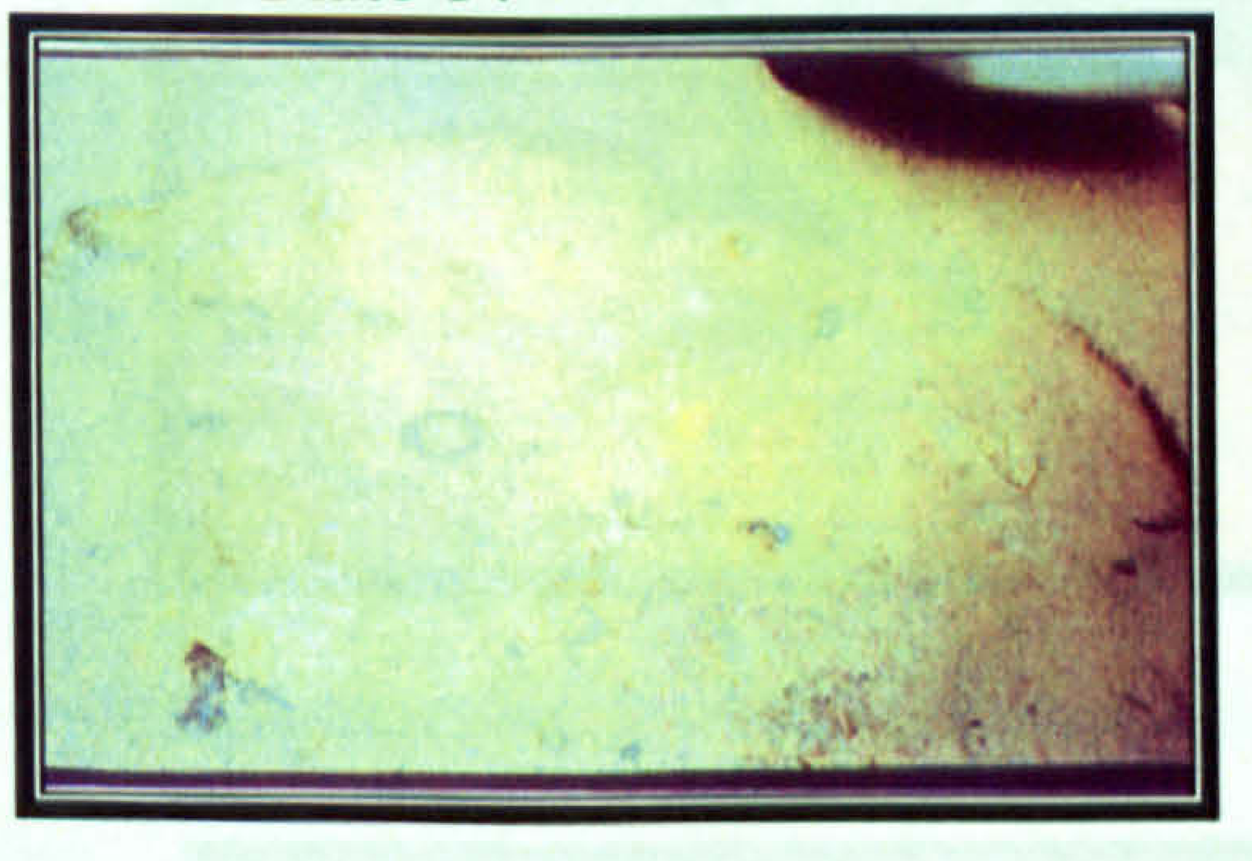


Plate 15

Plate 16

Plate 17

Plate 18

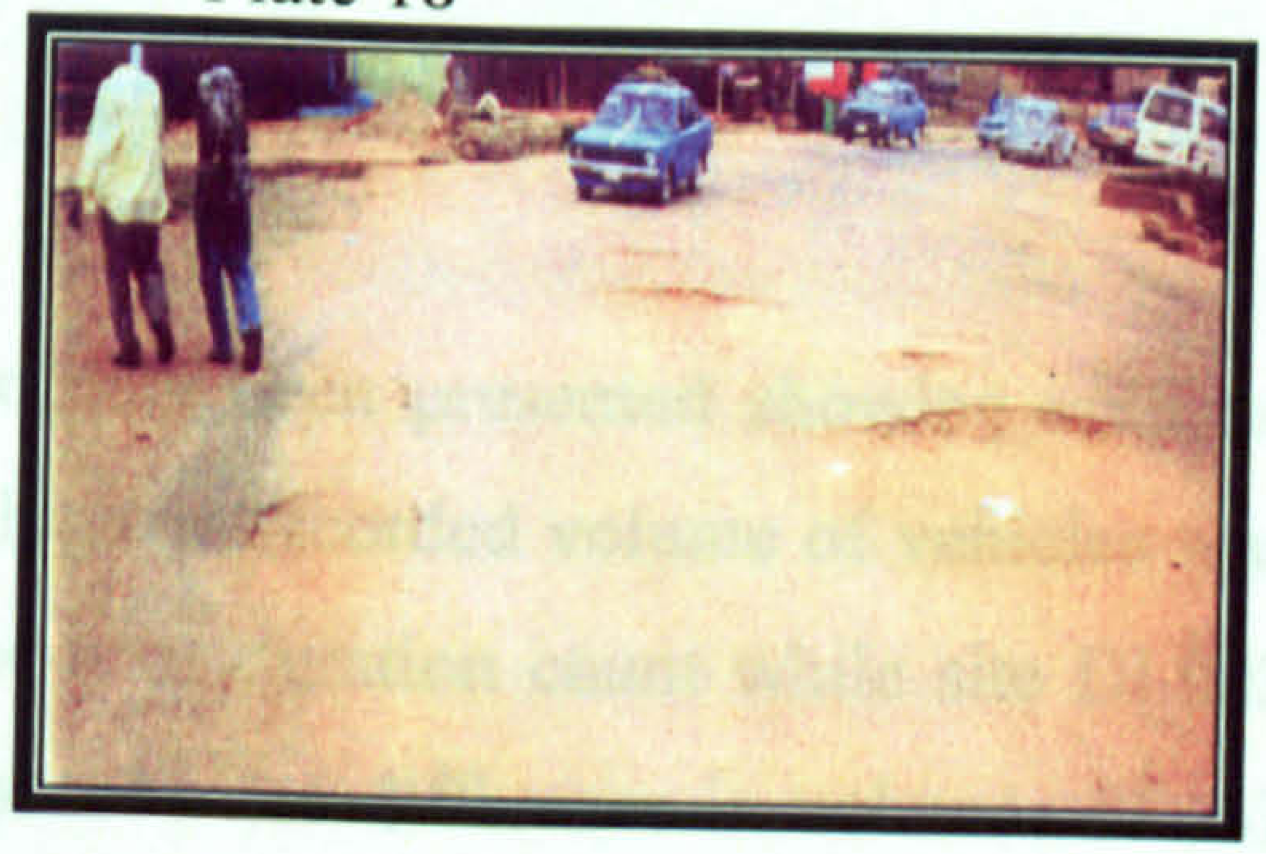


Plate 19

Plate 20

Plate 21

Plate 22

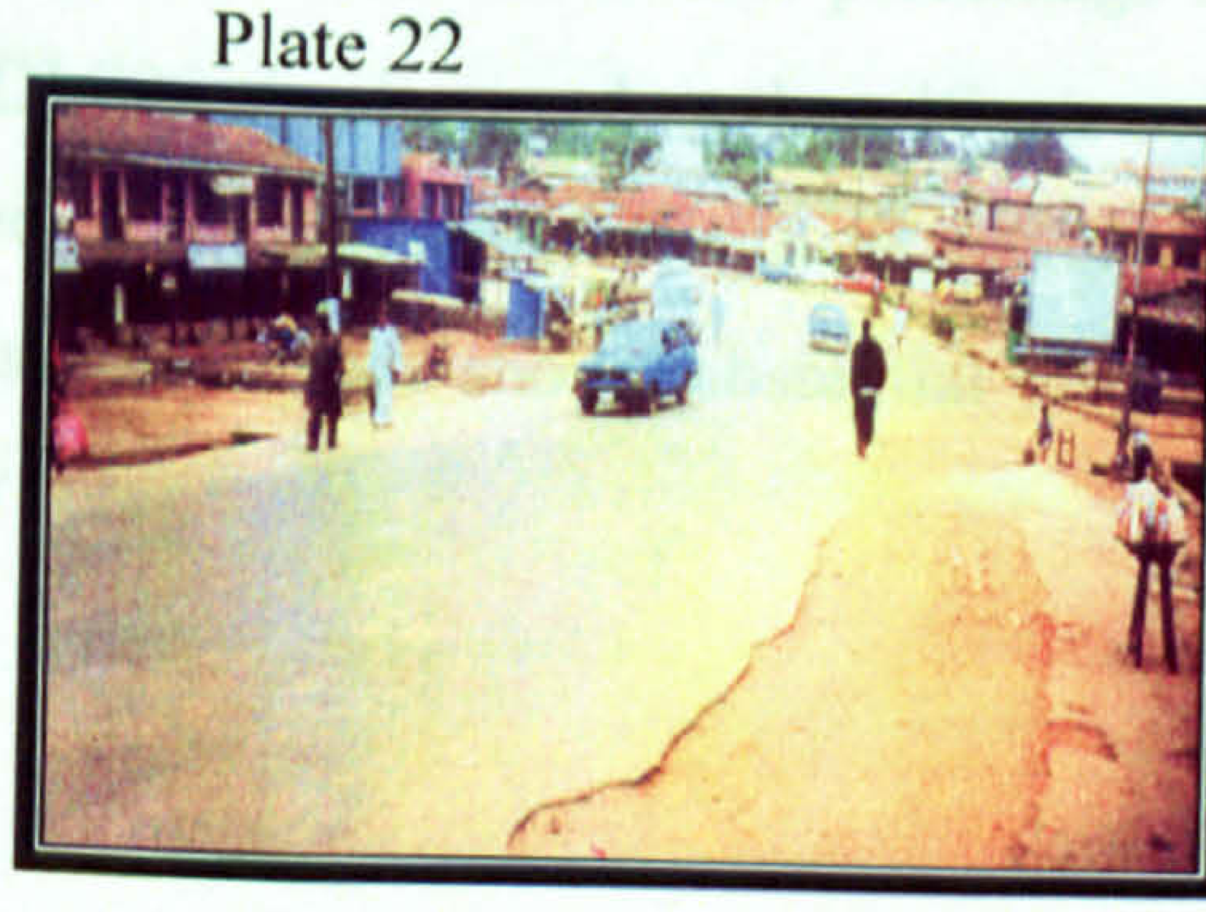


Plate 23

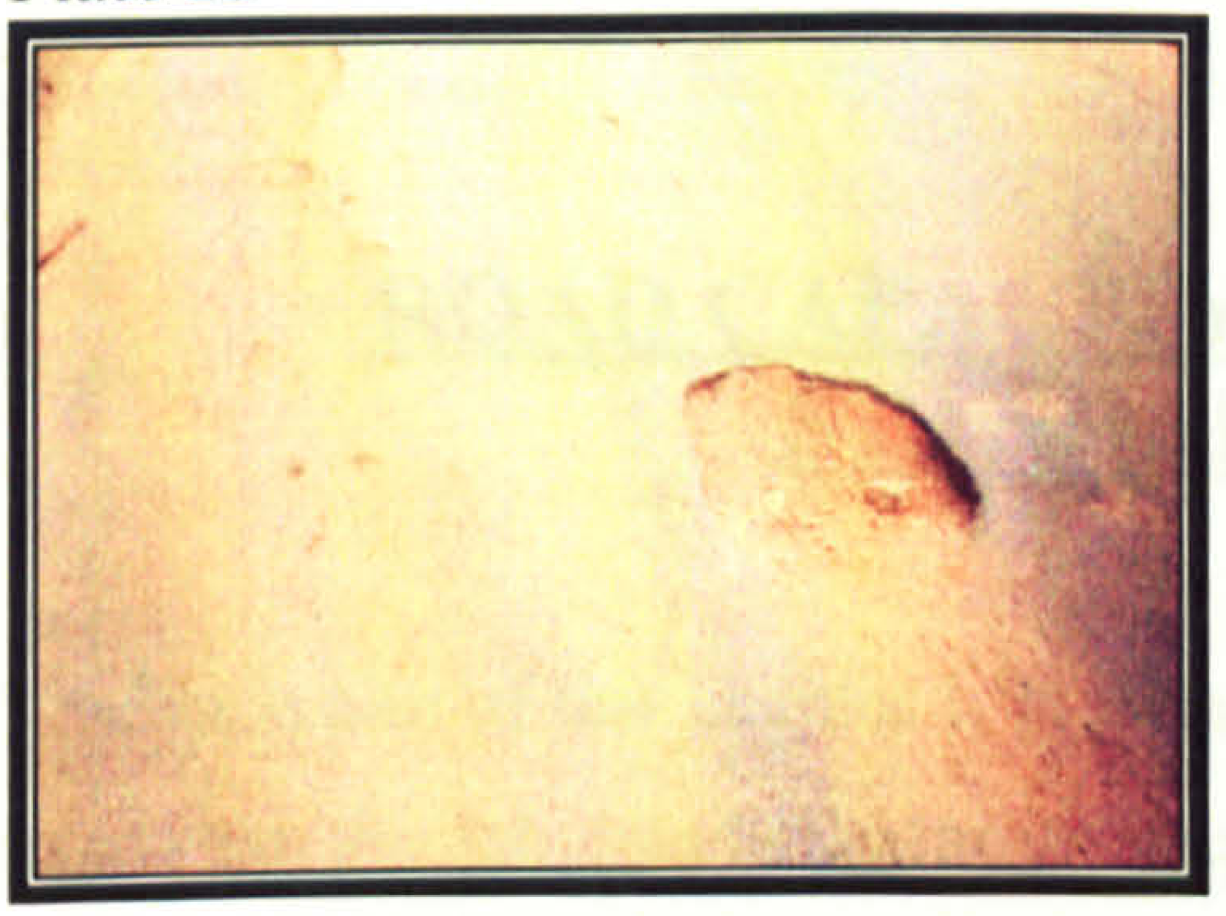


Plate 24

Source: Survey

5.3 SUMMARY

The empirical results from surveyed sites have now been presented showing volume, speed and the extent of pavement distress. The highest recorded volume of vehicles was at site AN001 with 666 vehicles during the one-hour duration count while site DL003 recorded the lowest at 483 vehicles. The highest recorded difference in volumes of 147 vehicles was at site AN001 with 666 vehicles at section A and 519 vehicles at section B. From the figure of 147 vehicles, passenger vehicles (62) and light good vehicles (65) accounted for 127 vehicles. The lowest recorded difference in volumes of 35 vehicles was at site DL003 with 483 vehicles at section A and 448 vehicles at section B. From 35 vehicles, passenger vehicles accounted for 29 vehicles. In some cases there were large presences of commercial vehicles and in others small. Site OS013; 62 per cent has the recorded percentage of commercial vehicles, with sites EK009, ED008, ED007, ED006, AN001 and DL002 having over 50 percent of commercial vehicles present during the surveyed period. By contrast, Site DL005 with 5 per cent has the lowest percentage of commercial vehicles, with sites OG010, DL004, DL005 also having less than 10 per cent commercial vehicle present at the time of survey. The sizes and depth of pavement distress vary from location to location. In all cases evidences show substantial drop in vehicle speeds especially with regard to passenger cars

6

ROAD CAPACITY LOSS ANALYSIS USING STANDARD PCE VALUES

The main aim of this chapter is to determine roadway capacity loss for the surveyed sites based on the tabulated results in chapter 5. The objectives are as follows: Determine traffic flow from vehicle volume and density from the speed / flow relationship relying on the fundamental diagram as shown in Figure 6.00; Compare the capacity in section A and B to establish whether a loss has occurred. By computing roadway capacity for each link section, it is recognised that capacity varies per road section and the method used for estimating capacities is based on the fundamental relationship between flow, speed and density. As mentioned in chapter 4 the estimation of this relationship is restricted to the un-congested part of flow/density curve. In the flow/density relationship density is used as the control parameter and flow is the objective function. However, before road capacity can be estimated it is important that the effect of mixed traffic is taken into consideration and this was done by way of volume conversion into passenger car equivalency units. PCE is usually the terminology employed in the United States and Canada, while PCU is commonly used in the United Kingdom.

Microsoft Excel quadratic function was used to compute the flow-density model coefficients and the coefficient of determination. The coefficient of determination compares estimated and actual y-values, and ranges in value from 0 to 1. If there it is 1, there is a perfect correlation in the sample-there is no difference between the estimated y-values and the actual y-value. At the other extreme if the coefficient of determination is 0, the quadratic equation is not helpful in predicting a y-value, thus cannot be used to estimate roadway capacities for the sections. The remainder of the chapter discusses the analyses of each surveyed site, summaries the model coefficients of the sites, and draw conclusions.

Figure 6.00 Schematic Diagrams of Roadway Capacity Loss Analyses

1. Using Tabulated Empirical Results in Chapter 5

Estimate Flow, Density, where

Flow (q) = 12 x volume / interval

Density (k) = flow / speed

Standard PCE values where PC =1, LGV = 1.5, HGV = 2

These are Nigerian Values modified and reapplied later on in Chapter 6

2. Use Flow/Density Relationship below:

$$q = -\beta_o + \beta_1 k - \beta_2 k^2$$

And determine flow/density model coefficients for the road sections, then

3. Estimate critical density by differentiating flow with respect to density for maximum flow (q_{max}) as follows:

$$\partial q / \partial \kappa = 0$$

$$- 2\beta_2 k + k = 0$$

For $k = k_{crt}$ (critical density) $\quad k_{crt} = \beta_1 / 2\beta_2$

4. Determine Roadway Capacity by estimating maximum flow per road section by plugging critical density into the flow / density model coefficients below:

$$q_{max} = -\beta_o + \beta_1 k_{crt} - \beta_2 k_{crt}^2$$

5. Compare the Road Capacity for Section A and B and determine road capacity Loss.

We assume that speed; flow and density relationships for the section A and B would be the same if it were not for the pavement distress. However, the pavement distresses on section B affect speed (v), flow (q) and density (k) relationship for section B. The roadway capacity models used here were adapted from Van Arem *et al (1994),* Minderhoud *et* al (*1998*), and Akcelik *(1991)* of the form:

$$q = -\beta_o + \beta_1 k - \beta_2 k^2 \quad \textit{equation 6.1}$$

Step 1 Using Tabulated Empirical Results in Chapter 5, convert vehicle volumes into PCUs by applying the following PCE values: PC =1, LGV = 1.5, HGV = 2, then estimate Flow, Density, where flow = 12 x volume / interval and densities were calculated using the fundamental speed - v, flow – q, and density – k, relations: $q = vk$ as shown in table 6.01. The working assumption that passenger car equivalent values are as stated above will be tested later on in Chapter 7. From observations and speed measurements at various sites with pavement distress it would be unrealistic to expect passenger cars to perform better than light goods vehicles and heavy goods vehicles on this kind of surface. Hence the issues PCE values associated with different types of vehicles would have to be re-addressed later in chapter 7. Meanwhile we may assume that the PCE values would hold for now.

Table 6.01a Computed Flows and Densities for Road AN001 Section A

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
27	29	8	43.5	16	86.5	1038	95	10.93
24	26	7	39.0	14	77.0	924	90	10.27
17	18	5	27.0	10	54.0	648	86	7.53
23	24	7	36.0	14	73.0	876	86	10.19
31	33	10	49.5	20	100.5	1206	85	14.19
17	18	5	27.0	10	54.0	648	92	7.04
19	21	6	31.5	12	62.5	750	92	8.15
22	24	7	36.0	14	72.0	864	92	9.39
26	27	8	40.5	16	82.5	990	95	10.42
17	18	5	27.0	10	54.0	648	95	6.82
24	26	7	39.0	14	77.0	924	95	9.73
32	35	10	52.5	20	104.5	1254	99	12.67
279	*299*	*85*				898(±116)	92(±2)	10(±1)

Survey: 05-12-2000 Time (5min. interval) 1700-1800 **Site:** Enugu / Onitsha Road Onitsha ANAMBRA STATE

Note: Computed Errors associated with Flow 13%, Speed 2% and Density 10%

Table 6.01b 95% CI for Flows, Speeds and Densities for Road AN001 Section A

1038	1077444	95	9025	10.93	119.465
924	853776	90	8100	10.27	105.473
648	419904	86	7396	7.53	56.701
876	767376	86	7396	10.19	103.836
1206	1454436	85	7225	14.19	201.356
648	419904	92	8464	7.04	49.5616
750	562500	92	8464	8.15	66.4225
864	746496	92	8464	9.39	88.1721
990	980100	95	9025	10.42	108.576
648	419904	95	9025	6.82	46.5124
924	853776	95	9025	9.73	94.6729
1254	1572516	99	9801	12.67	160.529
10770	10128132	1102	101410	117.33	1201.278
Mean =	898	Mean =	92	Mean =	10
	9666075		101200.3		1147.19
	42005.2		19.06061		4.91669
Std.=	204.95	Std.=	4.37	Std.=	2.22
Error	115.96	Error	2.47	Error	1.25
Section A	Flow	Section A	Speed	Section A	Density

Table 6.01c Computed Flows and Densities for Road AN001 Section B

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
22	23	7	34.50	14	70.50	846	44	19.23
17	18	5	27.00	10	54.00	648	44	14.73
13	14	4	21.00	8	42.00	504	47	10.72
20	21	6	31.50	12	63.50	762	45	16.93
18	19	6	28.50	12	58.50	702	45	15.60
18	20	6	30.00	12	60.00	720	45	16.00
19	20	6	30.00	12	61.00	732	47	15.57
19	21	6	31.50	12	62.50	750	47	15.96
21	23	7	34.50	14	69.50	834	47	17.74
15	16	5	24.00	10	49.00	588	48	12.25
18	19	6	28.50	12	58.50	702	48	14.63
17	18	5	27.00	10	54.00	648	45	14.40
217	232	69				703(±55)	46(±1)	15(±1)

Survey: 05-12-2000 Time: (5min. interval) 1700-1800 **Site:** Enugu / Onitsha Road Onitsha ANAMBRA STATE

Note: Computed Errors associated with Flow 8%, Speed 2% and Density 7%

Table 6.01d 95% CI for Flows, Speeds and Densities for Road AN001 Section B (Downstream)

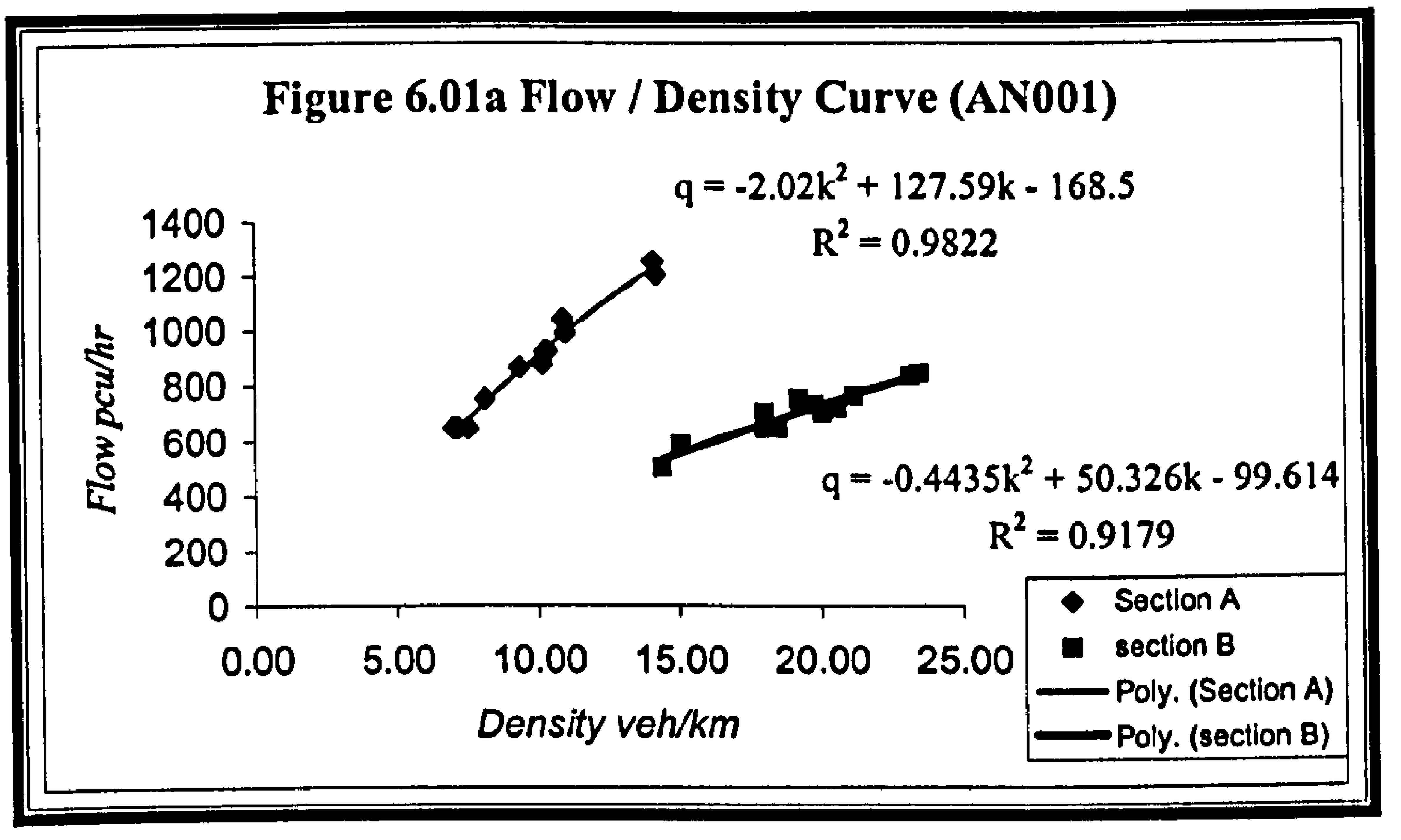
846	715716	44	1936	19.23	369.793
648	419904	44	1936	14.73	216.973
504	254016	47	2209	10.72	114.918
762	580644	45	2025	16.93	286.625
702	492804	45	2025	15.6	243.360
720	518400	45	2025	16	256.000
732	535824	47	2209	15.57	242.425
750	562500	47	2209	15.96	254.722
834	695556	47	2209	17.74	314.708
588	345744	48	2304	12.25	150.063
702	492804	48	2304	14.63	214.037
648	419904	45	2025	14.4	207.360
8436	6033816	552	25416	183.76	2870.983
Mean =	703	Mean =	46	Mean =	15
	5930508		25392		2813.9781
	9391.636		2.181818		5.1822242
Std.=	96.91	Std.=	1.48	Std.=	2.28
Error	54.83	Error	0.84	Error	1.29
Section B	Flow	Section B	Speed	Section B	Density

Step 2 By plugging the figures above for flow and density into equation 6.1, the model coefficients (see figure 6.01a) for both road sections were determined as:

$$q_A = -2.02k^2 + 27.598k - 168.5 \quad \textit{equation 6.2.1}$$

$$q_B = -0.4435k^2 + 50.326k - 99.614 \quad \textit{equation 6.3.1}$$

The model coefficients in equations 6.2.1and 6.3.1 have the expected signs and the coefficients of determinations (R^2) for road section A (upstream) 0.98 and Section B (downstream) 0.92 are much greater than 0.85 (see Table 2.3 HCM *1994*), it can be suggested that a strong relationship between flows and densities exists and the model could be used to estimate roadway capacity for the link sections. The F –observed statistics at 10 degree of freedom is much greater than F critical (4.94) suggesting that the relationship did not occur by chance. Also the t – observed statistic at 10 degree of freedom tested at 5 % significance level is much greater than 2 thus suggesting that density is an important variable when estimating flow. The statistics were taken directly from Microsoft Excel Spreadsheet output.



Step 3 By differentiating q with respect to κ; for a maximum value of flow (q): $\partial q / \partial \kappa = 0$; the critical densities (κ_{crt}) for sections A and B were established as:

Section A	$\partial q / \partial \kappa = 2(-2.02k) + 127.59;$
And	$-4.04k + 127.59 = 0$
	$\kappa_{crt} = 32 \ veh \ (km^{-1})$
Section B	$\partial q / \partial \kappa = 2(-0.4435k) + 50.326;$
And	$-0.887k + 50.326 = 0$
	$\kappa_{crt} = 57 \ veh \ (km^{-1})$

Step 4 The computed critical densities were plugged into equations 6.2.1 and 6.3.1 in order to determine the maximum flow per road sections as shown below:

$$q_A = -2.02(32)^2 + 127.59(32) - 168.5$$

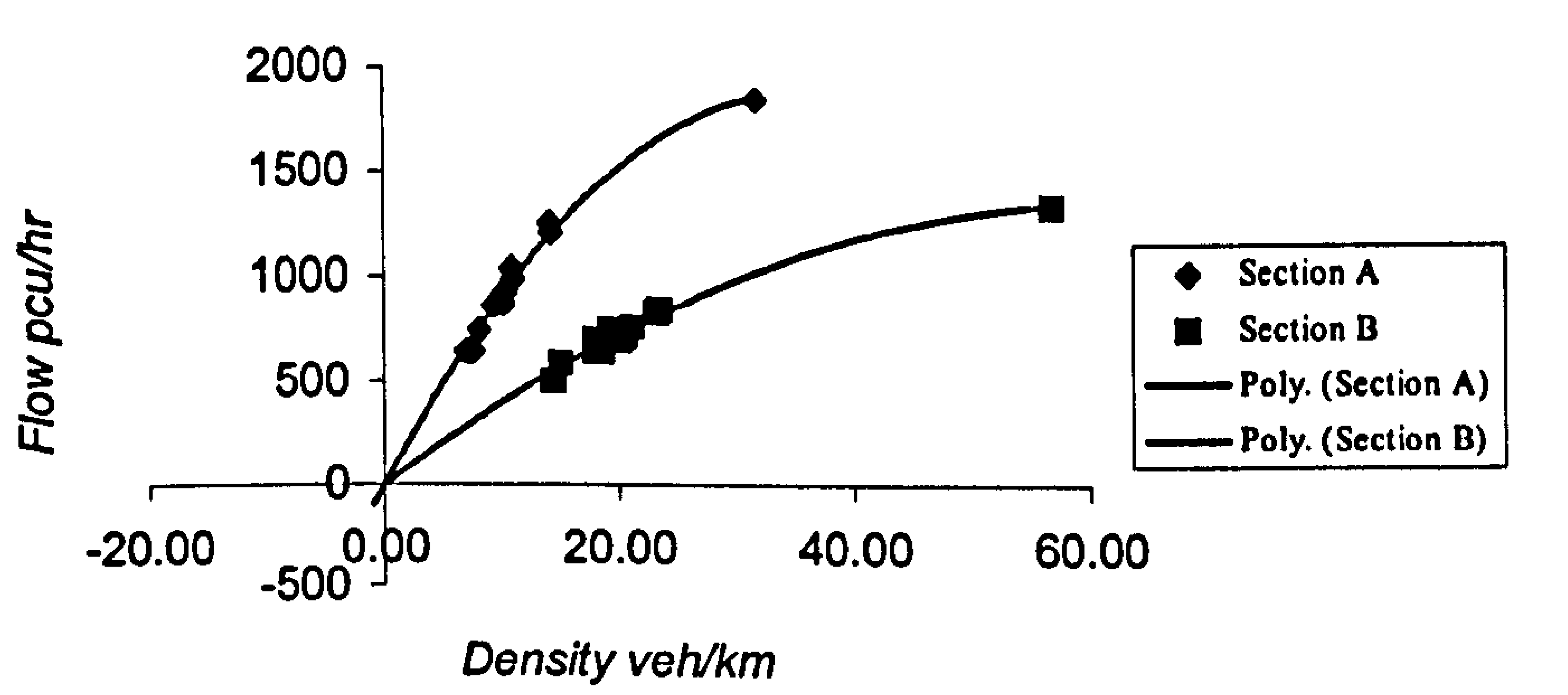
$$q_A = 1846 \ pcu/hr \ (\pm 13\%)$$

$$q_B = -0.4435(57)^2 + 50.326(57) - 99.614$$

$$q_B = 1328 \ pcu/hr (\pm 8\%)$$

However, the DTp advice note TA79/99 (*1999*) suggested a capacity of 1860 vehicle per hour for urban all-purpose UAP1 road with road carriageway width of 9.0m assuming a 60/40 directional split under favourable conditions. Therefore the computed capacity of 1846 pcu per hour *(±13%)* can be relied on to estimate road capacity loss. In any case since the DTp advice note TA79/99 (*1999*) did not suggest road capacity values under unfavourable conditions, the computed 1328 pcu/hr *(±8%)* for road section B was estimated and tested for reliability the way as that of section A, hence could be relied on for road capacity loss estimation.

Figure 6.01b Roadway At Capacity (AN001)



Step 5 Roadway Capacity loss for Road AN001 (1846 – 1328) = 518 *pcu/hr*

Percentage of Road Capacity loss (1846 – 14328) / 1846 = 28%

Road capacity loss resulted from 8 per cent pavement distress per km per carriageway lane in the presence of 58 per cent commercial vehicles. There are no other factors other than pavement distress that affected the roadway capacity loss between the road sections. As shown in Figures 6.01a and 601b flow / density curve for road the sections shifted from left to right suggesting that speeds decrease relative to higher densities (32 vehs/Km → 57 vehs/Km) and the argument that loss of speed will result from pavement distress remains valid. The curve shift from left to right means decrease in flows (figure 6.01a) and capacities (figure 6.01b). The road capacity loss estimations from remainder of the sites are illustrated below:

Site DL004 -

Table 6.02a Computed Flows and Densities for Road DL004 Section A

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
40	4	2	6	4	50	600	80	7.50
37	4	2	6	4	47	564	82	6.88
43	5	3	7.5	6	56.5	678	79	8.58
52	6	3	9	6	67	804	81	9.93
45	5	3	7.5	6	58.5	702	85	8.26
45	5	3	7.5	6	58.5	702	88	7.98
37	4	2	6	4	47	564	79	7.14
55	6	3	9	6	70	840	93	9.03
36	4	2	6	4	46	552	86	6.42
36	4	2	6	4	46	552	78	7.08
38	4	2	6	4	48	576	85	6.78
38	4	2	6	4	48	576	85	6.78
502	55	29				634(±57)	83(±2)	8(±1)

Survey: 07-12-2000 Time: (5min. interval) 0800-0900 Site: Refinery Road (16) Warri DELTA STATE
Note: Computed Errors associated with Flow 9%, Speed 2% and Density 12%

Table 6.02b Computed Flows and Densities for Road DL004 Section B

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
25	3	2	4.5	4	33.5	402	42	9.57
22	3	2	4.5	4	30.5	366	42	8.71
28	4	2	6	4	38	456	42	10.86
35	5	3	7.5	6	48.5	582	40	14.55
29	4	2	6	4	39	468	40	11.70
29	4	2	6	4	39	468	39	12.00
22	3	2	4.5	4	30.5	366	38	9.63
37	5	3	7.5	6	50.5	606	40	15.15
22	3	2	4.5	4	30.5	366	42	8.71
30	4	2	6	4	40	480	42	11.43
32	4	2	6	4	42	504	42	12.00
32	4	2	6	4	42	504	42	12.00
343	46	26				464(±45)	41(±1)	11(±1)

Survey: 07-12-2000 Time: (5min. interval) 0800-0900 Site: Refinery Road (16) Warri DELTA STATE
Note: Computed errors associated with Flow 10%, Speed 2% and Density 9%

By plugging the figures above for flow and density into equation 6.1, the model coefficients (see figure 6.04a) for both road sections were determined as:

$$q_A = -2.218k^2 + 123.98k - 177.83 \quad \textit{equation 6.2.2}$$
$$q_B = -0.5079k^2 + 50.26k - 39.438 \quad \textit{equation 6.3.2}$$

The model coefficients have the correct signs and as shown in Figure 6.04a, the coefficient of determination (R^2) 0.92 for section A and 0.94 for section B suggesting a strong relationship between flows and densities and the model could be used to estimate roadway capacity for the link sections. The F –observed statistics at 10 degree of freedom is much greater than F critical (4.94) suggesting that the relationship did not occur by chance. Also the t – observed statistic at 10 degree of freedom tested at 5 % significance level is much greater than 2 thus suggesting that density is an important variable when estimating flow. By differentiating q with respect to κ; for a maximum value of q:

$$\partial q / \partial \kappa = 0.$$

The critical densities (κ_{crt}) for sections A and B were established as:

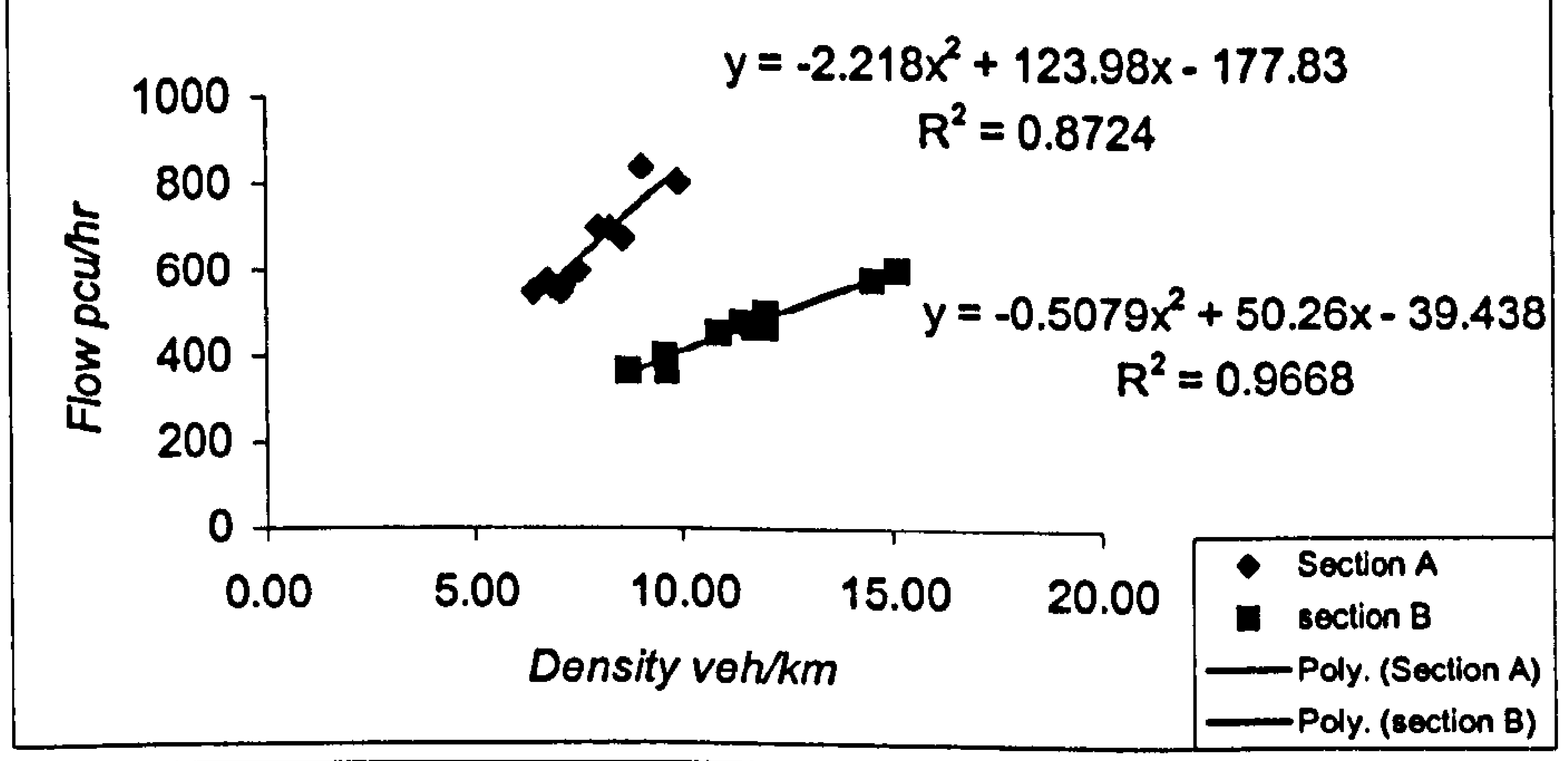
Section A $\quad \partial q / \partial \kappa = -4.436k + 123.98 = 0;$

And $\quad \kappa_{crt} = 28 \ veh \ (km^{-1})$

Section B $\quad \partial q / \partial \kappa = -1.0158k + 50.26 = 0;$

And $\quad \kappa_{crt} = 50 \ veh \ (km^{-1})$

Figure 6.04a Flow / Density Curve (DL004)



The computed critical densities were plugged into equations 6.2.2 and 6.3.2 in order to determine the maximum flow per road sections as shown below:

$$q_A = -2.218(28)^2 + 123.98(28) - 177.83 \quad \textit{equation 6.2.2}$$

$$q_A = 1555\ pcu/hr\ (\pm 9\%)$$

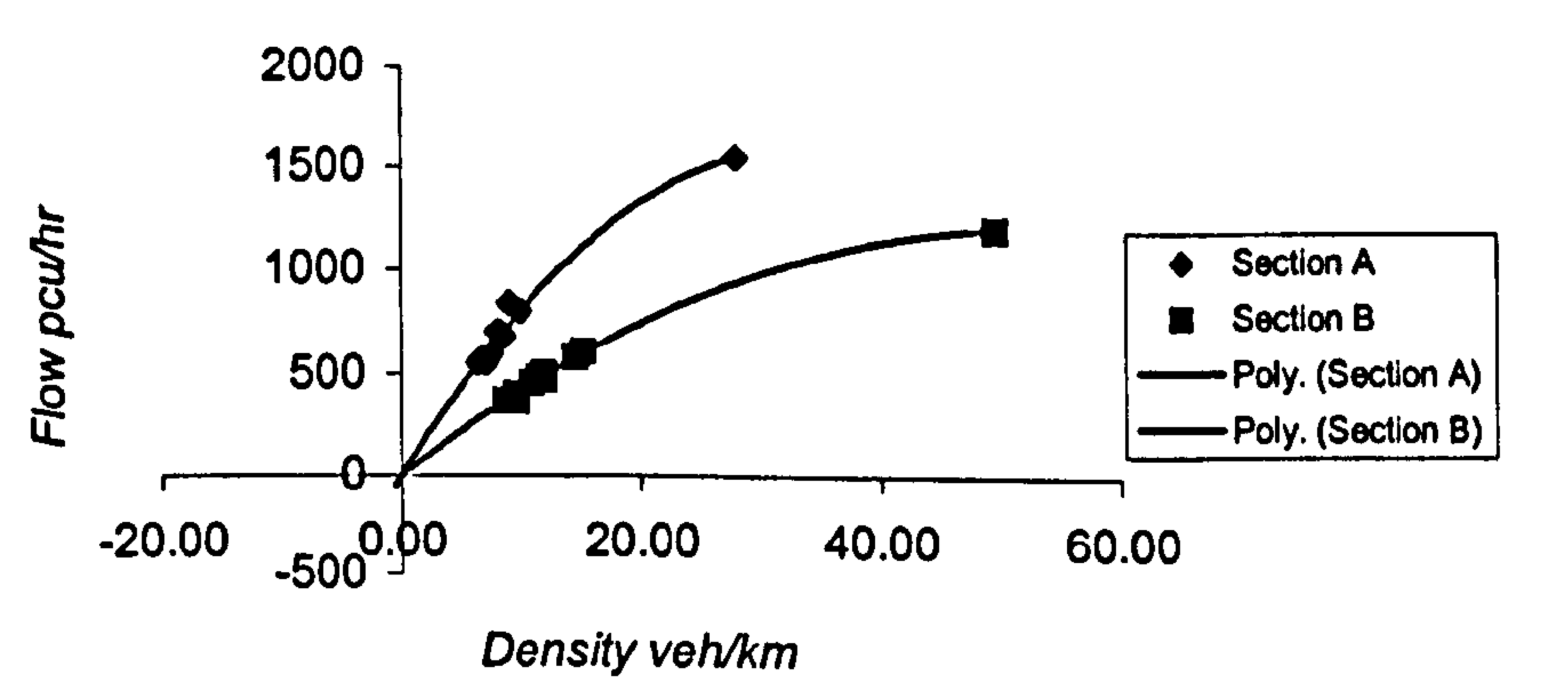
$$q_B = -0.5079(50)^2 + 50.26(50) - 39.438 \quad \textit{equation 6.3.2}$$

$$q_B = 1204\ pcu/hr (\pm 10\%)$$

Roadway Capacity loss for Road DL004 (1555 – 1204) = *351 pcu/hr*
Percentage of Capacity loss (1555 – 1204) / 1555 = 23.0%

Based on the roadway capacity analysis shown above, 23 % capacity loss resulted from 4.4% pavement distress per Km per carriageway lane in the presence of 16.9 % commercial vehicles. As shown in Figures 6.04a and 6.04b flow / density curve for road the sections shifted from left to right suggesting that speeds decrease relative to higher densities (28vehs/Km → 50vehs/Km) and the argument that loss of speed will result from pavement distress remains valid.

Figure 6.04b Roadway At Capacity (DL004)



Site DL005 –

Table 6.03a Computed Flows and Densities for Road DL005 Section A

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
33	1	1	1.5	2	36.5	438	82	5.34
48	2	1	3	2	53	636	82	7.76
46	2	0	3	0	49	588	90	6.53
32	1	1	1.5	2	35.5	426	90	4.73
36	2	0	3	0	39	468	89	5.26
33	1	1	1.5	2	36.5	438	89	4.92
44	2	0	3	0	47	564	85	6.64
37	2	0	3	0	40	480	90	5.33
30	1	1	1.5	2	33.5	402	89	4.52
43	2	0	3	0	46	552	85	6.49
38	2	0	3	0	41	492	83	5.93
45	2	0	3	0	48	576	83	6.94
465	20	5				505(±43)	86(±2)	6(±0.5)

Survey: 07-12-2000 Time: (5min. interval) 1700-1800 **Site:** Warri / Sapele Road Warri, DELTA STATE
Note: Computed errors associated with Flow 8%, Speed 1% and Density 8.3%

Table 6.03b Computed Flows and Densities for Road DL005 Section B

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
31	1	1	1.5	2	34.5	414	39	10.62
40	2	1	3	2	45	540	40	13.50
42	2	0	3	0	45	540	40	13.50
31	1	1	1.5	2	34.5	414	40	10.35
38	2	0	3	0	41	492	41	12.00
33	1	1	1.5	2	36.5	438	40	10.95
37	2	0	3	0	40	480	38	12.63
50	2	0	3	0	53	636	38	16.74
33	1	1	1.5	2	36.5	438	39	11.23
32	1	0	1.5	0	33.5	402	39	10.31
38	2	0	3	0	41	492	39	12.62
38	2	0	3	0	41	492	39	12.62
443	19	5				482(±38)	39(±0.5)	12(±1)

Survey: 07-12-2000 Time: (5min. interval) 1700-1800 **Site:** Warri / Sapele Road Warri, DELTA STATE
Note: Computed errors associated with Flow 8%, Speed 1% and Density 8%

By plugging the figures above for flow and density into equation 6.1, the model coefficients (see figure 6.05a) for both road sections were determined as:

$$q_A = -2.2922k^2 + 101.28k - 8.1055 \quad \textit{equation 6.2.3}$$
$$q_B = -1.0255k^2 + 63.795k - 143.15 \quad \textit{equation 6.3.3}$$

The model coefficients have the correct signs and as shown in Figure 6.05a, the coefficient of determination (R^2) 0.92 for section A and 0.99 for section B suggesting a strong relationship between flows and densities and the model could be used to estimate roadway capacity for the link sections. The F –observed statistics at 10 degree of freedom is much greater than F critical (4.94) suggesting that the relationship did not occur by chance. Also the t – observed statistic at 10 degree of freedom tested at 5 % significance level is much greater than 2 thus suggesting that density is an important variable when estimating flow. By differentiating q with respect to κ; for a maximum value of q:

$$\partial q / \partial \kappa = 0;$$

The critical densities (κ_{crt}) for sections A and B were established as:

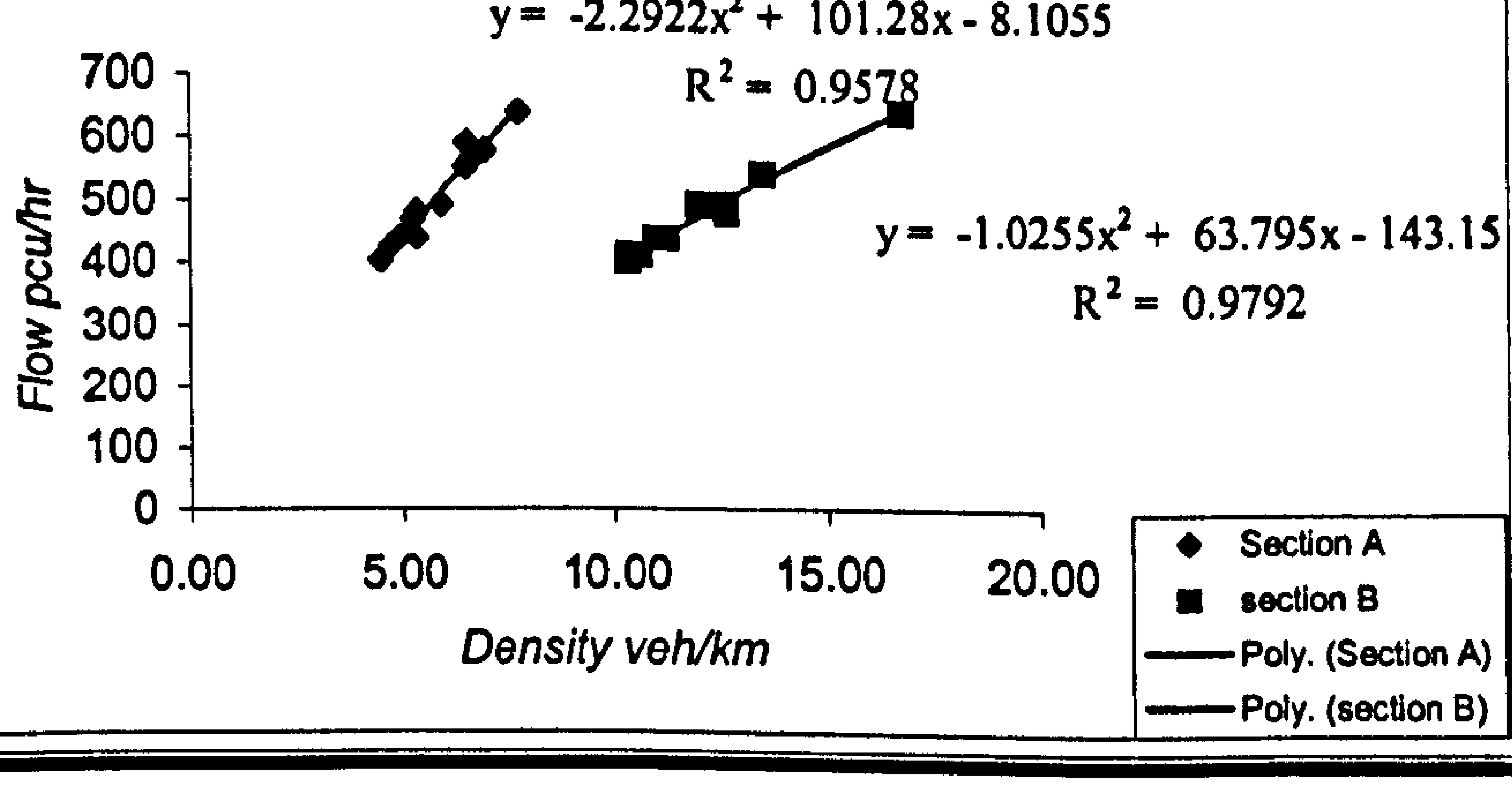
Section A $\quad \partial q / \partial \kappa = 2(-2.2922k) + 101.28 = 0;$

And $\quad \kappa_{crt} = 22$ *veh* (km^{-1})

Section B $\quad \partial q / \partial \kappa = 2(-1.0255k) + 63.795 = 0;$

And $\quad \kappa_{crt} = 31$ veh (km^{-1})

Figure 6.05a Flow / Density Curve (DL005)



The computed critical densities were plugged into equations 6.2.3 and 6.3.3 in order to determine the maximum flow per road sections as shown below:

$q_A = -2.2922(22)^2 + 101.28(22) - 8.1055$ *equation 6.2.3*

$q_A = 1111$ *pcu/hr (±8%)*

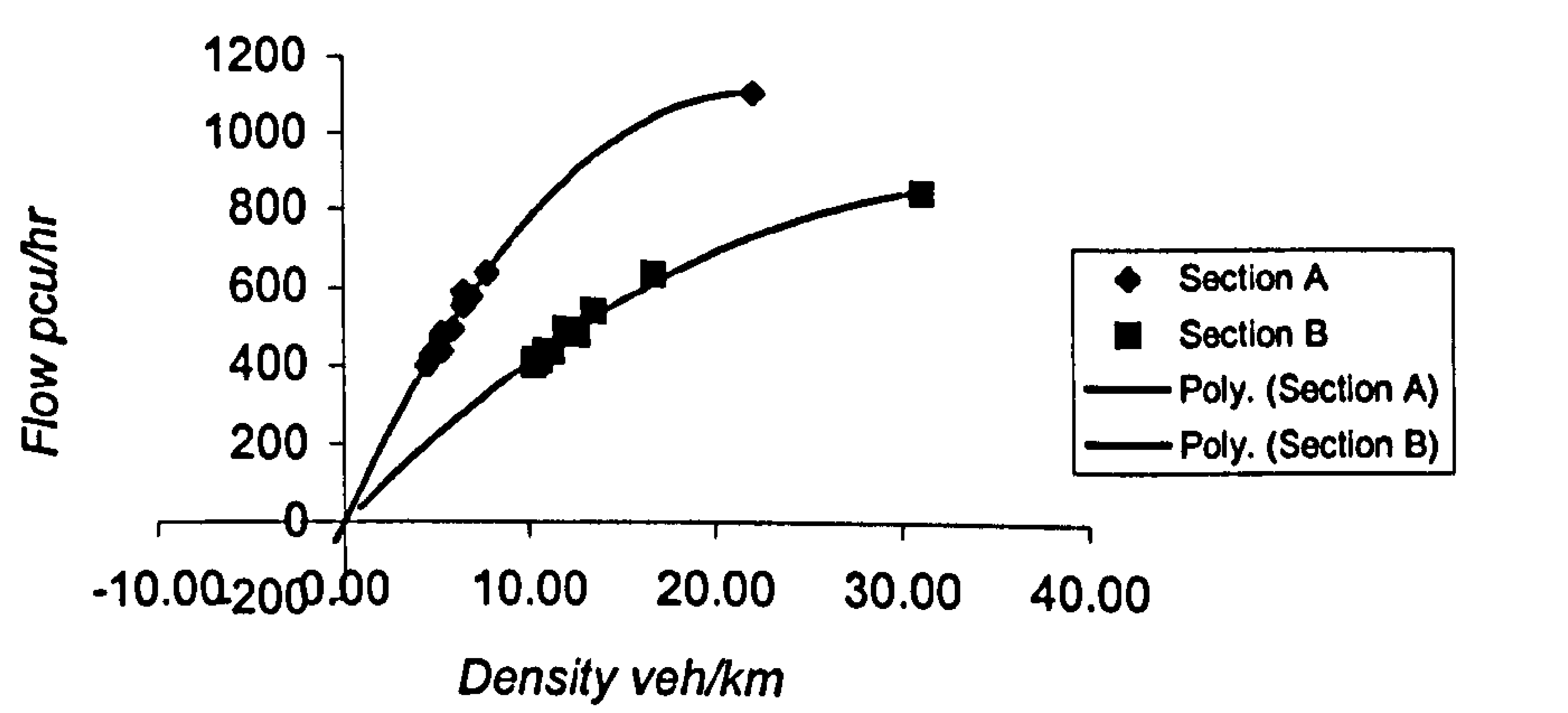
$q_B = -1.0255(31)^2 + 63.795(31) - 143.15$ *equation 6.3.3*

$q_B = 849$ pcu/hr *(±8%)*

Roadway Capacity loss for Road DL005 (1111 – 849) = 261 pcu/hr
Percentage of Capacity loss (1111 – 849) / 1111 = 24.0%

Based on the roadway capacity analysis shown above, 24% capacity loss resulted from 4.9% pavement distress per Km per carriageway lane in the presence of 4.9% commercial vehicles. As shown in Figures 6.05a and 6.5b, flow / density curve for road the sections shifted from left to right suggesting that speeds decrease relative to higher densities 22vehs/Km → 31vehs/Km) and the argument that loss of speed will result from pavement distress remains valid.

Figure 6.05b Roadway At Capacity (DL005)



Site ED006 -

Table 6.04a Computed Flows and Densities for Road ED006 Section A

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
21	27	3	40.5	6	67.5	810	89	9.10
24	30	3	45	6	75	900	80	11.25
26	32	3	48	6	80	960	85	11.29
27	34	3	51	6	84	1008	80	12.60
27	34	3	51	6	84	1008	80	12.60
21	27	3	40.5	6	67.5	810	85	9.53
28	36	3	54	6	88	1056	85	12.42
23	29	3	43.5	6	72.5	870	86	10.12
30	38	4	57	8	95	1140	83	13.73
26	32	3	48	6	80	960	86	11.16
15	19	2	28.5	4	47.5	570	86	6.63
16	20	2	30	4	50	600	85	7.06
284	358	35				891(±97)	84(±2)	11(±1)

Survey: 08-12-2000 Time: (5min. interval) 0800-0900 **Site:** Ogida Road Benin EDO STATE
Note: Computed errors associated with Flow 11%, Speed 2% and Density 9%

Table 6.04b Computed Flows and Densities for Road ED006 Section B

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
20	25	2	37.5	4	61.5	738	39	18.92
17	22	2	33	4	54	648	37	17.51
26	33	3	49.5	6	81.5	978	39	25.08
24	30	3	45	6	75	900	37	24.32
18	23	2	34.5	4	56.5	678	39	17.38
24	30	3	45	6	75	900	39	23.08
19	24	2	36	4	59	708	40	17.70
24	30	3	45	6	75	900	40	22.50
23	29	3	43.5	6	72.5	870	40	21.75
21	27	3	40.5	6	67.5	810	39	20.77
15	20	2	30	4	49	588	39	15.08
17	21	2	31.5	4	52.5	630	40	15.75
248	314	30				779(±73)	39(±0.6)	20(±2)

Survey: 08-12-2000 Time: (5min. interval) 0800-0900 **Site:** Ogida Road Benin EDO STATE
Note: Computed errors associated with Flow 9%, Speed 1% and Density 10%

By plugging the figures above for flow and density into equation 6.1, the model coefficients (see figure 6.06a) for both road sections were determined as:

$$q_A = -1.8229k^2 + 113.35k - 99.337 \quad \textit{equation 6.2.4}$$

$$q_B = -0.5283k^2 + 59.133k - 186.32 \quad \textit{equation 6.3.}$$

The model coefficients have the correct signs and as shown in Figure 6.06a, the coefficient of determination (R^2) 0.94 for section A and 0.94 for section B suggesting a strong relationship between flows and densities and the model could be used to estimate roadway capacity for the link sections. The F –observed statistics at 10 degree of freedom is much greater than F critical (4.94) suggesting that the relationship did not occur by chance. Also the t – observed statistic at 10 degree of freedom tested at 5 % significance level is much greater than 2 thus suggesting that density is an important variable when estimating flow. By differentiating q with respect to κ; for a maximum value of q:

$$\partial q / \partial \kappa = 0.$$

The critical densities (κ_{crt}) for sections A and B were established as:

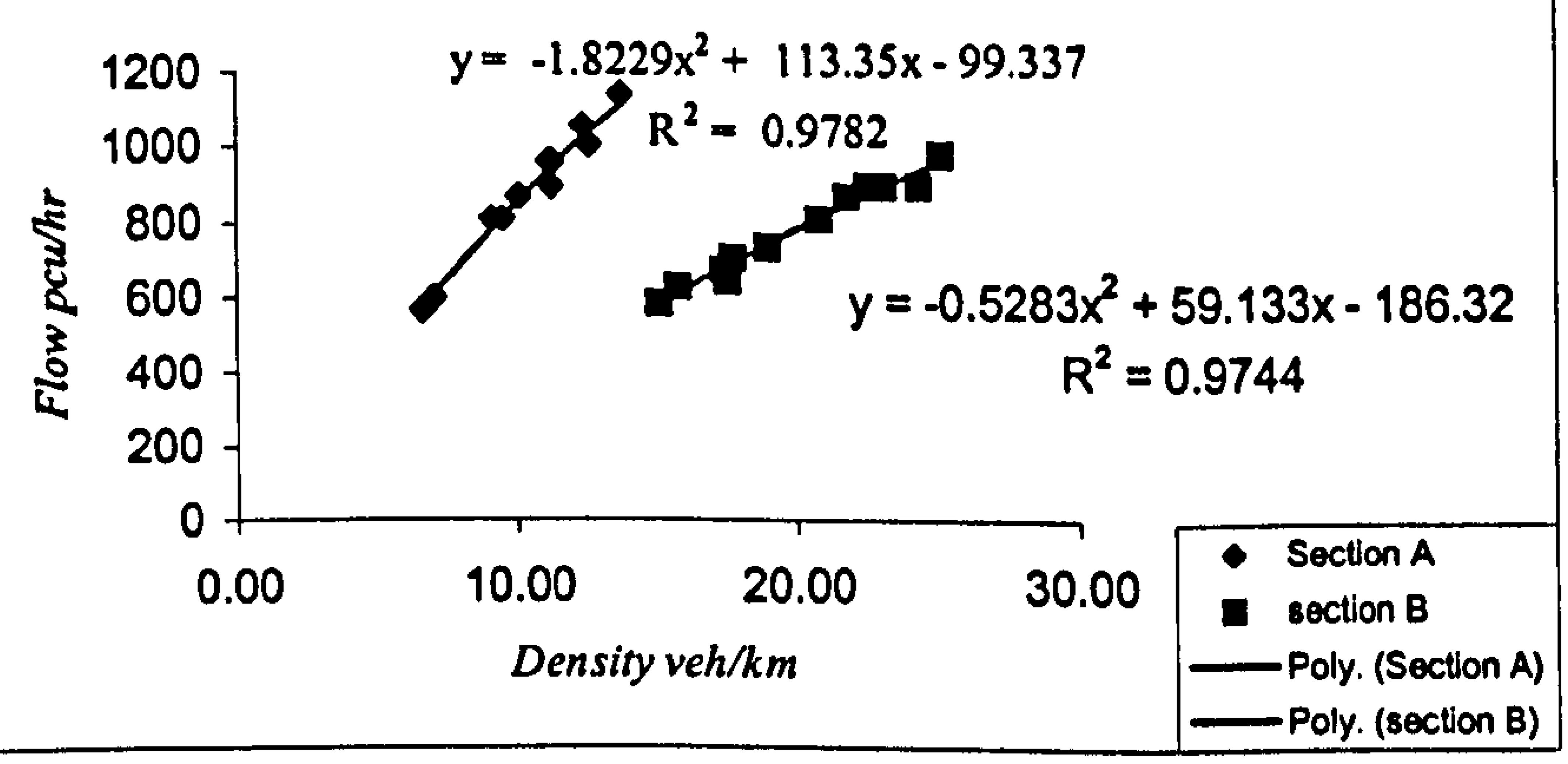
Section A $\quad \partial q / \partial \kappa = 2(-1.8229k) + 113.35 = 0;$

And $\quad \kappa_{crt} = 31 \text{ veh } (km^{-1})$

Section B $\quad \partial q / \partial \kappa = 2(-0.5283k) + 59.133 = 0;$

And $\quad \kappa_{crt} = 56 \text{ veh } (km^{-1})$

Figure 6.06a Flow / Density Curve (ED006)



The computed critical densities were plugged into equations 6.2.4 and 6.3.4 in order to determine the maximum flow per road sections as shown below:

$$q_A = -1.8229(31)^2 + 113.35(31) - 99.337 \quad \text{equation 6.2.4}$$

$$q_A = 1663\ pcu/hr\ (\pm 11\%)$$

$$q_B = -0.5283(56)^2 + 59.133(56) - 186.32 \quad \text{equation 6.3.4}$$

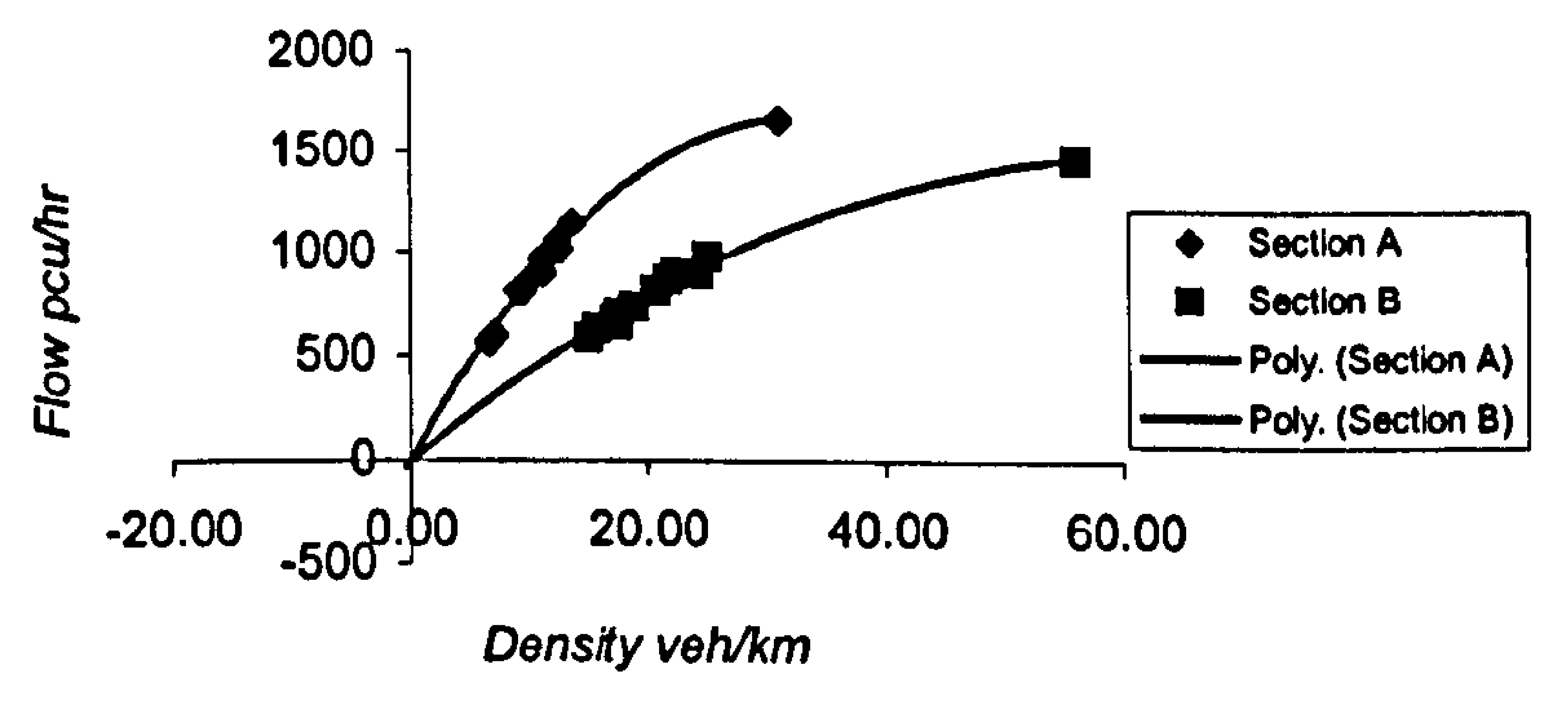
$$q_B = 1468\ pcu/hr\ (\pm 9\%)$$

Roadway Capacity loss for Road ED006 (1663 – 1468) = 194 pcu/hr

Percentage of Capacity loss (1663 – 1468) / 1663 = 12.0%

Based on the roadway capacity analysis shown above, 12% capacity loss resulted from 7.2% pavement distress per Km per carriageway lane in the presence of 55% commercial vehicles. As shown in Figures 6.06a and 6.06b, flow / density curve for road the sections shifted from left to right suggesting that speeds decrease relative to higher densities (31vehs/Km → 56vehs/Km) and the argument that loss of speed will result from pavement distress remains valid.

Figure 6.05b Roadway At Capacity (ED006)



Site ED007 -

Table 6.05a Computed Flows and Densities for Road ED007 Section A

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
19	24	2	36	4	59	708	80	8.85
12	15	1	22.5	2	36.5	438	79	5.54
21	27	3	40.5	6	67.5	810	86	9.42
24	30	3	45	6	75	900	79	11.39
14	17	2	25.5	4	43.5	522	83	6.29
21	27	3	40.5	6	67.5	810	80	10.13
16	21	2	31.5	4	51.5	618	84	7.36
18	23	2	34.5	4	56.5	678	86	7.88
16	21	2	31.5	4	51.5	618	80	7.73
18	23	2	34.5	4	56.5	678	78	8.69
19	24	2	36	4	59	708	79	8.96
24	31	3	46.5	6	76.5	918	80	11.48
222	283	27				701(±81)	81(±1.6)	9(±1)

Survey: 08-12-2000 Time: (5min. interval) 1700-1800 **Site:** Upper Sakponba Road Benin EDO STATE
Note: Computed errors associated with Flow 11%, Speed 1% and Density 11%

Table 6.05b Computed Flows and Densities for Road ED007 Section B

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
16	20	2	30	4	50	600	36	16.67
11	13	1	19.5	2	32.5	390	38	10.26
13	17	2	25.5	4	42.5	510	43	11.86
16	21	2	31.5	4	51.5	618	45	13.73
13	16	2	24	4	41	492	44	11.18
20	25	2	37.5	4	61.5	738	40	18.45
10	12	1	18	2	30	360	44	8.18
16	21	2	31.5	4	51.5	618	44	14.05
12	15	1	22.5	2	36.5	438	43	10.19
21	26	2	39	4	64	768	40	19.20
16	21	2	31.5	4	51.5	618	40	15.45
15	19	2	28.5	4	47.5	570	39	14.62
179	226	21				560(±72)	41(±1.6)	14(±2)

Survey: 08-12-2000 Time: (5min. interval) 1700-1800 **Site:** Upper Sakponba Road Benin EDO STATE
Note: Computed errors associated with Flow 13%, Speed 4% and Density 14%

By plugging the figures above for flow and density into equation 6.1, the model coefficients (see figure 6.07a) for both road sections were determined as:

$$q_A = -1.8194k^2 + 109k - 100.07 \quad \textit{equation 6.2.5}$$
$$q_B = -0.5088k^2 + 49.646k - 17.473 \quad \textit{equation 6.3.5}$$

The model coefficients have the correct signs and as shown in Figure 6.07a, the coefficient of determination (R^2) 0.87 for section A and 0.93 for section B suggesting a strong relationship between flows and densities and the model could be used to estimate roadway capacity for the link sections. The F –observed statistics at 10 degree of freedom is much greater than F critical (4.94) suggesting that the relationship did not occur by chance. Also the t – observed statistic at 10 degree of freedom tested at 5 % significance level is much greater than 2 thus suggesting that density is an important variable when estimating flow. By differentiating q with respect to κ; for a maximum value of q:

$$\partial q / \partial \kappa = 0;$$

The critical densities (κ_{crt}) for sections A and B were established as:

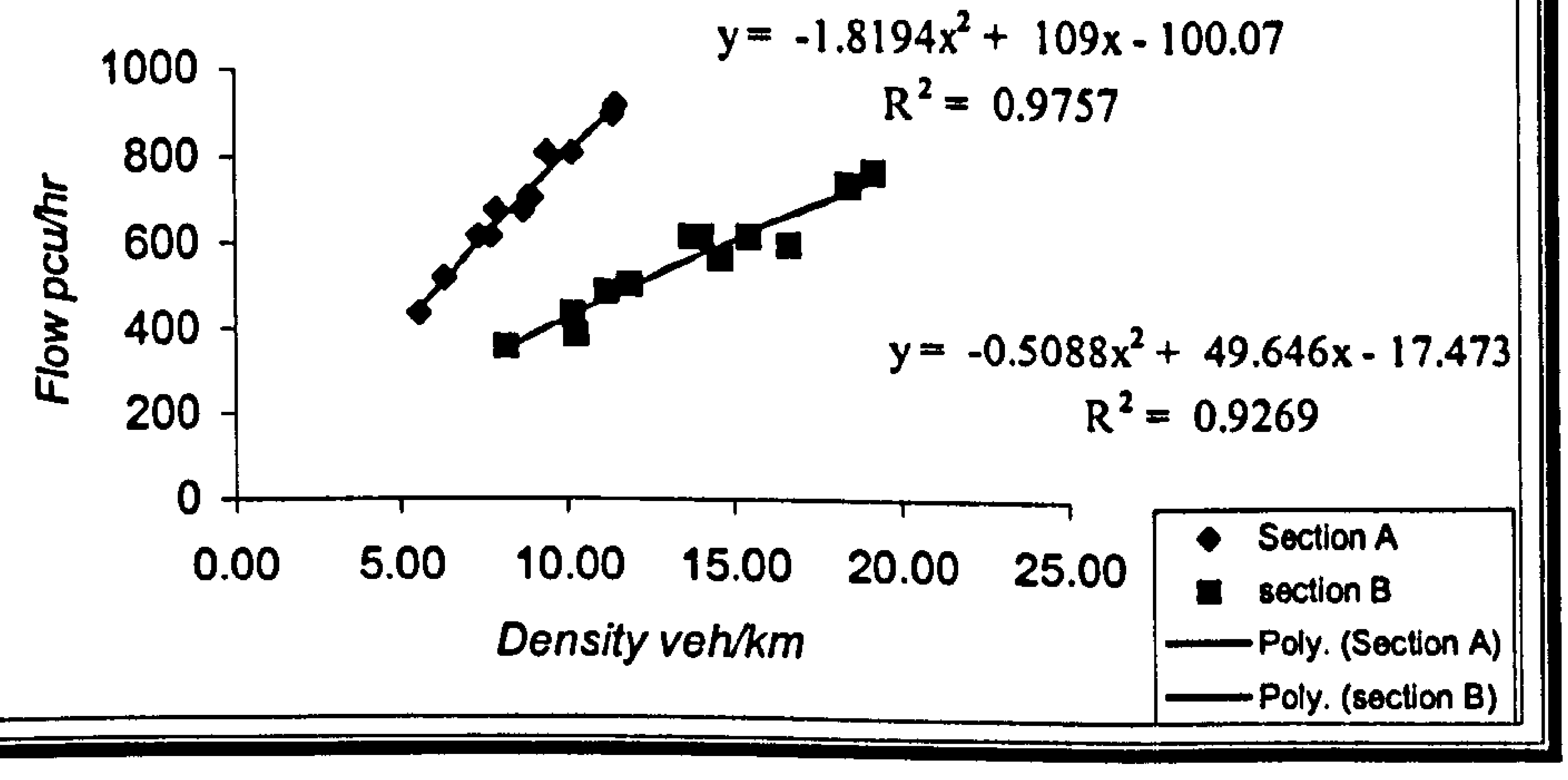
Section A $\quad \partial q / \partial \kappa = 2(-1.8194k) + 109 = 0;$

And $\quad \kappa_{crt} = 30 \ veh\ (km^{-1})$

Section B $\quad \partial q / \partial \kappa = 2(-0.5088k) + 49.646 = 0;$

And $\quad \kappa_{crt} = 49 \ veh\ (km^{-1})$

Figure 6.07a Flow / Density Curve (ED007)



The computed critical densities were plugged into equations 6.2.5 and 6.3.5 in order to determine the maximum flow per road sections as shown below:

$$q_A = -1.8194(30)^2 + 109(30) - 100.07 \quad \textit{equation 6.2.5}$$

$$q_A = 1533\ pcu/hr\ \ (11\%)$$

$$q_B = -0.5088(49)^2 + 49.646(49) - 17.473 \quad \textit{equation 6.3.5}$$

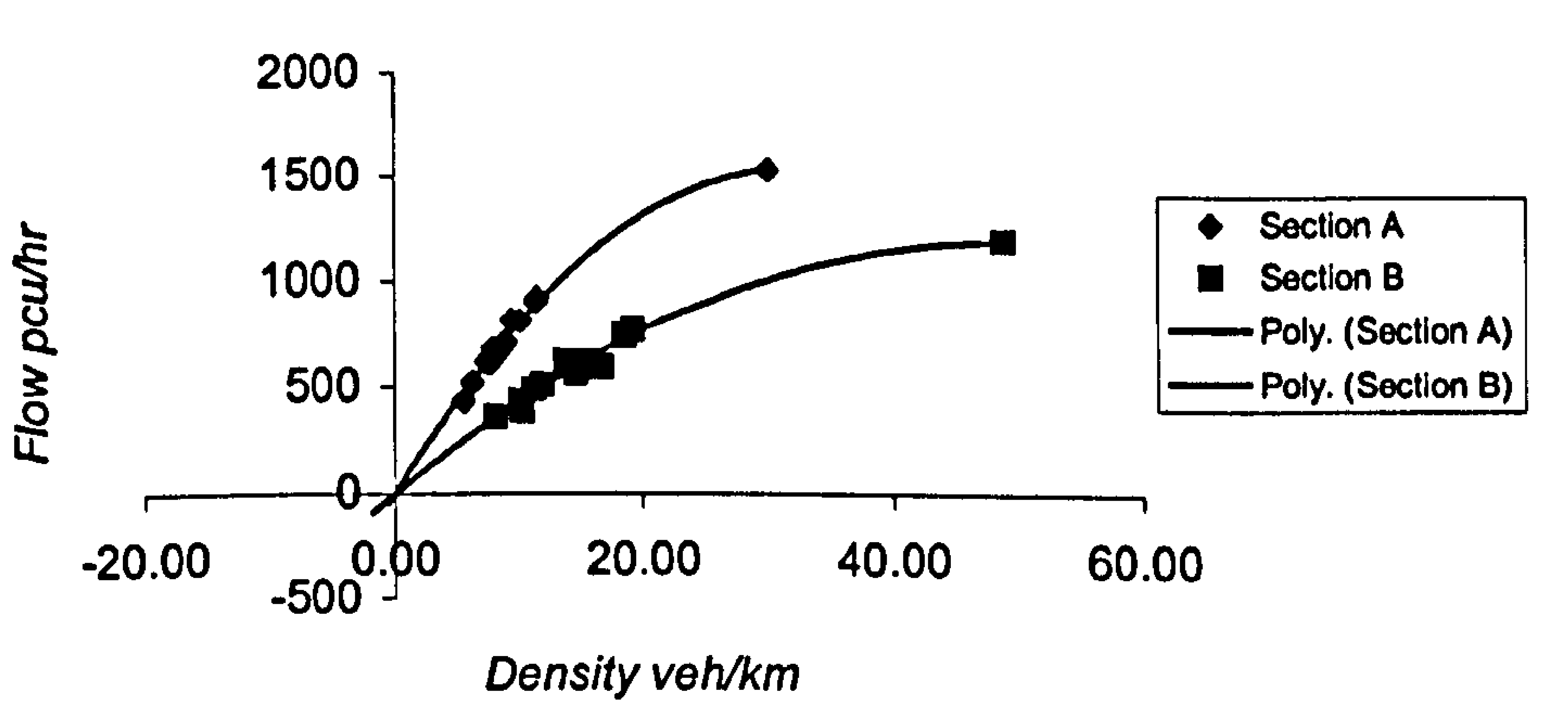
$$q_B = 1194\ pcu/hr\ (13\%)$$

Roadway Capacity loss for Road ED007 (1533 – 1194) = 339 pcu/hr

Percentage of Capacity loss (1533 – 1194) / 1533 = 22.0%

Based on the roadway capacity analysis shown above, 22 % capacity loss resulted from 5.3% pavement distress per Km per carriageway lane in the presence of 58% commercial vehicles. As shown in Figures 6.07a and 6.07b, flow / density curve for road the sections shifted from left to right suggesting that speeds decrease relative to higher densities (30vehs/Km → 49vehs/Km) and the argument that loss of speed will result from pavement distress remains valid.

Figure 6.07b Roadway At Capacity (ED007)



Site ED008 –

Table 6.06a Computed Flows and Densities for Road ED008 Section A

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
20	23	2	34.5	4	58.5	702	90	7.80
20	23	2	34.5	4	58.5	702	89	7.89
21	24	2	36	4	61	732	88	8.32
15	17	2	25.5	4	44.5	534	87	6.14
23	27	3	40.5	6	69.5	834	85	9.81
18	20	2	30	4	52	624	85	7.34
21	24	2	36	4	61	732	80	9.15
12	14	1	21	2	35	420	85	4.94
20	23	2	34.5	4	58.5	702	85	8.26
24	28	3	42	6	72	864	85	10.16
22	25	2	37.5	4	63.5	762	83	9.18
17	20	2	30	4	51	612	80	7.65
233	268	25				685(±70)	85(±1.8)	8(±0.8)

Survey: 11-12-2000 Time: (5min. interval) 0800-0900 **Site:** Upper Siluko Road Benin EDO STATE
Note: Computed errors associated with Flow 10%, Speed 2% and Density 10%

Table 6.06b Computed Flows and Densities for Road ED008 Section B (Downstream)

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
16	18	2	27	4	47	564	36	15.67
15	18	2	27	4	46	552	39	14.15
12	14	1	21	2	35	420	40	10.50
15	17	2	25.5	4	44.5	534	40	13.35
9	11	1	16.5	2	27.5	330	43	7.67
16	19	2	28.5	4	48.5	582	43	13.53
19	22	2	33	4	56	672	40	16.80
8	10	1	15	2	25	300	43	6.98
17	19	2	28.5	4	49.5	594	43	13.81
17	20	2	30	4	51	612	39	15.69
13	15	1	22.5	2	37.5	450	40	11.25
15	18	2	27	4	46	552	39	14.15
172	201	20				514(±65)	40(±1.2)	13(±1.7)

Survey: 11-12-2000 Time: (5min. interval) 0800-0900 **Site:** Upper Siluko Road Benin EDO STATE
Note: Computed errors associated with Flow 12%, Speed 3% and Density 13%

By plugging the figures above for flow and density into equation 6.1, the model coefficients (see figure 6.08a) for both road sections were determined as:

$$q_A = -1.5755k^2 + 105.47k - 59.044 \quad \textit{equation 6.2.6}$$

$$q_B = -0.5022k^2 + 47.701k - 10.25 \quad \textit{equation 6.3.6}$$

The model coefficients have the correct signs and as shown in Figure 6.08a, the coefficient of determination (R^2) 0.93 for section A and 0.92 for section B suggesting a strong relationship between flows and densities and the model could be used to estimate roadway capacity for the link sections. The F –observed statistics at 10 degree of freedom is much greater than F critical (4.94) suggesting that the relationship did not occur by chance. Also the t – observed statistic at 10 degree of freedom tested at 5 % significance level is much greater than 2 thus suggesting that density is an important variable when estimating flow. By differentiating q with respect to κ; for a maximum value of q:

$$\partial q / \partial \kappa = 0.$$

The critical densities (κ_{crt}) for sections A and B were established as:

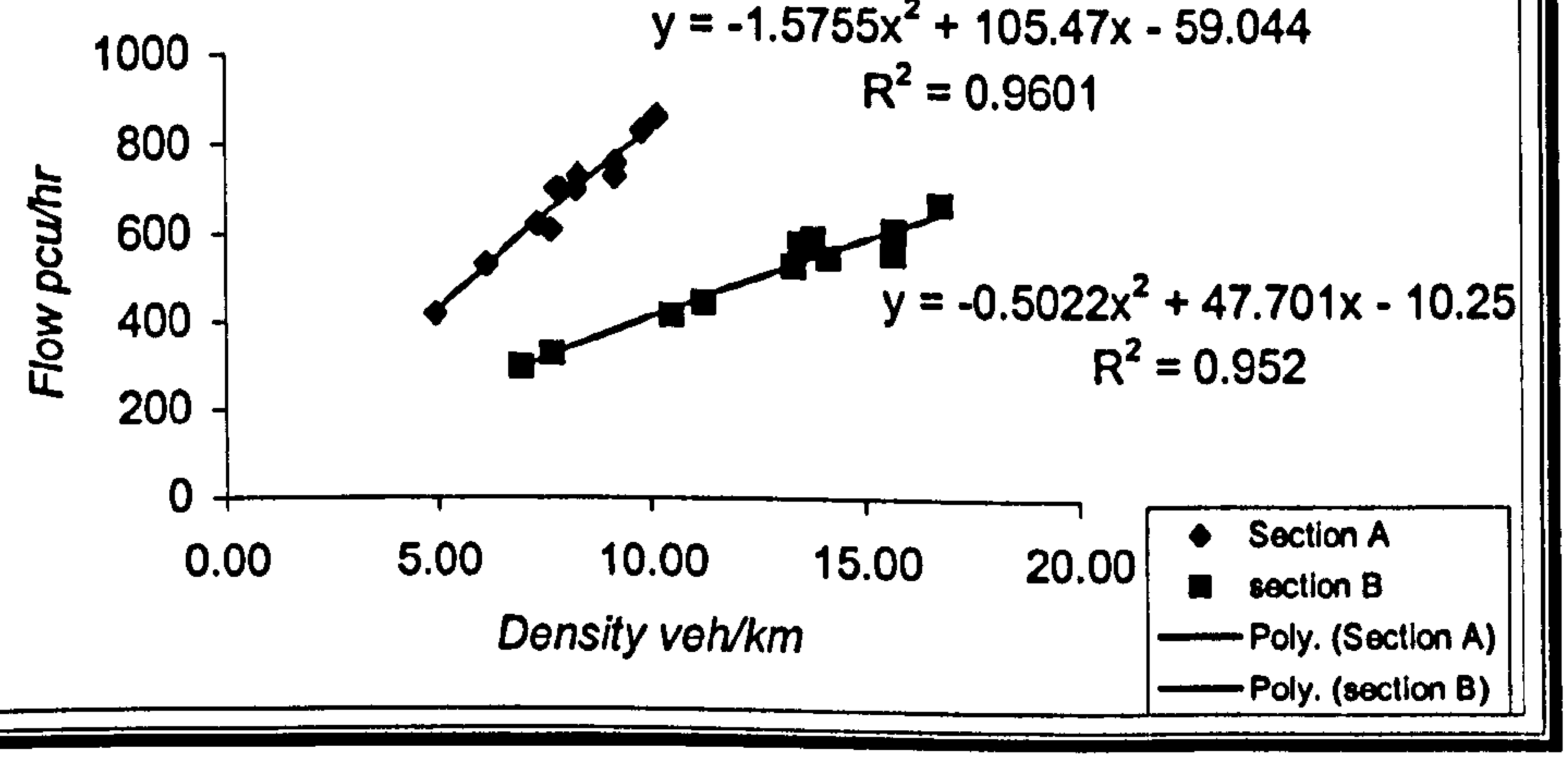
Section A $\quad \partial q / \partial \kappa = 2(-1.5755k) + 105.47 = 0;$

And $\quad \kappa_{crt} = 34 \text{ veh } (km^{-1})$

Section B $\quad \partial q / \partial \kappa = 2(-0.5022k) + 47.701 = 0;$

And $\quad \kappa_{crt} = 48 \text{ veh } (km^{-1})$

Figure 6.08a Flow / Density Curve (ED008)



The computed critical densities were plugged into equations 6.2.6 and 6.3.6 in order to determine the maximum flow per road sections as shown below:

$$q_A = -1.5755(34)^2 + 105.47(34) - 59.044 \quad \textit{equation 6.2.6}$$

$$q_A = 1706\ pcu/hr\ (\pm 10\%)$$

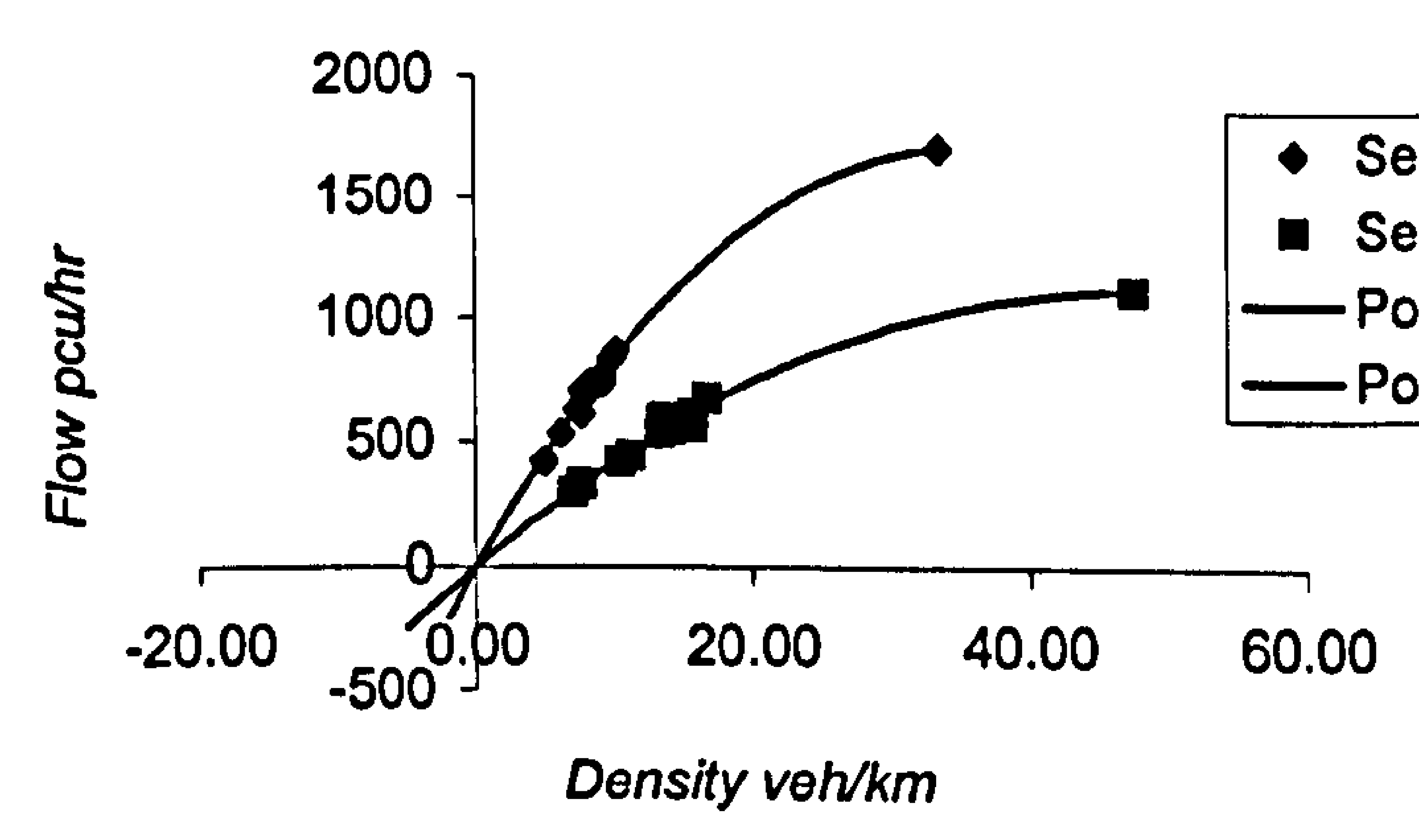
$$q_B = -0.5022(48)^2 + 47.701(48) - 10.25 \quad \textit{equation 6.3.6}$$

$$q_B = 1123\ pcu/hr\ (\pm 12\%)$$

Roadway Capacity loss for Road ED008 (1706 – 1123) = 584 pcu/hr
Percentage of Capacity loss (1706 – 1123) / 1706 = 34.0%

Based on the roadway capacity analysis shown above, 9.9 % capacity loss resulted from 34% pavement distress per Km per carriageway lane in the presence of 56% commercial vehicles. As shown in Figures 6.08a and 6.08b, flow / density curve for road the sections shifted from left to right suggesting that speeds decrease relative to higher densities (34vehs/Km → 48vehs/Km) and the argument that loss of speed will result from pavement distress remains valid.

Figure 6.08b Roadway At Capacity (ED008)



Site EK009 -

Table 6.07a Computed Flows and Densities for Road EK009 Section A

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
25	29	2	43.5	4	72.5	870	89	9.78
27	31	2	46.5	4	77.5	930	89	10.45
29	34	2	51	4	84	1008	85	11.86
23	26	2	39	4	66	792	85	9.32
18	21	1	31.5	2	51.5	618	85	7.27
19	22	1	33	2	54	648	95	6.82
31	35	2	52.5	4	87.5	1050	87	12.07
24	28	2	42	4	70	840	89	9.44
18	21	1	31.5	2	51.5	618	90	6.87
19	22	1	33	2	54	648	90	7.20
20	23	1	34.5	2	56.5	678	95	7.14
24	28	2	42	4	70	840	96	8.75
277	320	19				795(±86)	90(±1)	9(±1)

Survey: 16-10-2000 Time: (5min. interval) 1700-1800 **Site:** Ajilosun Street, Ado-Ekiti EKITI STATE
Note: Computed errors associated with Flow 11%, Speed 1% and Density 11%

Table 6.07b Computed Flows and Densities for Road EK009 Section B

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
23	26	2	39	4	66	792	35	22.63
22	25	1	37.5	2	61.5	738	34	21.71
22	25	1	37.5	2	61.5	738	35	21.09
4	28	2	42	4	50	600	36	16.67
17	20	1	30	2	49	588	39	15.08
14	16	1	24	2	40	480	38	12.63
27	31	2	46.5	4	77.5	930	35	26.57
25	29	2	43.5	4	72.5	870	36	24.17
14	16	1	24	2	40	480	36	13.33
19	22	1	33	2	54	648	40	16.20
19	22	1	33	2	54	648	40	16.20
22	25	1	37.5	2	61.5	738	40	18.45
228	285	16				688(±79)	37(±1)	19(±2)

Survey: 16-10-2000 Time: (5min. interval) 1700-1800 **Site:** Ajilosun Street, Ado-Ekiti EKITI STATE
Note: Computed errors associated with Flow 11%, Speed 3% and Density 10%

By plugging the figures above for flow and density into equation 6.1, the model coefficients (see figure 6.09a) for both road sections were determined as:

$$q_A = -1.782k^2 + 112.42k - 59.545 \quad \textit{equation 6.2.7}$$

$$q_B = -0.4928k^2 + 49.815k - 63.593 \quad \textit{equation 6.3.7}$$

The model coefficients have the correct signs and as shown in Figure 6.09a, the coefficient of determination (R^2) 0.96 for section A and 0.95 for section B suggesting a strong relationship between flows and densities and the model could be used to estimate roadway capacity for the link sections. The F –observed statistics at 10 degree of freedom is much greater than F critical (4.94) suggesting that the relationship did not occur by chance. Also the t – observed statistic at 10 degree of freedom tested at 5 % significance level is much greater than 2 thus suggesting that density is an important variable when estimating flow. By differentiating q with respect to κ; for a maximum value of q:

$$\partial q / \partial \kappa = 0.$$

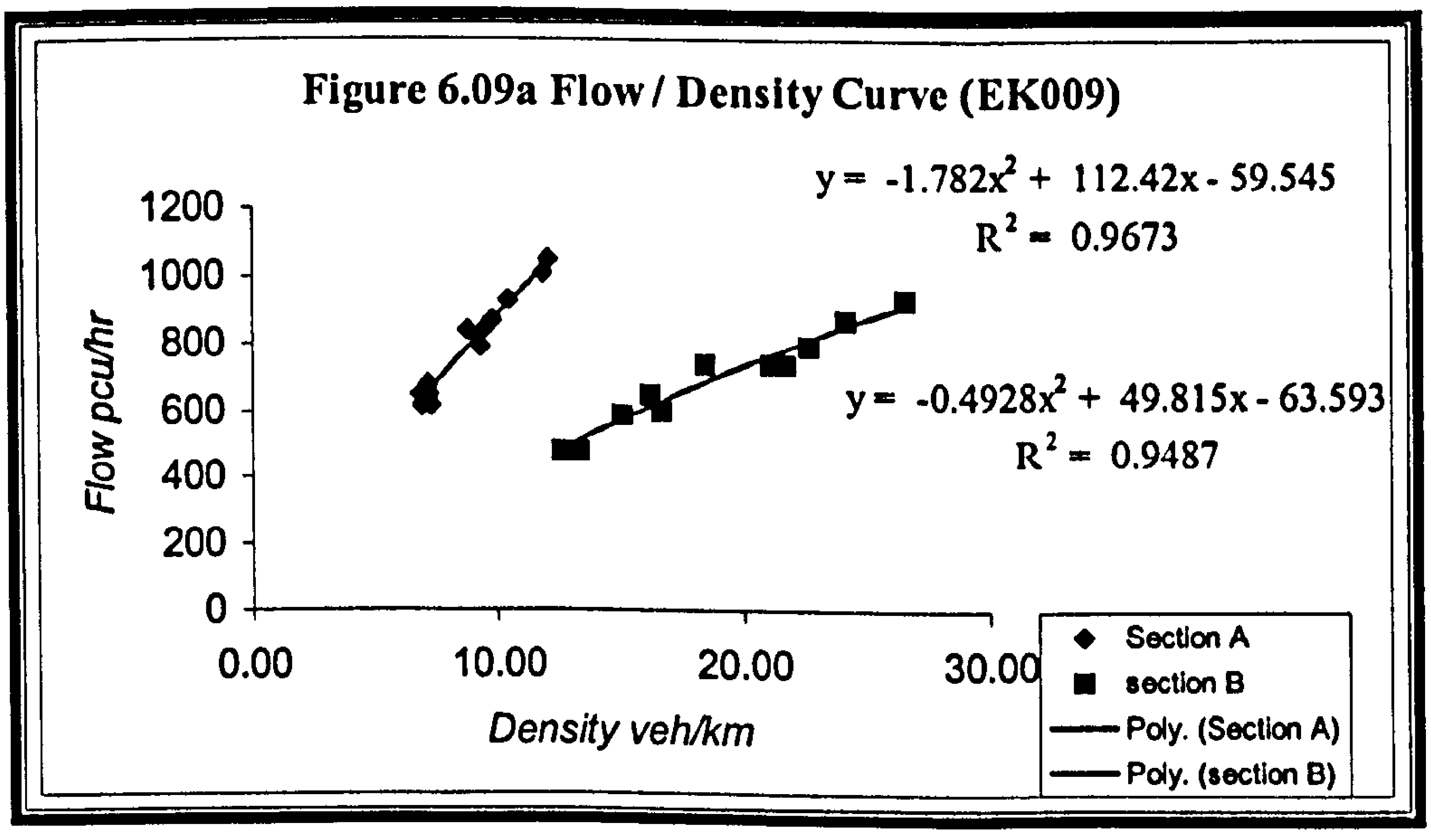
The critical densities (κ_{crt}) for sections A and B were established as:

Section A $\quad \partial q / \partial \kappa = -1.782k^2 + 112.42k = 0;$

And $\quad \kappa_{crt} = 32$ *veh* (km^{-1})

Section B $\quad \partial q / \partial \kappa = -0.4928k^2 + 49.815k = 0;$

And $\quad \kappa_{crt} = 51$ *veh* (km^{-1})



The computed critical densities were plugged into equations 6.2.7 and 6.3.7 in order to determine the maximum flow per road sections as shown below:

$$q_A = -1.782(32)^2 + 112.42(51) - 59.545 \quad equation\ 6.2.7$$

$$q_A = 1714\ pcu/hr\ (\pm 11\%)$$

$$q_B = -0.4928k^2 + 49.815k - 63.593 \quad equation\ 6.3.7$$

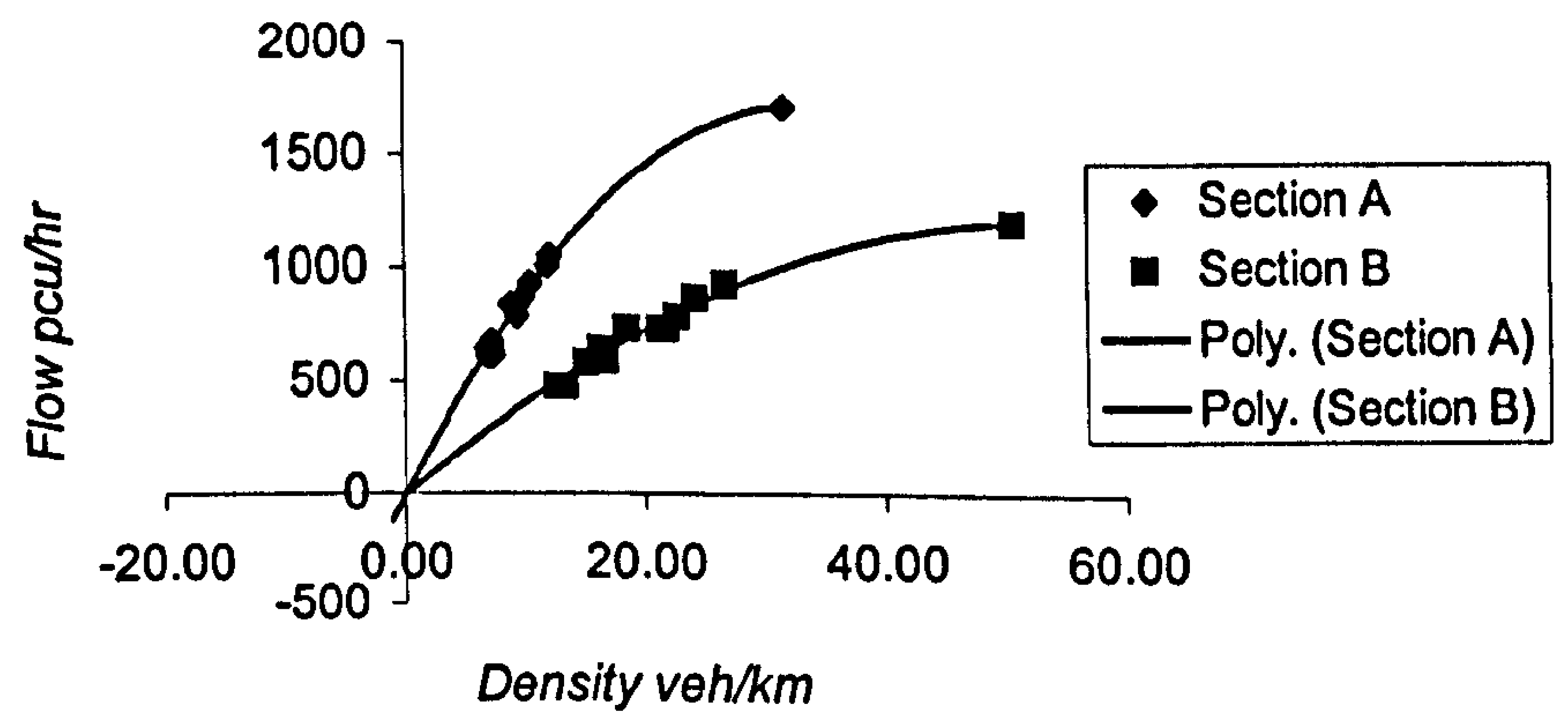
$$q_B = 1195\ pcu/hr\ (\pm 11\%)$$

Roadway Capacity loss for Road EK009 (1714 – 1195) = 518 pcu/hr

Percentage of Capacity loss (1714 – 1195) / 1714 = 30.0%

Based on the roadway capacity analysis shown above, 30% capacity loss resulted from 6.4% pavement distress per Km per carriageway lane in the presence of 55% commercial vehicles. As shown in Figures 6.09a and 6.09b, flow / density curve for road the sections shifted from left to right suggesting that speeds decrease relative to higher densities (32vehs/Km → 51vehs/Km) and the argument that loss of speed will result from pavement distress remains valid.

Figure 6.09b Roadway At Capacity (EK009)



Site OG010 -

Table 6.08a Computed Flows and Densities for Road OG010 Section A

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
50	2	2	3	4	57	684	95	7.20
50	2	2	3	4	57	684	93	7.35
52	2	2	3	4	59	708	95	7.45
53	2	2	3	4	60	720	99	7.27
55	2	2	3	4	62	744	95	7.83
51	2	2	3	4	58	696	93	7.48
51	2	2	3	4	58	696	93	7.48
53	2	2	3	4	60	720	95	7.58
55	2	2	3	4	62	744	97	7.67
41	2	1	3	2	46	552	93	5.94
40	3	0	4.5	0	44.5	534	90	5.93
44	3	0	4.5	0	48.5	582	90	6.47
595	26	19				672(±73)	94(±1.5)	7(±0.4)

Survey: 09-10-2000 Time: (5min. interval) 0800-0900 Site: Lantoro Road Abeokuta, OGUN STATE
Note: Computed errors associated with Flow 11%, Speed 1.6% and Density 5.7%

Table 6.08b Computed Flows and Densities for Road OG010 Section B

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
43	2	1	3	2	48	576	45	12.80
47	2	2	3	4	54	648	45	14.40
37	2	1	3	2	42	504	44	11.45
45	2	1	3	2	50	600	48	12.50
48	2	2	3	4	55	660	44	15.00
56	2	2	3	4	63	756	44	17.18
42	2	1	3	2	47	564	45	12.53
47	2	2	3	4	54	648	45	14.40
37	2	1	3	2	42	504	48	10.50
33	1	1	1.5	2	36.5	438	47	9.32
37	2	1	3	2	42	504	46	10.96
29	1	1	1.5	2	32.5	390	46	8.48
501	22	16				566(±59)	46(±0.8)	12(±1.4)

Survey: 09-10-2000 Time: (5min. interval) 0800-0900 Site: Lantoro Road Abeokuta, OGUN STATE
Note: Computed errors associated with Flow 10%, Speed 2% and Density 12%

By plugging the figures above for flow and density into equation 6.1, the model coefficients (see figure 6.10a) for both road sections were determined as:

$$q_A = 1.2016k^2 + 93.551k - 57.534 \quad \textit{equation 6.2.8}$$
$$q_B = -5199k^2 + 54.186k - 25.449 \quad \textit{equation 6.3.8}$$

The model coefficients do not have the correct signs and as shown in Figure 6.10a, suggesting that the data is defective and cannot be relied on for further analysis. In order not to violate the concavity rule the coefficient $1.2016x^2$ for road section 'A' must have the minus sign and shown in Figure 6.10a the coefficients do not have the correct signs.

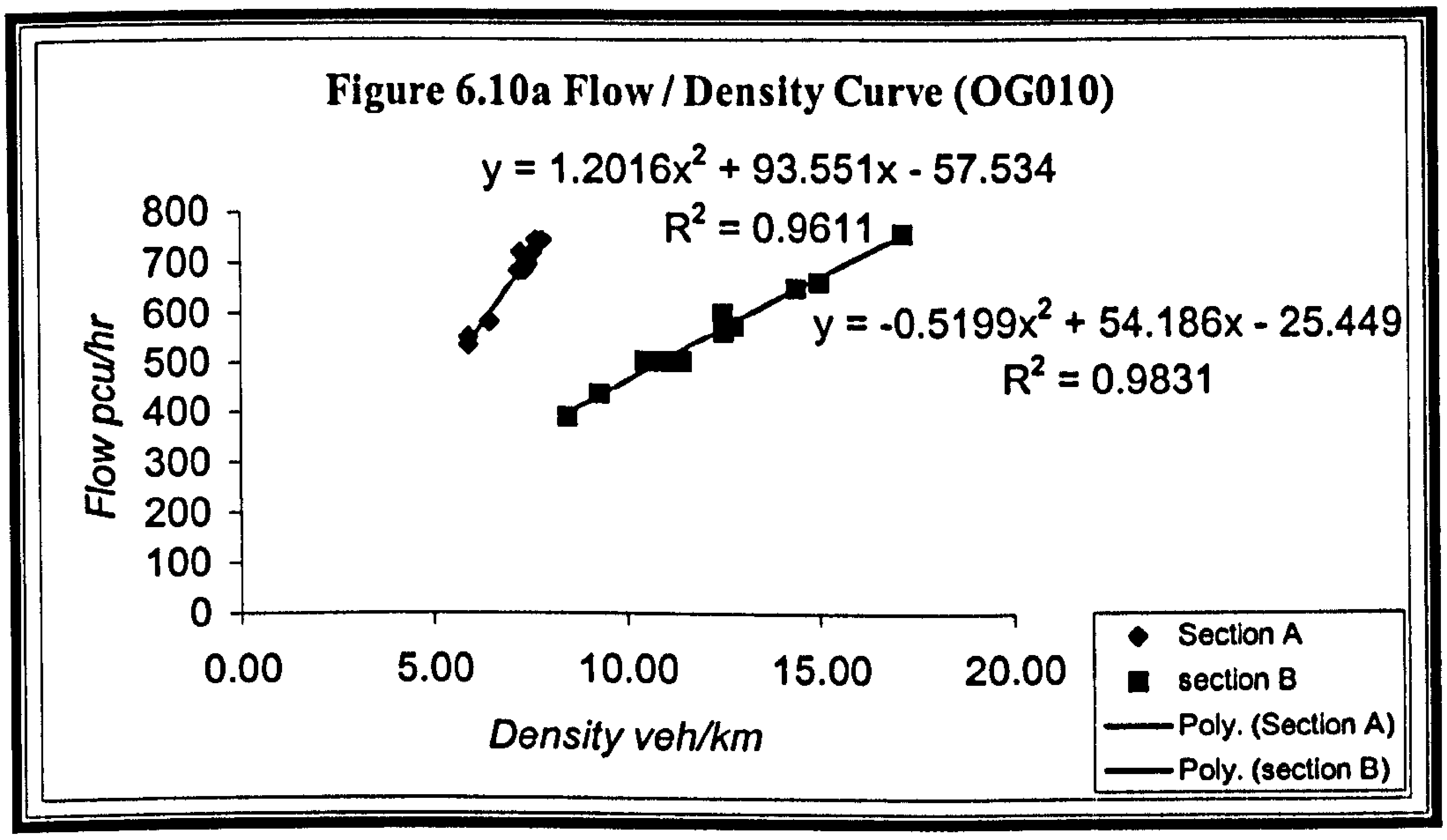


Figure 6.10a Flow / Density Curve (OG010)

Site OG011 -

Table 6.09a Computed Flows and Densities for Road OG011 Section A

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
23	10	4	15	8	46	552	90	6.13
32	14	5	21	10	63	756	95	7.96
25	11	4	16.5	8	49.5	594	99	6.00
29	13	5	19.5	10	58.5	702	95	7.39
34	15	6	22.5	12	68.5	822	99	8.30
43	20	7	30	14	87	1044	90	11.60
22	10	4	15	8	45	540	95	5.68
25	11	4	16.5	8	49.5	594	95	6.25
21	10	3	15	6	42	504	97	5.20
24	11	4	16.5	8	48.5	582	99	5.88
17	8	3	12	6	35	420	95	4.42
22	10	4	15	8	45	540	89	6.07
317	143	53				638(±96)	95(±2)	7(±1)

Survey: 28-09-2000 Time: (5min. interval) 1700-1800 **Site:** Aiyetoro Road Abeokuta, OGUN STATE
Note: Computed errors associated with Flow 14%, Speed 2% and Density 14%

Table 6.09b Computed Flows and Densities for Road OG011 Section B

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
19	8	3	12	6	37	444	39	11.38
19	8	3	12	6	37	444	38	11.68
18	8	3	12	6	36	432	38	11.37
25	11	4	16.5	8	49.5	594	39	15.23
25	11	4	16.5	8	49.5	594	38	15.63
28	13	5	19.5	10	57.5	690	38	18.16
18	8	3	12	6	36	432	39	11.08
19	9	3	13.5	6	38.5	462	39	11.85
19	9	3	13.5	6	38.5	462	39	11.85
24	11	4	16.5	8	48.5	582	39	14.92
24	11	4	16.5	8	48.5	582	38	15.32
18	8	3	12	6	36	432	38	11.37
256	115	42				566(±59)	46(±0.8)	12(±1.4)

Survey: 28-09-2000 Time: (5min. interval) 1700-1800 **Site:** Aiyetoro Road Abeokuta, OGUN STATE
Note: Computed errors associated with Flow 10%, Speed 1.7% and Density 11%

By plugging the figures above for flow and density into equation 6.1, the model coefficients (see figure 6.11a) for both road sections were determined as:

$$q_A = -2.4825k^2 + 128.76k - 109.47 \quad \text{equation 6.2.9}$$
$$q_B = -0.5045k^2 + 51.792k - 85.221 \quad \text{equation 6.3.9}$$

The model coefficients have the correct signs and as shown in Figure 6.11a, the coefficient of determination (R^2) 0.95 for section A and 0.92 for section B suggesting a strong relationship between flows and densities and the model could be used to estimate roadway capacity for the link sections. The F –observed statistics at 10 degree of freedom is much greater than F critical (4.94) suggesting that the relationship did not occur by chance. Also the t – observed statistic at 10 degree of freedom tested at 5 % significance level is much greater than 2 thus suggesting that density is an important variable when estimating flow. By differentiating q with respect to κ; for a maximum value of q:

$$\partial q / \partial \kappa = 0;$$

The critical densities (κ_{crt}) for sections A and B were established as:

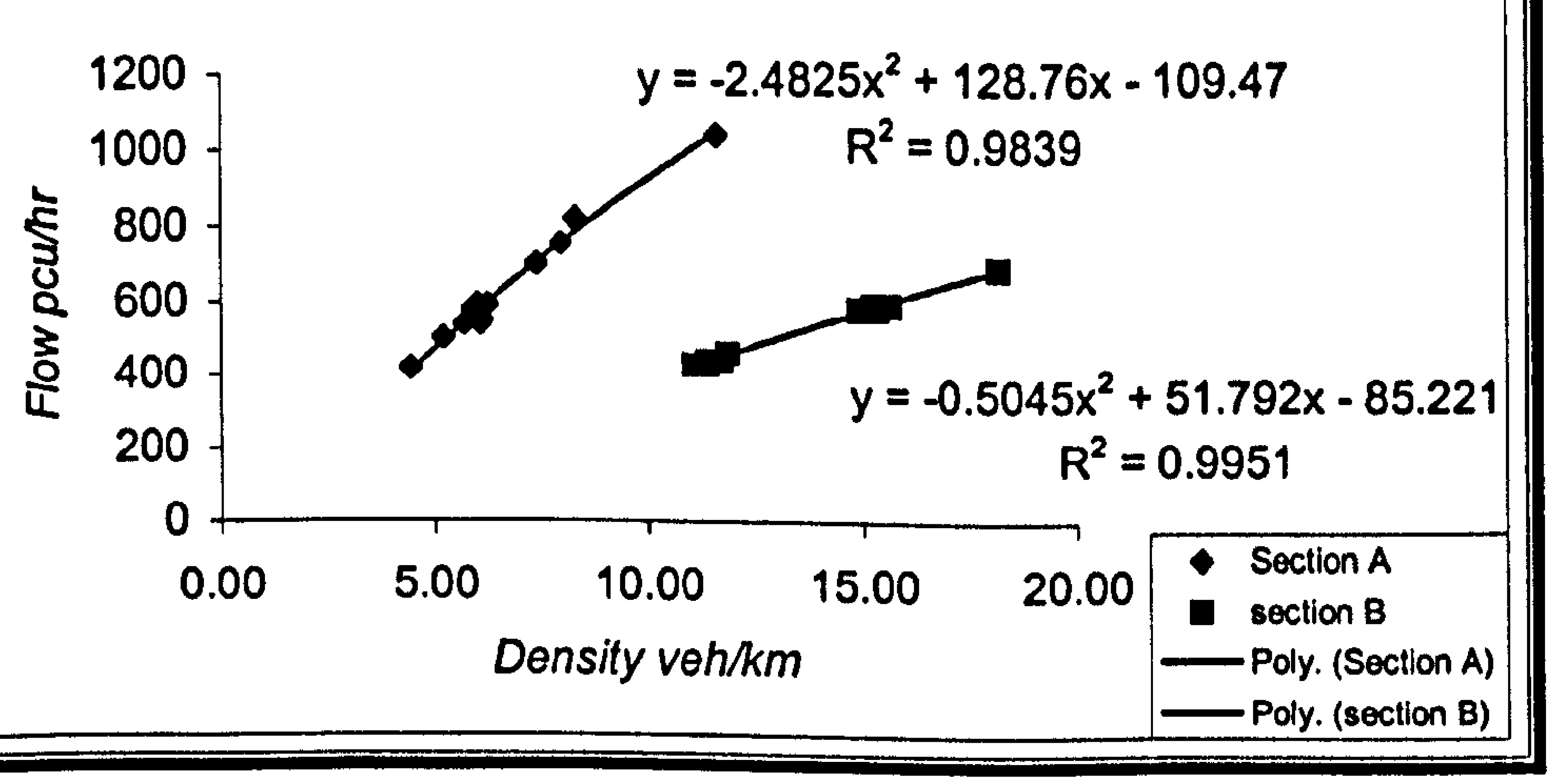
Section A $\quad \partial q / \partial \kappa = -2.4825k^2 + 128.76k = 0;$

And $\quad \kappa_{crt} = 26 \text{ veh } (km^{-1})$

Section B $\quad \partial q / \partial \kappa = -0.5045k^2 + 51.792k = 0;$

And $\quad \kappa_{crt} = 51 \text{ veh } (km^{-1})$

Figure 6.11a Flow / Density Curve (OG011)



The computed critical densities were plugged into equations 6.2.9 and 6.3.9 in order to determine the maximum flow per road sections as shown below:

$$q_A = -2.4825(26)^2 + 128.76(26) - 109.47 \quad \textit{equation 6.2.9}$$

$$q_A = 1560\ pcu/hr\ (\pm 15\%)$$

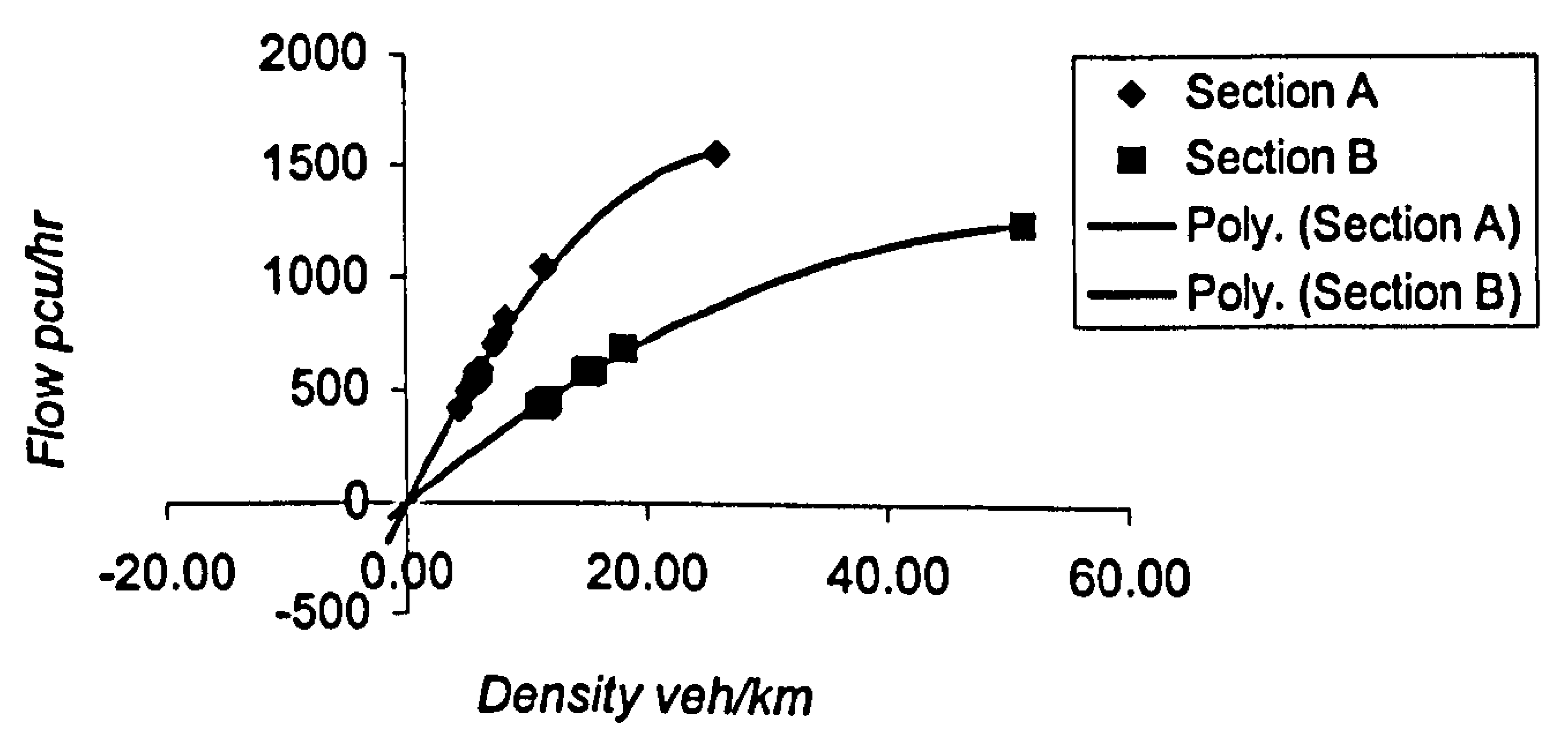
$$q_B = -0.5045k^2 + 51.792k - 85.221 \quad \textit{equation 6.3.9}$$

$$q_B = 1244\ pcu/hr\ (\pm 10\%)$$

Roadway Capacity loss for Road OG011 (1560 – 1244) = 316 pcu/hr
Percentage of Capacity loss (1560 – 1244) / 1560 = 20.0%

Base on the roadway capacity analysis shown above, 20% capacity loss resulted from 3% pavement distress per Km per carriageway lane in the presence of % commercial vehicles. As shown in Figures 6.11a and 6.1b, flow / density curve for road the sections shifted from left to right suggesting that speeds decrease relative to higher densities (26vehs/Km → 51vehs/Km) and the argument that loss of speed will result from pavement distress remains valid.

Figure 6.11b Roadway At Capacity (OG011)



Site OG012 –

Table 6.10a Computed Flows and Densities for Road OG012 Section A

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
33	6	6	9	12	54	648	86	7.53
37	6	7	9	14	60	720	86	8.37
36	6	7	9	14	59	708	86	8.23
35	6	7	9	14	58	696	89	7.82
37	6	7	9	14	60	720	85	8.47
43	5	8	7.5	16	66.5	798	85	9.39
29	8	6	12	12	53	636	89	7.15
30	8	6	12	12	54	648	85	7.62
25	8	5	12	10	47	564	89	6.34
29	6	6	9	12	50	600	85	7.06
15	3	3	4.5	6	25.5	306	85	3.60
31	6	6	9	12	52	624	85	7.34
380	74	74				639(±69)	86(±1)	7(±0.8)

Survey: 28-09-2000 Time: (5min. interval) 0800-0900 **Site:** Oba Simolade Road Shagamu OGUN STATE
Note: Computed errors associated with Flow 11%, Speed 1% and Density 11%

Table 6.10b Computed Flows and Densities for Road OG012 Section B

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
27	6	6	9	12	48	576	38	15.16
22	6	7	9	14	45	540	38	14.21
18	6	7	9	14	41	492	38	12.95
27	6	7	9	14	50	600	38	15.79
24	6	7	9	14	47	564	39	14.46
20	5	8	7.5	16	43.5	522	35	14.91
27	8	6	12	12	51	612	38	16.11
19	8	6	12	12	43	516	38	13.58
18	8	5	12	10	40	480	39	12.31
29	6	6	9	12	50	600	37	16.22
23	3	3	4.5	6	33.5	402	38	10.58
33	6	6	9	12	54	648	37	17.51
287	74	74				546(±38)	38(±0.6)	14(±1)

Survey: 28-09-2000 Time: (5min. interval) 0800-0900 **Site:** Oba Simolade Road Shagamu OGUN STATE
Note: Computed errors associated with Flow 7%, Speed 1.6% and Density 7%

By plugging the figures above for flow and density into equation 6.1, the model coefficients (see figure 6.12a) for both road sections were determined as:

$$q_A = -1.822k^2 + 108.03k - 58.054 \quad \textit{equation 6.2.10}$$

$$q_B = -0.4696k^2 + 48.046k - 49.719 \quad \textit{equation 6.3.10}$$

The model coefficients have the correct signs and as shown in Figure 6.12a, the coefficient of determination (R^2) 0.96 for section A and 0.92 for section B suggesting a strong relationship between flows and densities and the model could be used to estimate roadway capacity for the link sections. The F –observed statistics at 10 degree of freedom is much greater than F critical (4.94) suggesting that the relationship did not occur by chance. Also the t – observed statistic at 10 degree of freedom tested at 5 % significance level is much greater than 2 thus suggesting that density is an important variable when estimating flow. By differentiating q with respect to κ; for a maximum value of q:

$$\partial q / \partial \kappa = 0;$$

The critical densities (κ_{crt}) for sections A and B were established as:

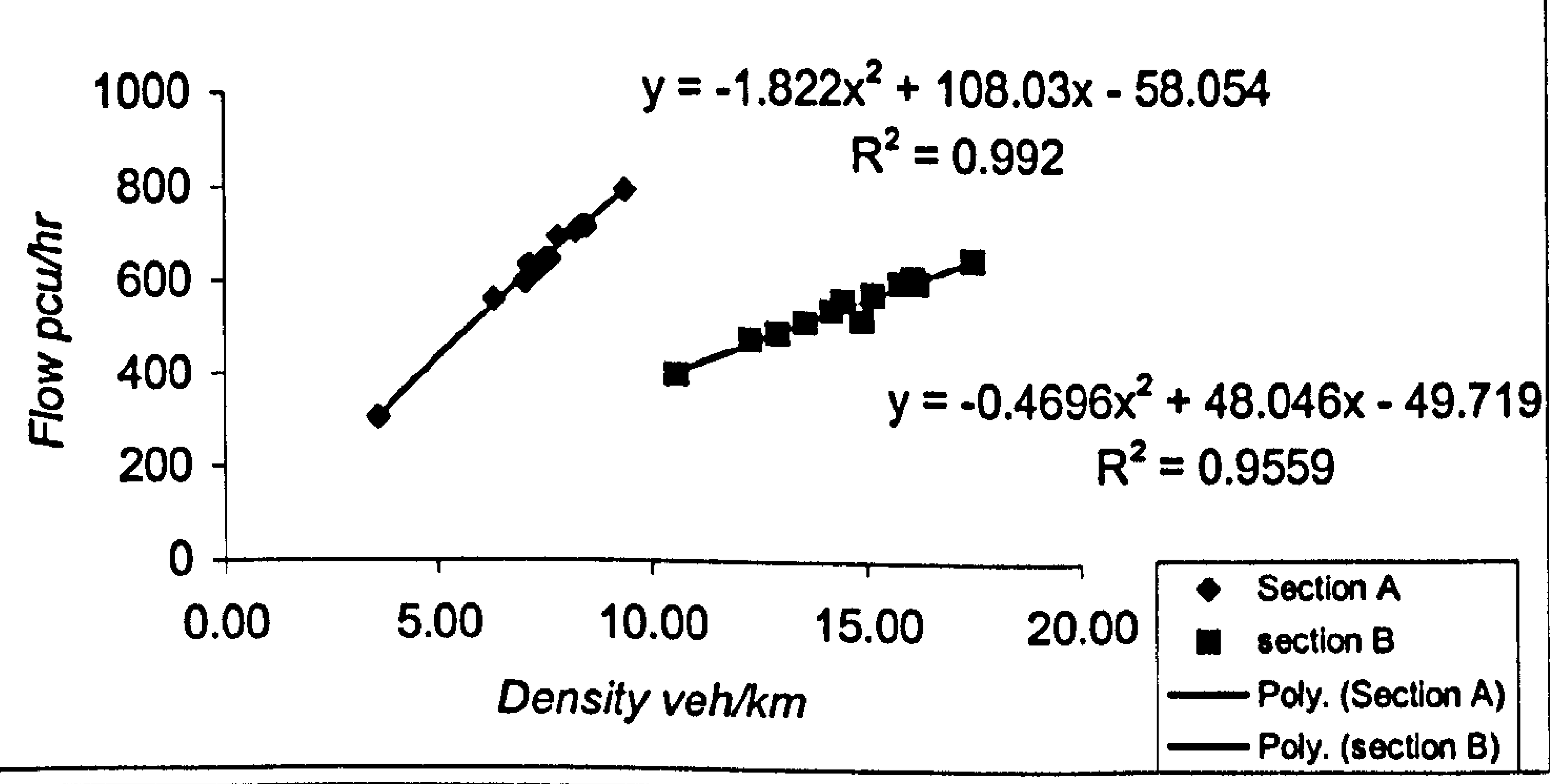
Section A $\quad \partial q / \partial \kappa = -1.822k^2 + 108.03k = 0;$

And $\quad \kappa_{crt} = 30 \ veh \ (km^{-1})$

Section B $\quad \partial q / \partial \kappa = -0.4696k^2 + 48.046k = 0;$

And $\quad \kappa_{crt} = 51 \ veh \ (km^{-1})$

Figure 6.12a Flow / Density Curve (OG012)



The computed critical densities were plugged into equations 6.2.10 and 6.3.10 in order to determine the maximum flow per road sections as shown below:

$$q_A = -1.822k^2 + 108.03k - 58.054 \quad \textit{equation 6.2.10}$$

$$q_A = 1543\ pcu/hr\ (\pm 11\%)$$

$$q_B = -0.4696k^2 + 48.046k - 49.719 \quad \textit{equation 6.3.10}$$

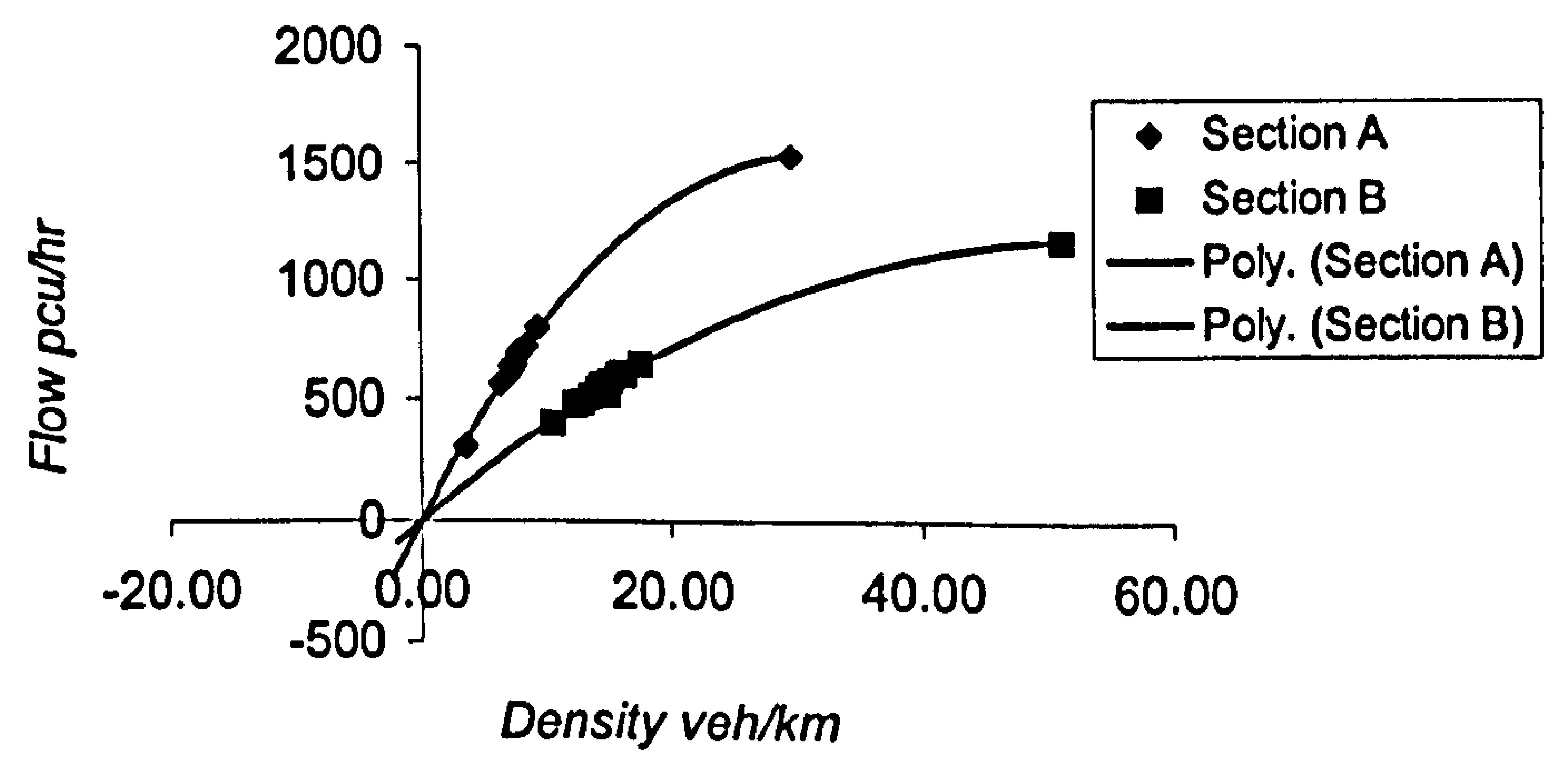
$$q_B = 1179 pcu/hr\ (\pm 7\%)$$

Roadway Capacity loss for Road OG012 (1543 - 1179) = 364 pcu/hr

Percentage of Capacity loss (1543 – 1179) / 1543 = 24.0%

Base on the roadway capacity analysis shown above, 14.6 % capacity loss resulted from 3.5% pavement distress per Km per carriageway lane in the presence of 28% commercial vehicles. As shown in Figures 6.12a and 6.12b, flow / density curve for road the sections shifted from left to right suggesting that speeds decrease relative to higher densities (30vehs/Km → 51vehs/Km) and the argument that loss of speed will result from pavement distress remains valid.

Figure 6.12b Roadway At Capacity (OG012)



Site OY018 -

Table 6.11a Computed Flows and Densities for Road OY018 Section A

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
42	10	4	15	8	65	780	95	8.21
38	9	4	13.5	8	59.5	714	95	7.52
46	10	5	15	10	71	852	93	9.16
38	9	4	13.5	8	59.5	714	95	7.52
37	8	4	12	8	57	684	100	6.84
40	9	4	13.5	8	61.5	738	99	7.45
39	9	4	13.5	8	60.5	726	95	7.64
38	9	4	13.5	8	59.5	714	95	7.52
41	9	4	13.5	8	62.5	750	95	7.89
37	8	4	12	8	57	684	93	7.35
35	8	4	12	8	55	660	92	7.17
34	8	4	12	8	54	648	93	6.97
465	106	49				722(±31)	95(±1.3)	8(±0.3)

Survey: 03-10-2000 Time: (5min. interval) 1700-1800 **Site:** Awolowo Avenue (Bodija), Ibadan OYO STATE
Note: Computed errors associated with Flow 4%, Speed 1.4% and Density 3.7%

Table 6.11b Computed Flows and Densities for Road OY018 Section B

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
35	8	4	12	8	55	660	41	16.10
38	9	4	13.5	8	59.5	714	45	15.87
43	10	5	15	10	68	816	44	18.55
30	7	3	10.5	6	46.5	558	44	12.68
33	7	4	10.5	8	51.5	618	47	13.15
36	8	4	12	8	56	672	46	14.61
37	8	4	12	8	57	684	46	14.87
35	8	4	12	8	55	660	46	14.35
38	9	4	13.5	8	59.5	714	46	15.52
33	7	4	10.5	8	51.5	618	45	13.73
37	8	4	12	8	57	684	44	15.55
32	7	3	10.5	6	48.5	582	42	13.86
427	96	47				665(±38)	45(±1)	15(±0.9)

Survey: 03-10-2000 Time: (5min. interval) 1700-1800 **Site:** Awolowo Avenue (Bodija), Ibadan OYO STATE
Note: Computed errors associated with Flow 5.7%, Speed 2% and Density 6%

By plugging the figures above for flow and density into equation 6.1, the model coefficients (see figure 6.18a) for both road sections were determined as:

$$q_A = -1.4786k^2 + 109.66k - 25.826 \quad equation\ 6.2.11$$
$$q_B = -0.4431k^2 + 53.886k - 38.603 \quad equation\ 6.3.11$$

The model coefficients have the correct signs and as shown in Figure 6.18a, the coefficient of determination (R^2) 0.91 for section A and 0.92 for section B suggesting a strong relationship between flows and densities and the model could be used to estimate roadway capacity for the link sections. The F –observed statistics at 10 degree of freedom is much greater than F critical (4.94) suggesting that the relationship did not occur by chance. Also the t – observed statistic at 10 degree of freedom tested at 5 % significance level is much greater than 2 thus suggesting that density is an important variable when estimating flow. By differentiating q with respect to κ; for a maximum value of q:

$$\partial q / \partial \kappa = 0;$$

The critical densities (κ_{crt}) for sections A and B were established as:

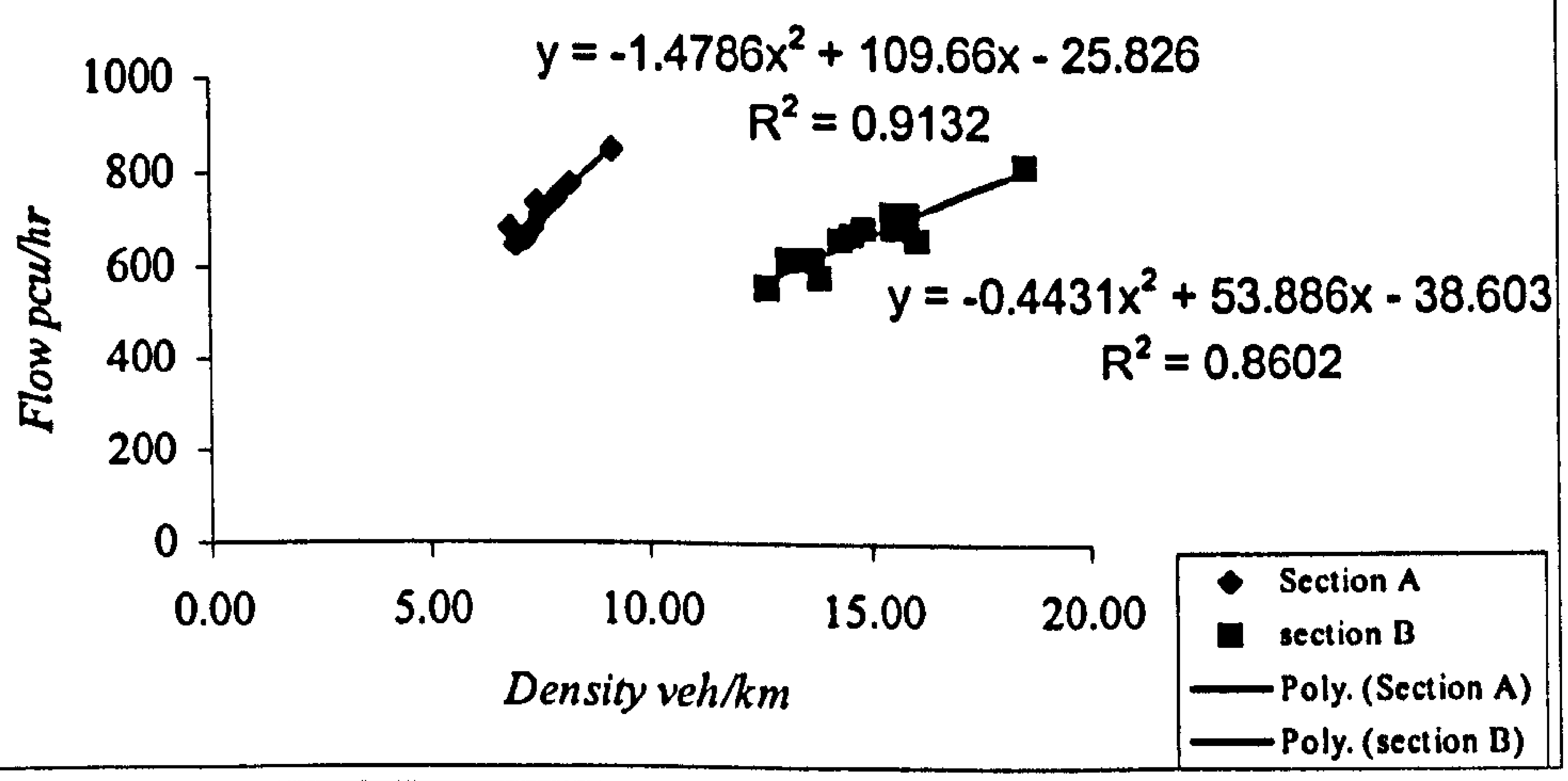
Section A $\quad \partial q / \partial \kappa = -1.4786k^2 + 109.66k = 0;$

And $\quad \kappa_{crt} = 37\ veh\ (km^{-1})$

Section B $\quad \partial q / \partial \kappa = -0.4431k^2 + 53.886k = 0;$

And $\quad \kappa_{crt} = 61\ veh\ (km^{-1})$

Figure 6.18a Flow / Density Curve (OY018)



The computed critical densities were plugged into equations 6.2.11 and 6.3.11 in order to determine the maximum flow per road sections as shown below:

$$q_A = -1.4786(37)^2 + 109.66(37) - 25.826 \quad \text{equation 6.2.11}$$

$$q_A = 2007\ pcu/hr\ (\pm 4\%)$$

$$q_B = -0.4431(61)^2 + 53.886(61) - 38.603 \quad \text{equation 6.3.11}$$

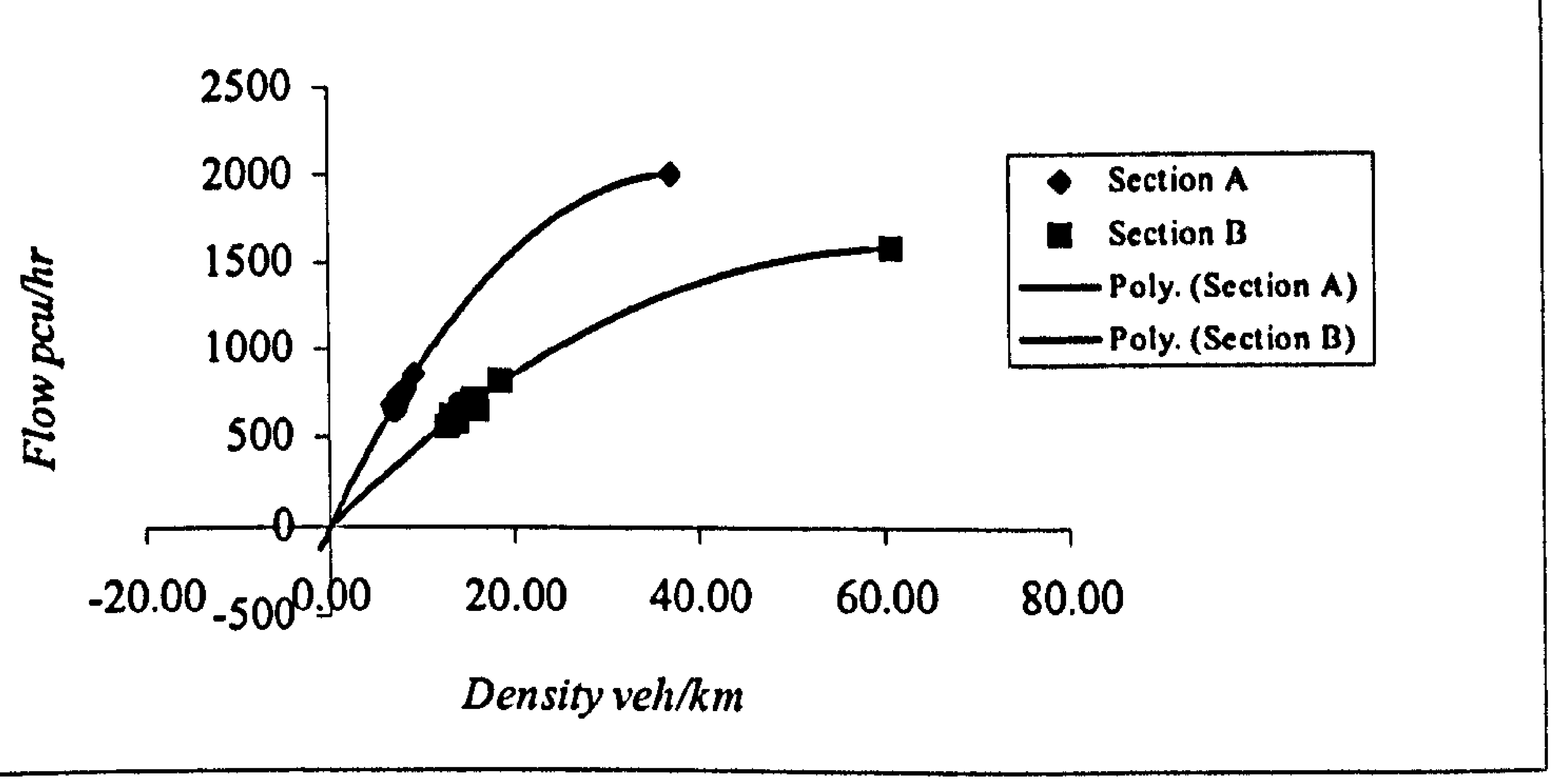
$$q_B = 1600\ pcu/hr\ (\pm 6\%)$$

Roadway Capacity loss for Road OY018 (2007-1600) = 407 pcu/hr

Percentage of Capacity loss (2007 – 1600) / 2007 = 20%

Base on the roadway capacity analysis shown above, 20% capacity loss resulted from 2.7% pavement distress per Km per carriageway lane in the presence of 25% commercial vehicles. As shown in Figures 6.18a and 6.18b, flow / density curve for road the sections shifted from left to right suggesting that speeds decrease relative to higher densities (37vehs/Km → 61vehs/Km) and the argument that loss of speed will result from pavement distress remains valid.

Figure 6.18b Roadway At Capacity (OY018)



Site OY019 -

Table 6.12a Computed Flows and Densities for Road OY019 Section A

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
38	19	5	28.5	10	76.5	918	89	10.31
40	20	5	30	10	80	960	85	11.29
36	18	5	27	10	73	876	89	9.84
37	18	5	27	10	74	888	90	9.87
35	16	5	24	10	69	828	90	9.20
31	21	4	31.5	8	70.5	846	89	9.51
41	22	5	33	10	84	1008	86	11.72
43	20	6	30	12	85	1020	89	11.46
39	20	5	30	10	79	948	89	10.65
40	20	5	30	10	80	960	89	10.79
40	20	5	30	10	80	960	93	10.32
34	17	4	25.5	8	67.5	810	96	8.44
454	231	59				919(±39)	90(±1.6)	10(±0.5)

Survey: 05-10-2000 Time: (5min. interval) 0800-0900 Site: Oyo Road (Mokola) Ibadan OYO STATE
Note: Computed errors associated with Flow 4.2%, Speed 1.8% and Density 5%

Table 6.12b Computed Flows and Densities for Road OY019 Section B

PC	LGVs	HGVs	LGVs*1.5	HGVs* 2	Flow/5min	Flow/Hr	Speed	Density
29	15	4	22.5	8	59.5	714	36	19.83
34	17	4	25.5	8	67.5	810	36	22.50
34	19	4	28.5	8	70.5	846	38	22.26
29	15	4	22.5	8	59.5	714	38	18.79
30	15	4	22.5	8	60.5	726	37	19.62
32	16	4	24	8	64	768	36	21.33
32	16	4	24	8	64	768	38	20.21
34	17	4	25.5	8	67.5	810	38	21.32
26	13	3	19.5	6	51.5	618	38	16.26
28	14	4	21	8	57	684	38	18.00
27	14	4	21	8	56	672	37	18.16
29	15	4	22.5	8	59.5	714	37	19.30
364	186	47				737(±37)	37(±0.5)	20(±1)

Survey: 05-10-2000 Time: (5min. interval) 0800-0900 Site: Oyo Road (Mokola) Ibadan OYO STATE
Note: Computed errors associated with Flow 5%, Speed 1.3% and Density 5%

By plugging the figures above for flow and density into equation 6.1, the model coefficients (see figure 6.19a) for both road sections were determined as:

$$q_A = -1.6822k^2 + 113.27k - 69.403 \quad \textit{equation 6.2.12}$$
$$q_B = -0.5066k^2 + 55.218k - 151.96 \quad \textit{equation 6.3.12}$$

The model coefficients have the correct signs and as shown in Figure 6.19a, the coefficient of determination (R^2) 0.82 for section A and 0.94 for section B suggesting a strong relationship between flows and densities and the model could be used to estimate roadway capacity for the link sections. The F –observed statistics at 10 degree of freedom is much greater than F critical (4.94) suggesting that the relationship did not occur by chance. Also the t – observed statistic at 10 degree of freedom tested at 5 % significance level is much greater than 2 thus suggesting that density is an important variable when estimating flow. By differentiating q with respect to κ; for a maximum value of q:

$$\partial q / \partial \kappa = 0.$$

The critical densities (κ_{crt}) for sections A and B were established as:

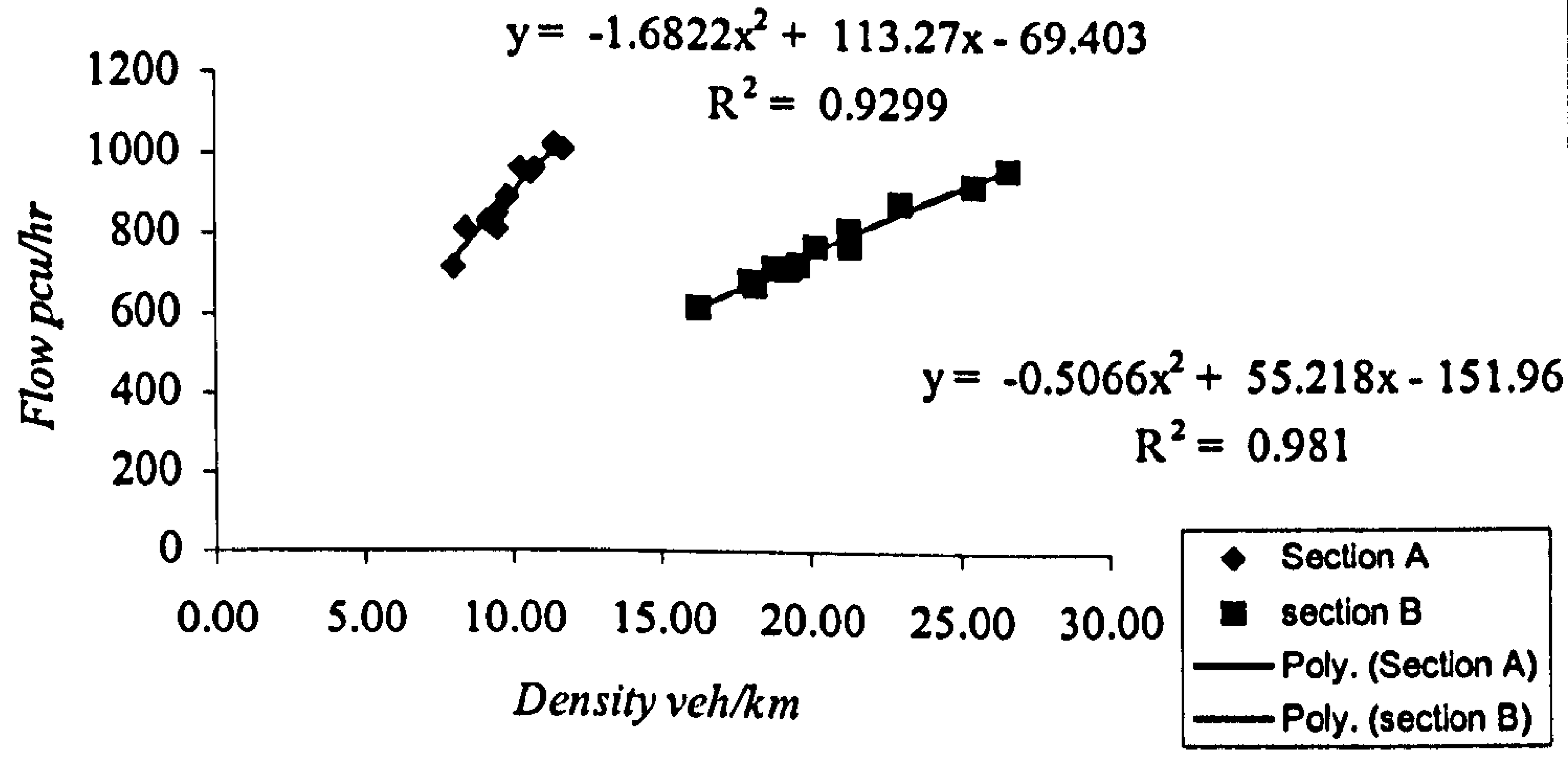
Section A $\partial q / \partial \kappa = -1.6822k^2 + 113.27k = 0;$

And $\kappa_{crt} = 34 \ veh \ (km^{-1})$

Section B $\partial q / \partial \kappa = -0.5066k^2 + 55.218k = 0;$

And $\kappa_{crt} = 55 \ veh \ (km^{-1})$

Figure 6.19a Flow / Density Curve (0Y019)



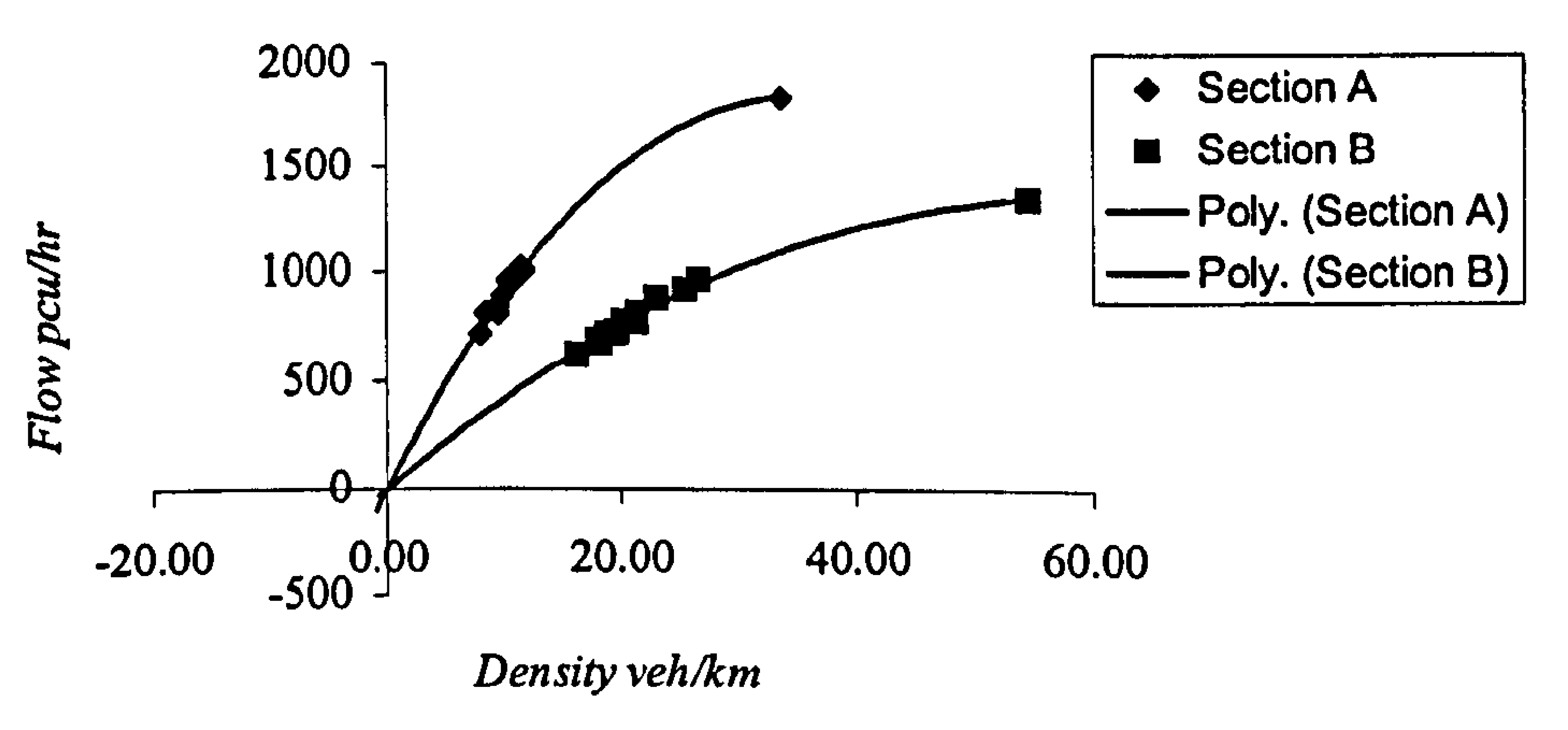
The computed critical densities were plugged into equations 6.2.12 and 6.3.12 in order to determine the maximum flow per road sections as shown below:

$$q_A = -1.6822k^2 + 113.27k - 69.403 \text{ equation 6.2.12}$$
$$q_A = 1837 \text{ pcu/hr } (\pm 4\%)$$
$$q_B = -0.5066k^2 + 55.218k - 151.96 \text{ equation 6.3.12}$$
$$q_B = 1353 \text{ pcu/hr } (\pm 5\%)$$

Roadway Capacity loss for Road OY019 (1837 – 1353) = 485 pcu/hr
Percentage of Capacity loss (1837– 1353) / 1837 = 26.0%

Base on the road capacity analysis shown above, 26% capacity loss resulted from 5.4% pavement distress per Km per carriageway lane in the presence of 39% commercial vehicles. As shown in Figures 6.18a and 6.19b, flow / density curve for road the sections shifted from left to right suggesting that speeds decrease relative to higher densities (34vehs/Km → 55vehs/Km) and the argument that loss of speed will result from pavement distress remains valid.

Figure 6.19b Roadway At Capacity (OY019)



6.1 Model Coefficients- Summary of the model coefficients of all road sections investigated is shown below in Table 6.13. Note that the coefficients for road section A (without PD) speed (β_1) and flow (β_2) are lower than that of road section B (with PD), where PD is pavement distress.

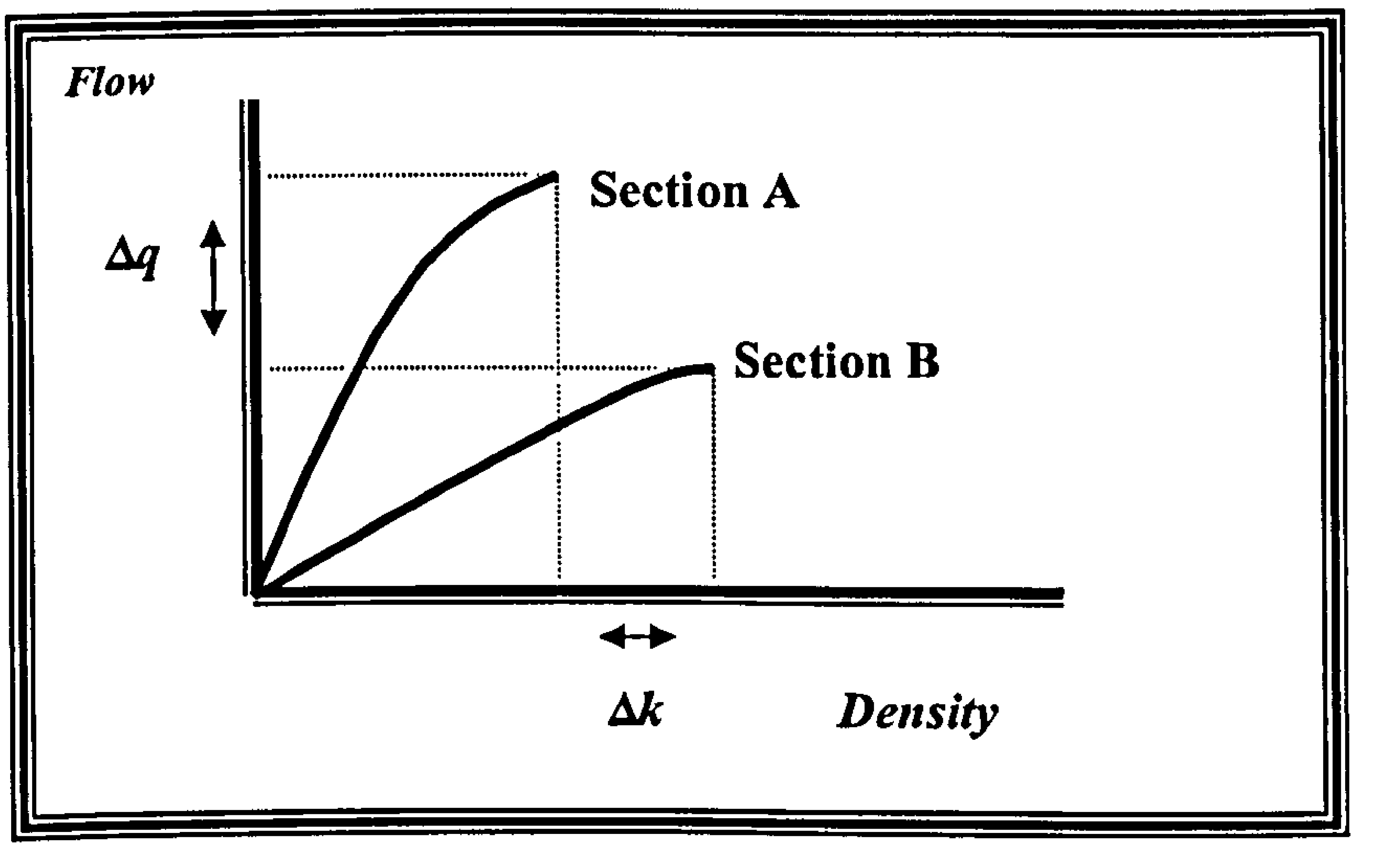
Table 6.13 Summary of Model Coefficients

SITE		Density $-\beta_0$	Speed $\beta_1 k$	Flow $-\beta_1 k^2$	R^2
AN001	Without PD	168.50	127.59	2.0200	0.9822
	With PD	99.614	50.326	0.4435	0.9179
DL004	Without PD	8.1055	123.98	2.2180	0.8724
	With PD	39.438	50.260	0.5079	0.9668
DL005	Without PD	8.1055	101.28	2.2922	0.9578
	With PD	143.15	63.795	1.0255	0.9792
ED006	Without PD	99.337	113.35	1.8229	0.9782
	With PD	186.32	59.133	0.5283	0.9744
ED007	Without PD	100.07	109.00	1.8194	0.9757
	With PD	17.473	49.646	0.5088	0.9269
ED008	Without PD	59.044	105.47	1.5755	0.9601
	With PD	10.250	47.701	0.5022	0.9520
EK009	Without PD	59.545	112.42	1.7820	0.9673
	With PD	63.593	49.815	0.4928	0.9487
OG011	Without PD	109.47	128.760	2.4825	0.9839
	With PD	85.221	51.792	0.5045	0.9951
OG012	Without PD	58.054	108.030	1.8220	0.9920
	With PD	49.719	48.046	0.4696	0.9559
OY018	Without PD	25.826	109.660	1.4786	0.9132
	With PD	38.603	53.886	0.4431	0.8602
0Y019	Without PD	69.403	113.27	1.6822	0.9299
	With PD	151.96	55.218	0.5066	0.9810

Source: Survey Data

6.2 Road Capacity Loss Results - . The results of the road capacity loss analysis as shown in Table 6.13 can best be summed as increase in density relative to increase in flow depicting a free flow situation where drivers can choose speeds, at this stage speed is relatively unaffected by flow until roadway capacity is reached as illustrated below in Figure 6.13. Note that predicted maximum flows were based on survey of road sections, critical density that is the density at which the maximum flow occurs and roadway capacities were all estimated. Road capacity loss equals capacity at section A less the capacity at section B.

Figure 6.13 Typical Roadway Capacity Loss



Road capacities at section A were substantially higher than those at section B for all investigated locations. Maximum flows at road section A were higher than those at section B for all investigated locations. Also critical densities at road section B were higher than those at section A for all investigated locations. Vehicles operating at road section A were completely unaffected by the pavement distress at section B. They are almost completely unimpeded in their ability to manoeuvre within the traffic stream because the operating conditions afford the driver high speeds. Whereas at road section B drivers were operating at lower speeds because freedom to manoeuvre within the traffic stream was limited due to pavement distress. Table 6.14 below contains summary of Road Capacity Loss Analysis Using Standard PCE values

Table 6.14 Summary of Road Capacity Loss Analysis Using Standard PCE values

1	2	3	4	5	6	7	8	9	10	11
ROAD CODE	SECTION WITHOUT DISTRESS				SECTION WITH DISTRESS				CAPACITY LOSS	
	Flow Pcu/hr	Speed Km/h	Density Veh/km	Capacity Pcu/hr	Flow Pcu/hr	Speed Km/h	Density Veh/km	Capacity Pcu/hr	Pcu/hr	%
AN001	1254	115	32	1846 (±13%)	846	47	57	1328 (±8%)	518	28
DL004	804	97	28	1555 (±9%)	606	48	50	1204 (±10%)	315	23
DL005	636	101	22	1111 (±8%)	636	55	31	849 (±8%)	262	24
ED006	1140	107	31	1663 (±11%)	900	52	56	1468 (±9%)	195	12
ED007	918	102	30	1532 (±11%)	768	49	49	1194 (±13%)	338	22
ED008	864	100	34	1706 (±10%)	672	47	48	1122 (±12%)	584	34
EK009	1050	107	32	1713 (±11%)	930	47	51	1195 (±11%)	518	30
OG011	1044	107	26	1560 (±14%)	690	49	51	1244 (±10%)	316	20
OG012	798	120	30	1543 (±11%)	648	47	51	1179 (±7%)	364	24
OY018	852	103	37	2007 (±4%)	816	52	61	1600 (±4%)	407	20
OY019	1020	108	34	1837 (±4%)	960	46	55	1353 (±5%)	484	26

Source: Survey Data
Note: analysis on OG10 has been discontinued because of defective flow / density curve at section A.

Table 6.15 below shows road capacity condition Using Standard PCE values. Clearly it can be inferred that, the road sections were operating under capacity at the time of survey.

Table 6.15 Road Capacity Condition Using Standard PCE values

1	2	3	4	5	6	7	8	9
ROAD CODE	SECTION WITHOUT DISTRESS				SECTION WITH DISTRESS			
	Flow Pcu/ hr	Capacity Pcu/hr	RFC	Remark	Flow Pcu/hr	Capacity Pcu/hr	RFC	Remark
AN001	1254	1846	68	Under cap	846	1328	64	Under cap
DL004	804	1555	52	Under cap	606	1204	50	Under cap
DL005	636	1111	57	Under cap	636	849	75	Under cap
ED006	1140	1663	69	Under cap	900	1468	61	Under cap
ED007	918	1532	60	Under cap	768	1194	64	Under cap
ED008	864	1706	51	Under cap	672	1122	60	Under cap
EK009	1050	1713	61	Under cap	930	1195	78	Under cap
OG011	1044	1560	67	Under cap	690	1244	55	Under cap
OG012	798	1543	52	Under cap	648	1179	55	Under cap
OY018	852	2007	42	Under cap	816	1600	51	Under cap
OY019	1020	1837	56	Under cap	960	1353	71	Under cap

Source: Survey Data Note: Under cap. = under capacity

6.3 Summary - We set out our objectives in this chapter as follows: i) to determine traffic flow from vehicle volume, and density from the speed / flow relationship relying on the fundamental diagram: ii) to use the flow and density relationship to determine the road capacities for road sections A and B: iii) compare the capacity in section A and B to establish whether a loss has occurred.

In determining traffic flow for the road sections, vehicle volumes were converted from vehicles per hour to passenger car units per hour because traffic flow is made up of mixed vehicles and in this study three types were identified as passenger cars (PCs), light goods vehicles (LGVs), and heavy goods vehicle (HGVs). Road ED008 has the highest loss with 34 percent while road ED006 has the lowest with 12 percent. Generally the range of road capacity loss is 20 percent to 30 percent allowing for various margins of errors in estimated capacities.

It is apparent from the investigations so far that the effectiveness of road use has been constrained by multiple road pavement distresses such as potholes, loose aggregates, and broken edges, rutting and cracking among others. The shift from left to right in flow / density curve as shown in figures 6.01 to 6.19 is indicative of constraint on the roadway, further that:

- There is a significance change in capacity between the 'with' and without pavement distress sections. There are no other factors other than pavement distress that affected the traffic flow loss between both link sections.
- Average loss of capacity was attributed to pavement distress prevalent per surveyed road length per carriageway lane.
- The estimated percentage of capacity loss is substantial, the reason been that capacity was estimated rather than measured directly because flows at the sites were not high enough
- The hypothesis that pavement distress can influence roadway capacity loss remains valid

Since there are no scientific laws explaining the behaviour of traffic, and in practice vehicles are not homogeneous, the concept of passenger car units was used to describe the effect of vehicles of different sizes. The passenger car equivalent (*PCE*) values in use by the Federal Ministry of Works in Nigeria (1998) were relied on in the absence of reliable alternatives. We assumed that the PCE values would not affect the outcome of the comparative result road capacity substantially. If the assumption there were to hold there would be substantial difference between road capacities at section A, and section B of the surveyed road. This working assumption was tested in the next chapter by way of applying estimated PCE values to the surveyed vehicle volumes.

7

ROAD CAPACITY LOSS ANALYSIS USING MODIFIED PCE VALUES

In this chapter investigation will focus on the issue of modified passenger car equivalency values. The term 'passenger car equivalent' was first introduced in the 1965 HCM (*1965*). It was defined as 'the number of passenger cars displaced in the traffic flow by truck or a bus under the prevailing roadway and traffic conditions. This definition still holds today and the use of such equivalents is central to highway capacity analysis where mixed traffic stream are present. Three types of vehicles were distinguished in this study: passenger car (PC), light good vehicle (LGV), and heavy good vehicle (HGV) and the typical Nigerian PCE values applicable on roads are: cars = 1.0, light good vehicles = 1.5 and heavy good vehicles = 2.0. These PCE values were used in estimating road capacity loss the last chapter. however, from observations at the surveyed sites trucks were less affected by pavement distress than passenger car therefore, it can be argued that the passenger car equivalent values of trucks or HGVs are somewhat same or lower than those of passenger cars on such road sections.

Even though the PCE values as employed in Nigeria (see FMWH *1998*) were adopted in Chapter 6, we have attempted to estimate PCE values in this chapter that could reflect the effects of pavement distress on road capacity loss. Because of wide variance in PCE adopted by many scholars (see chapter 2) it is difficult to directly compare numerical results. In any case, the calibration of the PCE values is significant to road capacity estimations and would not affect the outcome of the study. Against the backdrop of discussion so far, the remainder of this chapter has been divided into three sections. Section 7.1 deals with assessment of passenger car equivalency values. Section 7.2 is on road capacity loss analysis using modified PCE values, Section 7.3 focuses on the relationship between Modified Road Capacity Loss and Pavement Distress and section 7.4 concludes the chapter.

7.1 ASSESSMENT OF PCE VALUES

The application of passenger car equivalency values from Nigerian Design Manual is doubtful because their derivation is based on model from the USA where it is obvious there are clear differences in terrain, driving population and pattern, lane width and lateral clearance. It may be argued that the positioning of defects like potholes has bearing on speed reduction and discomfort, this may be so, but effective roads must be free of such defects and the need for motorist and indeed pedestrians to navigate around pavement distress eliminated.

In the Highway Capacity Manuals where roadway capacity is computed in vehicles per hour, allowance is made for traffic mix by way of correction factors (lane width and lateral clearance, driver population, and terrain). In the United Kingdom, pre-determined passenger car equivalency values are usually applied to traffic volumes when converting from vehicles per hour. The study will use a simplistic approach based on vehicle headways from our survey database. The method of calculating PCE was presented by Greenshields (*1934*) and was based on measurement of headway between vehicles under saturated flow conditions.

However, Zhao *(1989)* concludes that Greenshields method of determining the headways combined with the regression method calculation of PCE is applicable to developing countries. But traffic in developing countries is usually characterised by a variety of transport modes ranging from pedestrians and handcarts, bicycles and rickshaws to trucks and buses. According to Seguin, Crowley and Zwieg *(IR, 1998)* PCEs can be defined as the ratio of the mean lagging headway of a subject vehicle divided by the mean lagging headway of the basic passenger car. Lagging headway is defined as the time or space from the rear of the leading vehicle to the rear of the vehicle of interest; it is composed of the length of the subject vehicle and the inter-vehicular gap.

In any case PCEs may be estimated as:

$$PCE_{ij} = H_{ij} / H_{pcj}$$

i, Headway = Spacing (m/veh) / Speed (m/sec) HCM (*1992*)

ii, Spacing = (1000m/km) / Density (veh/km) HCM (*1992*)

iii. Density (veh/km) = 1000 (m/km) / Spacing (m/veh) HCM (*1992*)

Where PCE_{ij} is the PCE of vehicle Type i under Conditions j, and H_{ij}, H_{pcj} is the average headway for vehicle Type i and passenger car for Conditions j.

The computed densities per roadway section and their relative average speed were plugged into the equations above for different types of vehicle (PCs, LGVs and HGVs). For example at site AN001:

Spacing = 1000 / 32 = 31.250 m/veh

Headway (PC) = 31.250 / 25 = 1.250 sec / veh

Headway (LGV) = 31.250 / 19 = 1.645 sec / veh

Headway (HGV) = 31.250 / 16 = 1.953 sec / veh

PCE (PC) = 1.0 unit

PCE (LGV) = 1.645 / 1.250 = 1.316unit

PCE (HGV) = 1.953 / 1.250 = 1.563 unit

Where:

Density = 32 vehicles per kilometre;

Speed (PC) = 90km/hr or 25 m/sec

Speed (PC) = 68km/hr or 19 m/sec

Speed (PC) = 58 km/hr or 16 m/sec

Note that the estimated PCE values in tables' 7.0 and 7.1 were calculated for the purpose of this project and may not be relied on for more widespread adoption. Note also that in Chapter 6 the flow / density curve for OG010 had the wrong signs, suggesting that the data was defective. It has been eliminated from further computations.

The results of the computed pce values for surveyed road section with pavement distress are shown in table 7.1

Table 7.0 Estimated PCE values for Road Section A

Site	Vehicle Type	Speed m/sec	Density Veh/hr	Spacing M/veh	Headway sec/veh	PCE unit
AN01	PC	25	32	31.250	1.250	1.000
	LGV	19	32	31.250	1.645	1.316
	HGV	16	32	31.250	1.953	1.563
DL04	PC	22	28	35.714	1.623	1.000
	LGV	17	28	35.714	2.101	1.294
	HGV	11	28	35.714	3.247	2.000
DL05	PC	22	22	45.455	2.066	1.000
	LGV	18	22	45.455	2.525	1.222
	HGV	13	22	45.455	3.497	1.692
ED06	PC	22	31	32.258	1.466	1.000
	LGV	17	31	32.258	1.898	1.294
	HGV	15	31	32.258	2.151	1.467
ED07	PC	22	30	33.333	1.515	1.000
	LGV	17	30	33.333	1.961	1.294
	HGV	15	30	33.333	2.222	1.467
ED08	PC	22	34	29.412	1.337	1.000
	LGV	19	34	29.412	1.548	1.158
	HGV	15	34	29.412	1.961	1.467
EK09	PC	24	32	31.250	1.302	1.000
	LGV	16	32	31.250	1.953	1.500
	HGV	14	32	31.250	2.232	1.714
OG11	PC	24	26	38.462	1.603	1.000
	LGV	17	26	38.462	2.262	1.411
	HGV	14	26	38.462	2.747	1.714
OG12	PC	24	30	33.333	1.389	1.000
	LGV	17	30	33.333	1.961	1.412
	HGV	13	30	33.333	2.564	1.846
OY18	PC	25	37	27.027	1.081	0.919
	LGV	19	37	27.027	1.422	1.210
	HGV	15	37	27.027	1.802	1.532
OY19	PC	22	34	29.412	1.337	1.088
	LGV	17	34	29.412	1.730	1.408
	HGV	13	34	29.412	2.262	1.841

Source: Survey Data

Table 7.1 Estimated PCE values for Road Section B

Site	Vehicle Type	Speed m/sec	Density veh/hr	Spacing m/veh	Headway sec/veh	PCE Unit
AN01	PC	9.72	57	17.544	1.805	1.000
	LGV	10.28	57	17.544	1.707	0.946
	HGV	10.00	57	17.544	1.754	0.972
DL04	PC	10.56	50	20.000	1.895	1.000
	LGV	11.11	50	20.000	1.800	0.950
	HGV	10.83	50	20.000	1.846	0.974
DL05	PC	10.83	31	32.258	2.978	1.000
	LGV	11.11	31	32.258	2.903	0.975
	HGV	10.56	31	32.258	3.056	1.026
ED06	PC	10.28	56	17.857	1.737	1.000
	LGV	10.83	56	17.857	1.648	0.949
	HGV	10.28	56	17.857	1.737	1.000
ED07	PC	10.83	49	20.408	1.884	1.000
	LGV	12.22	49	20.408	1.670	0.886
	HGV	11.11	49	20.408	1.837	0.975
ED08	PC	10.83	48	20.833	1.923	1.000
	LGV	11.94	48	20.833	1.744	0.907
	HGV	11.11	48	20.833	1.875	0.975
EK09	PC	9.72	51	19.608	2.017	1.000
	LGV	10.56	51	19.608	1.858	0.921
	HGV	10.00	51	19.608	1.961	0.972
OG11	PC	10.56	51	19.608	1.858	1.000
	LGV	10.83	51	19.608	1.810	0.974
	HGV	10.56	51	19.608	1.858	1.000
OG12	PC	10.28	51	19.608	1.908	1.000
	LGV	10.56	51	19.608	1.858	0.974
	HGV	10.83	51	19.608	1.810	0.949
OY18	PC	11.67	61	16.393	1.405	1.000
	LGV	12.50	61	16.393	1.311	0.933
	HGV	12.22	61	16.393	1.341	0.955
OY19	PC	10.00	55	18.182	1.818	1.000
	LGV	10.56	55	18.182	1.722	0.947
	HGV	12.22	61	16.393	1.341	0.955

Source: Survey Data

7.1.1 Comment on Estimated PCE values - As shown above in tables 7.2a and 7.2b the estimated PCE values for road section A, are PC = 1.0, LGV = 1.3, and HGV = 1.7. Whereas the estimated PCE values for road section B, are PC = 1, LGV = 1.0 and HGV = 1.0. PCE values as mentioned earlier are employed in highway capacity analysis to determine the number of passenger cars displaced in the traffic flow by LGVs and HGVs under the prevailing roadway and traffic conditions. Within the context of this study, traffic is free flowing, the terrain is flat, road is without and with pavement distress. If the definition of PCE values is to hold, their values on road section with pavement distress will be significantly different from that of road section without pavement distress under free flow condition.

It is useful to mention in passing that the PCE values in Nigeria (PC = 1.0, LGV = 1.5, and HGV = 2.0) for flat terrain are somewhat higher than the estimated values from this study. The Nigerian PCE values were adopted from Highway Capacity Manual without modifications to local conditions, or recalculation. Besides, traffic conditions in most developing countries are considerably different from those in the USA. Consequently, PCE values of the Highway Capacity Manual cannot be transferred without thorough evaluation. Thus, it is distorting to claim that 1.5 or 2.0 passenger cars are displaced by LGV and HGV respectively under a free flow and flat terrain conditions. Further research is needed to ascertain the PCE values of vehicle types in Nigeria. In this study headway was estimated from spacing and speed, it would be useful to conduct a separate headway distribution survey for vehicle types under varying road and traffic conditions.

However, under road pavement distress condition PCE values are near uniform, note also that PCE values of LGVs and HGVs are slightly less than 1.0. From observations at survey sites, passenger cars sometimes force HGVs to slow down especially when they are platoon leaders because of their manoeuvrability difficulties on road sections with pavement distress. These observations further validate the definition of PCE values and to some extent the reason why the PCE values of HGVs and LGVs are slightly less than 1.0. It is worth noting that PCE value is not a fixed values attached to the vehicle type, rather it depends on two main factors; the road condition and the traffic composition.

7.2 APPLICATION OF MODIFIED PCEs FOR CAPACITY LOSS ANALYSIS

Schematic Diagrams of Road Capacity Loss Analysis Using Modified PCE Values

1. Using Tabulated Empirical Results in Chapter 5

2. Estimate Flow, Density, where

Flow (q) = 12 x volume / interval

Density (k) = flow / speed

Modified PCE values PC =1.0, LGV = 1.3, HGV = 1.7 Road Section A

Modified PCE values PC =1.0, LGV = 1.0, HGV = 1.0 Road Section B

⇩

2. Use Flow/Density Relationship below:

$$q = -\beta_o + \beta_1 k - \beta_2 k^2$$

And determine flow/density model coefficients for the road sections, then

3. Estimate critical density by differentiating flow with respect to density for maximum flow (q_{max}) as follows:

$$\partial q / \partial \kappa = 0$$

$$-2\beta_2 k + k = 0$$

For $k = k_{crt}$ (critical density) $\quad k_{crt} = \beta_1 / 2\beta_2$

⇩

4. Determine Roadway Capacity by estimating maximum flow per road section by plugging critical density into the flow / density model coefficients below:

$$q_{max} = -\beta_o + \beta_1 k_{crt} - \beta_2 k_{crt}^2$$

5. Compare the Road Capacity for Section A and B and determine Road capacity Loss.

Table 7.2a Computed Flows and Densities for Road AN001 Section A

PC	LGVs	HGVs	LGVs* 1.3	HGVs* 1.7	Flow/5 min	Flow/hr	Speed	Density
27	29	8	37.7	13.6	78.3	940	95	9.89
24	26	7	33.8	11.9	69.7	836	90	9.29
17	18	5	23.4	8.5	48.9	587	86	6.82
23	24	7	31.2	11.9	66.1	793	86	9.22
31	33	10	42.9	17	90.9	1091	85	12.83
17	18	5	23.4	8.5	48.9	587	92	6.38
19	21	6	27.3	10.2	56.5	678	92	7.37
22	24	7	31.2	11.9	65.1	781	92	8.49
26	27	8	35.1	13.6	74.7	896	90	9.96
17	18	5	23.4	8.5	48.9	587	90	6.52
24	26	7	33.8	11.9	69.7	836	89	9.40
32	35	10	45.5	17	94.5	1134	89	12.74
279	299	85				1668		28.52

Source: Survey

Table 7.2b Computed Flows and Densities for Road AN001 Section B

PC	LGVs	HGVs	LGV s*1	HGVs* 1	Flow/5 min	Flow/hr	Speed	Density
22	23	7	23.0	7	52.0	624	36	17.33
17	18	5	18.0	5	40.0	480	35	13.71
13	14	4	14.0	4	31.0	372	35	10.63
20	21	6	21.0	6	47.0	564	36	15.67
18	19	6	19.0	6	43.0	516	35	14.74
18	20	6	20.0	6	44.0	528	35	15.09
19	20	6	20.0	6	45.0	540	37	14.59
19	21	6	21.0	6	46.0	552	39	14.15
21	23	7	23.0	7	51.0	612	36	17.00
15	16	5	16.0	5	36.0	432	39	11.08
18	19	6	19.0	6	43.0	516	39	13.23
17	18	5	18.0	5	40.0	480	36	13.33
217	232	69				1015		44.02

Source: Survey **Note:** Traffic Composition (PC) 42% (LGV) 45% (HGV) 13%

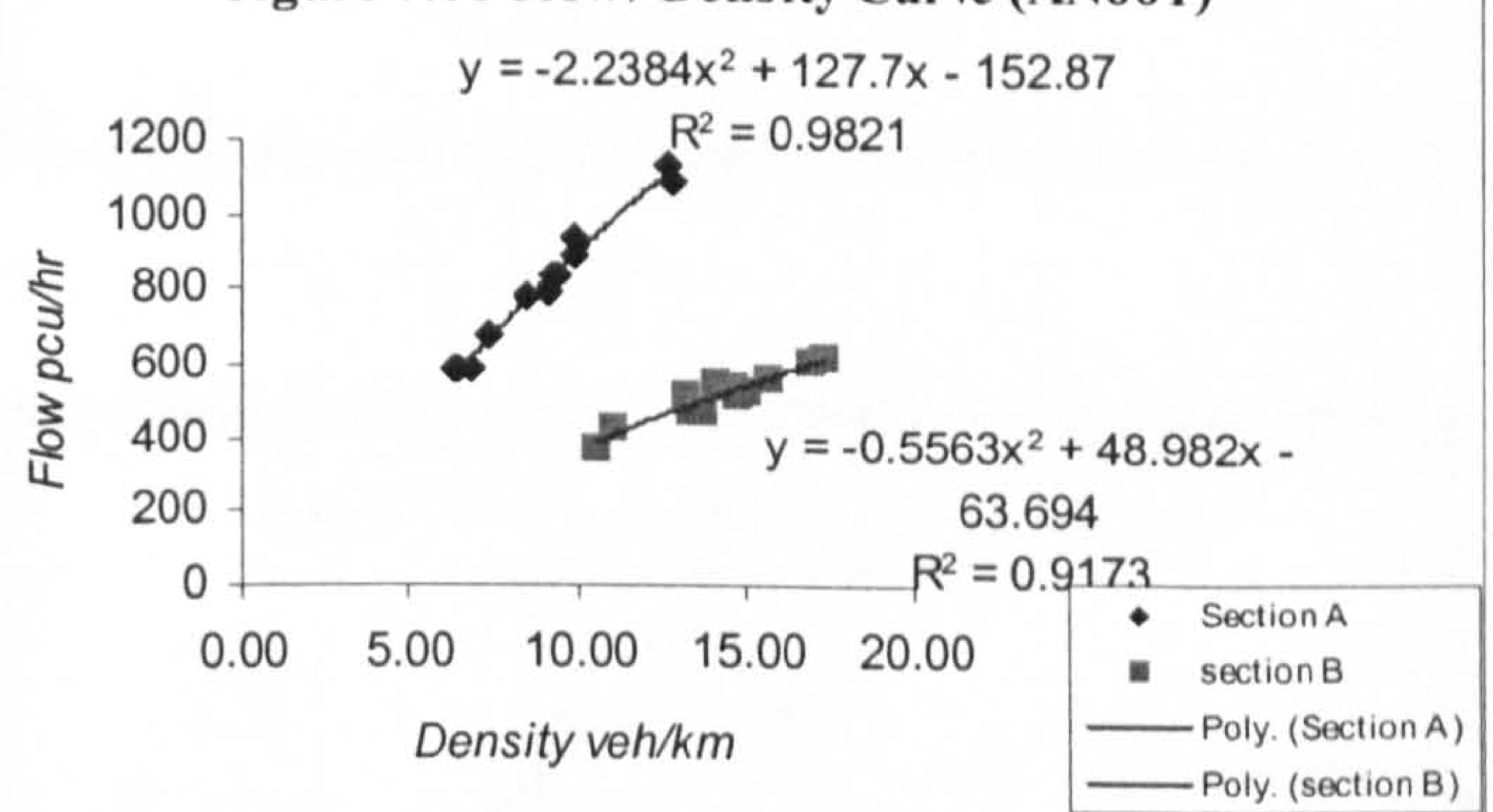
We assume that speed; flow and density relationships for the section A and B would be the same if it were not for the pavement distress. However, the pavement distresses on section B affect speed (v), flow (q) and density (k) relationship for section B. The road capacity models used here were adapted from studies in recent literature (Van Arem *et al (1994),* Minderhoud *et* al (*1998*), and Akcelik *(1991)* of the form:

$$q = -\beta_o + \beta_1 k - \beta_2 k^2$$

In this section the road capacity loss for surveyed sites were computed with the modified PCE by plugging the tabulated values of flows and densities in Tables 7.01a and 7.01b into the equation above. Note that the computed flows and densities for other sites are shown in Appendix D. The quadratic functions for both road sections were developed for site AN001 as shown below in Figure 7.01. The quadratic equations were treated the same way as previously done in Chapter 6 with the following results:

Roadway Capacity Loss	654 pcu/hr
Percentage of Loss	39%

Figure 7.01 Flow / Density Curve (AN001)



The model coefficients for remainder sites are shown below in Figures 7.04, 7.05, 7.06, 7.07.7.08.7.09, 7.11, 7.12, 7.18, and 7.19. Note that model coefficients of sites ED007, OG012 and OY018 show the wrong signs thus violating the expected concavity of the quadratic curves, suggesting that the data is defective and subsequently eliminated from further analysis.

Figure 7.04 Flow / Density Curve (DL004)

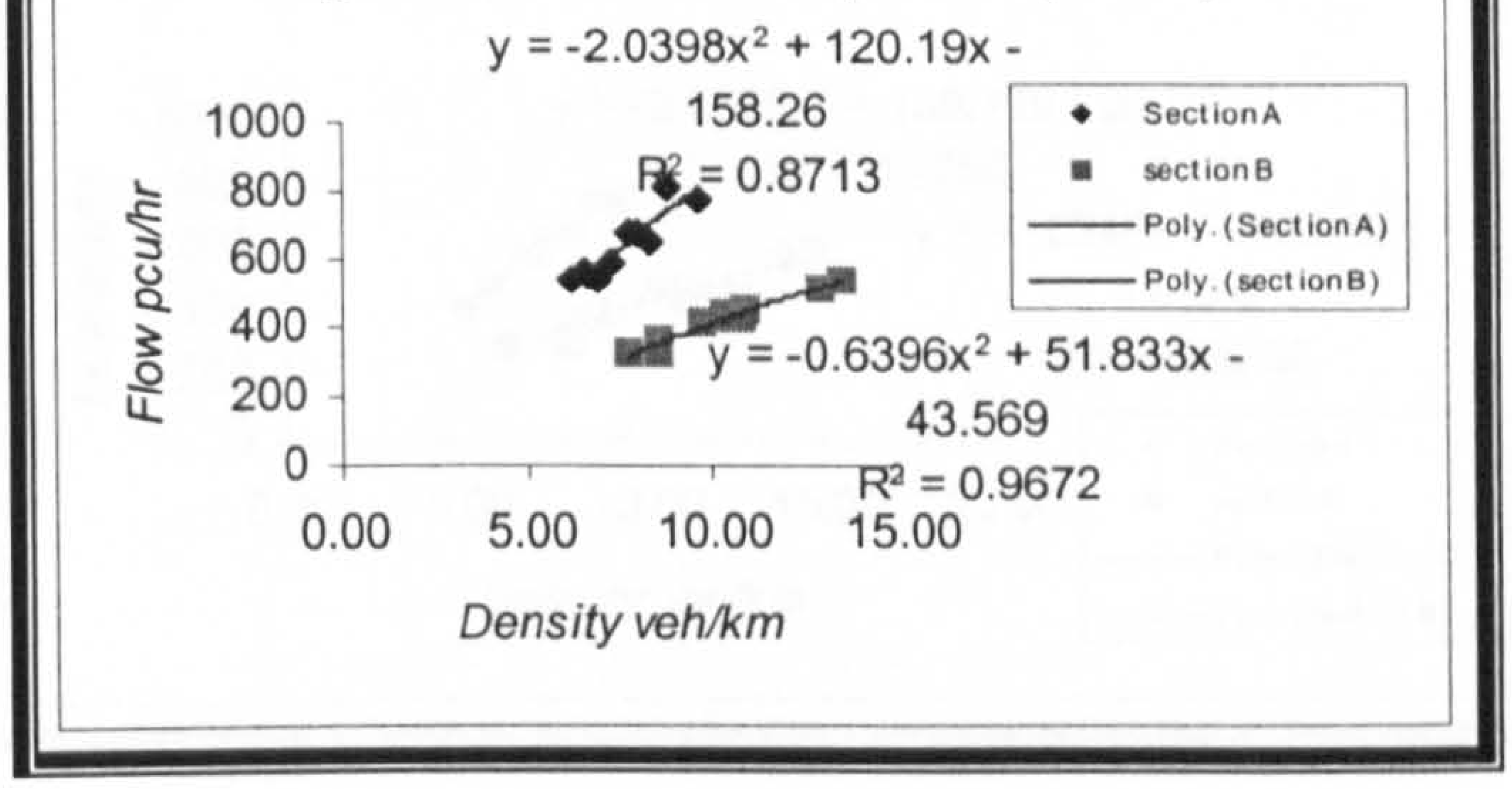


Figure 7.05 Flow / Density Curve (DL005)

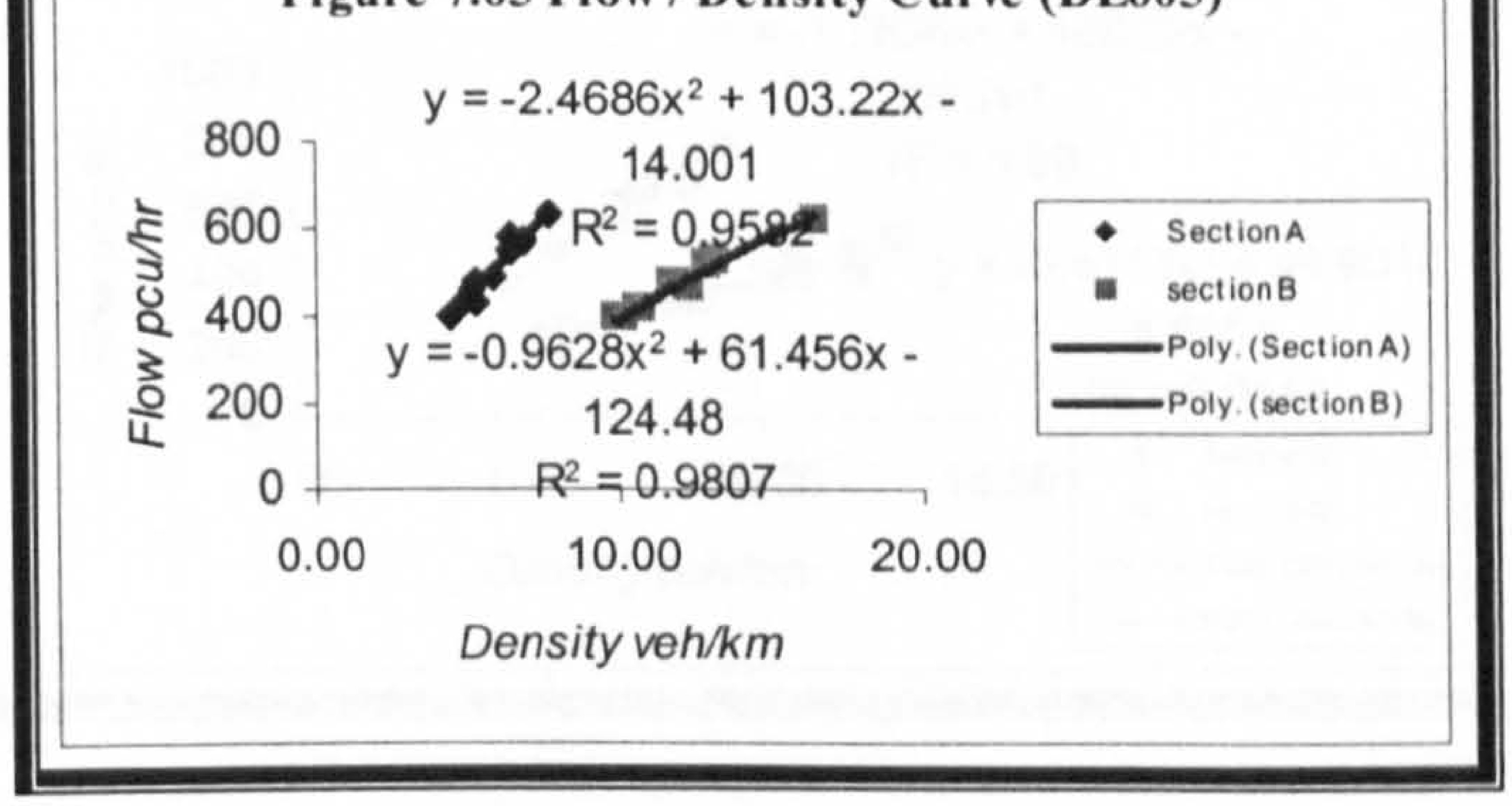


Figure 7.06 Flow / Density Curve (ED006)

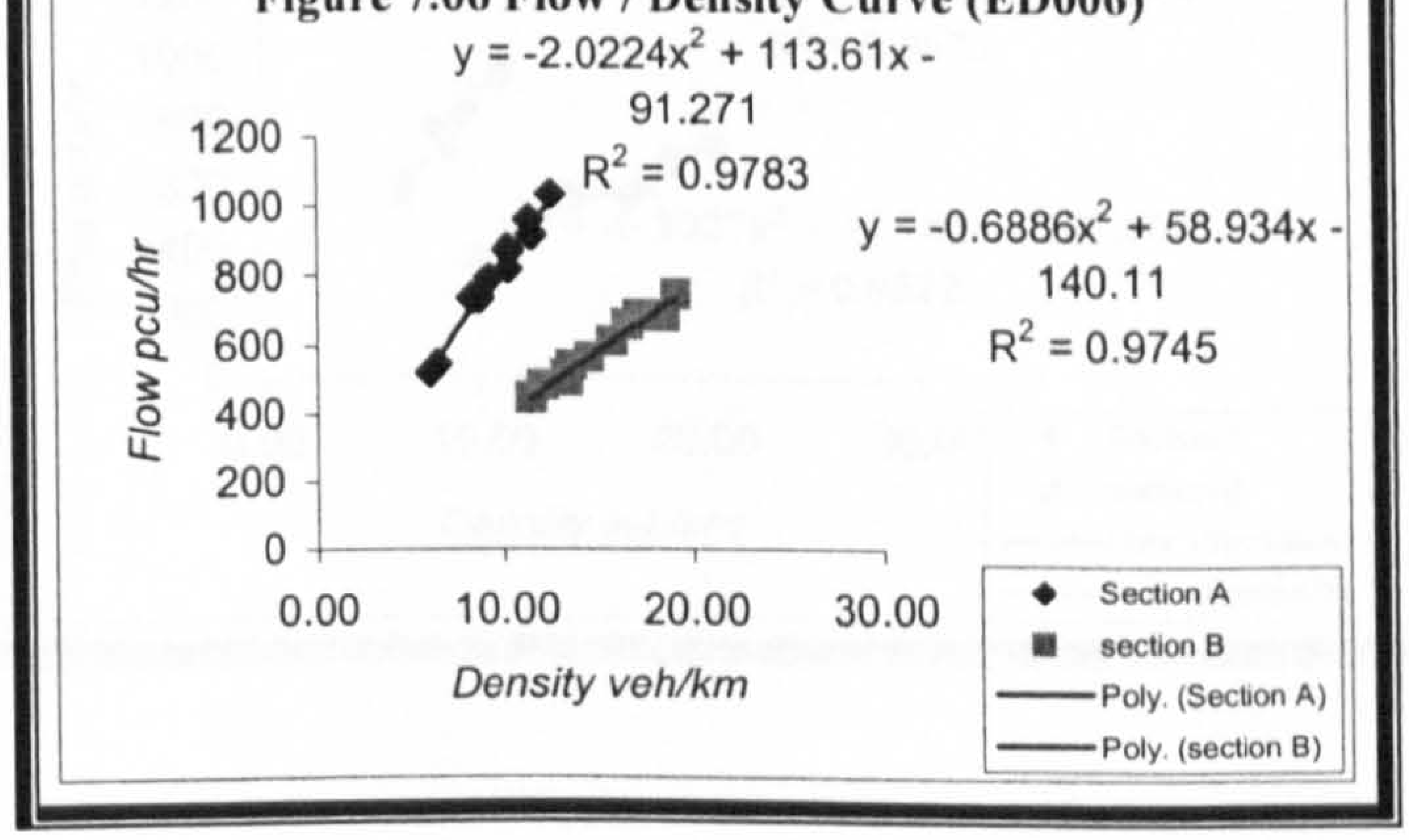


Figure 7.07 Flow / Density Curve (ED007)

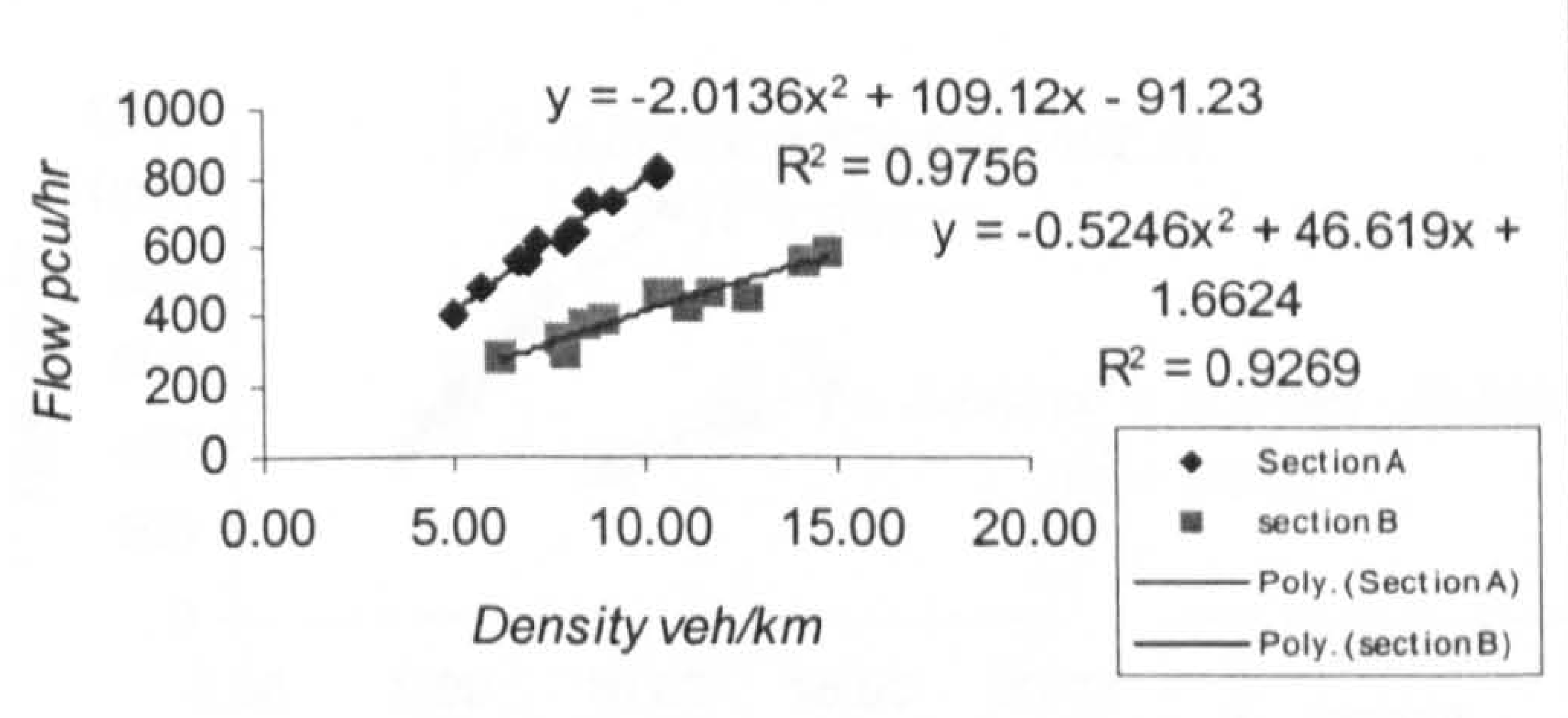


Figure 7.08 Flow / Density Curve (ED008)

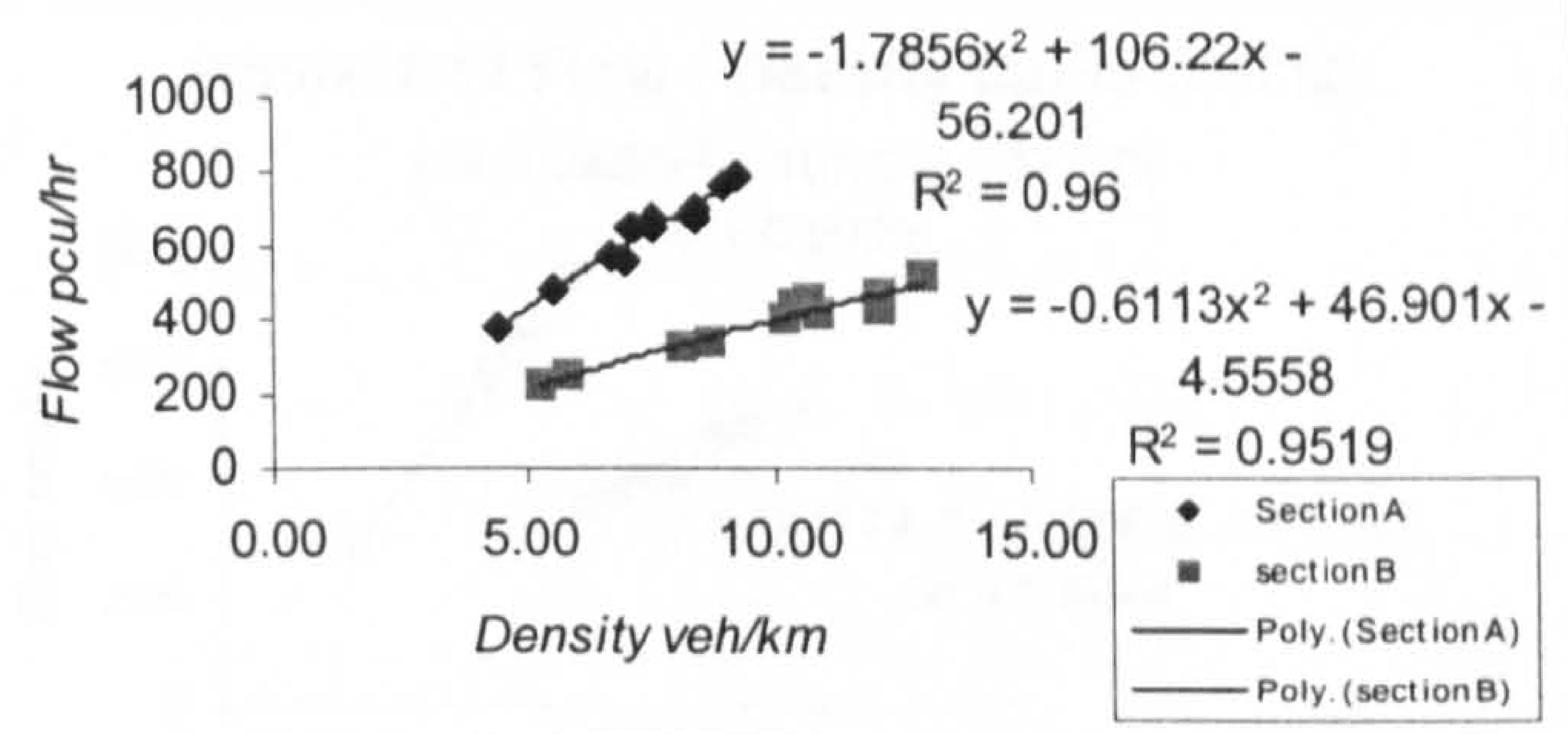


Figure 7.09 Flow / Density Curve (EK009)

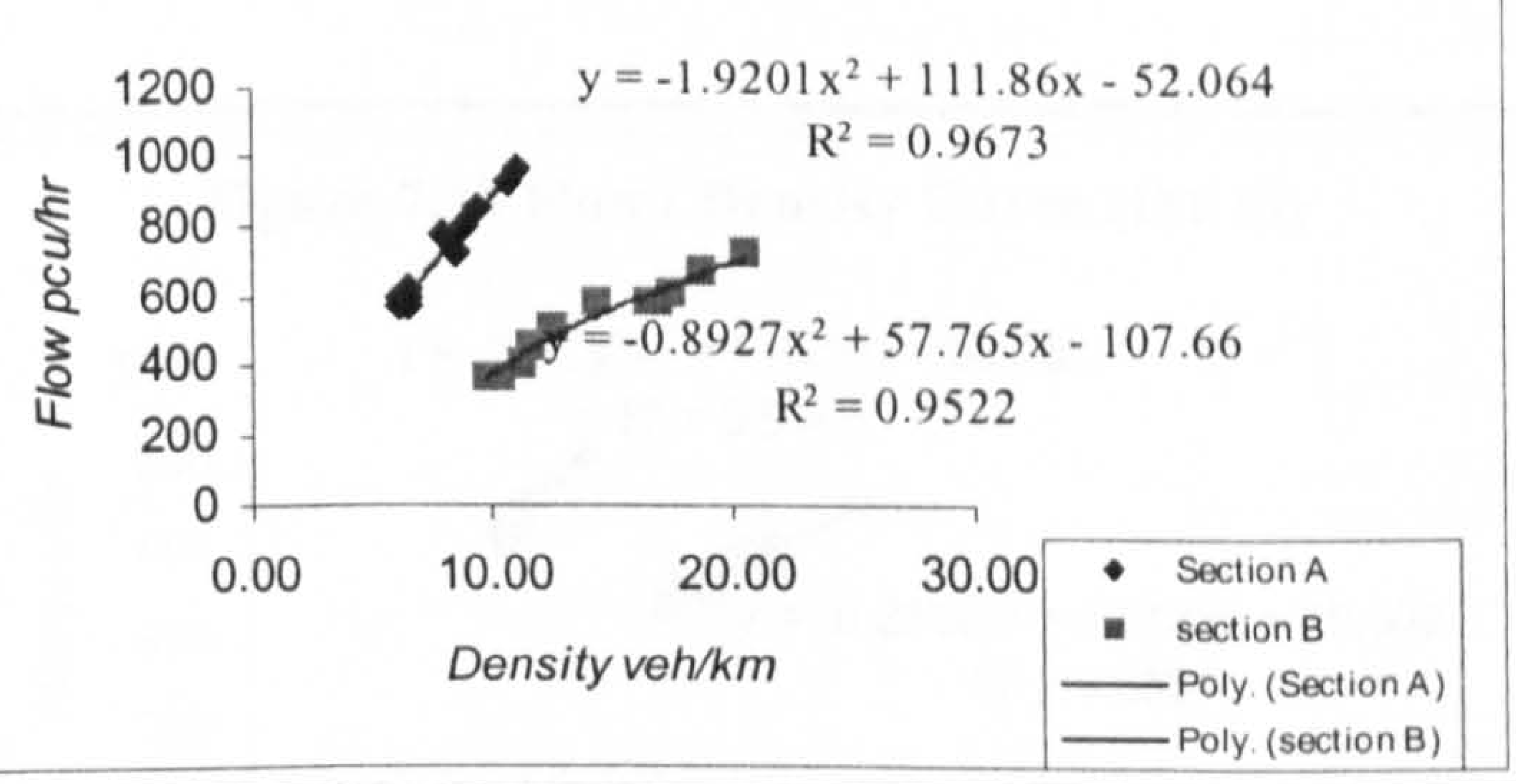


Figure 7.11 Flow / Density Curve (OG011)

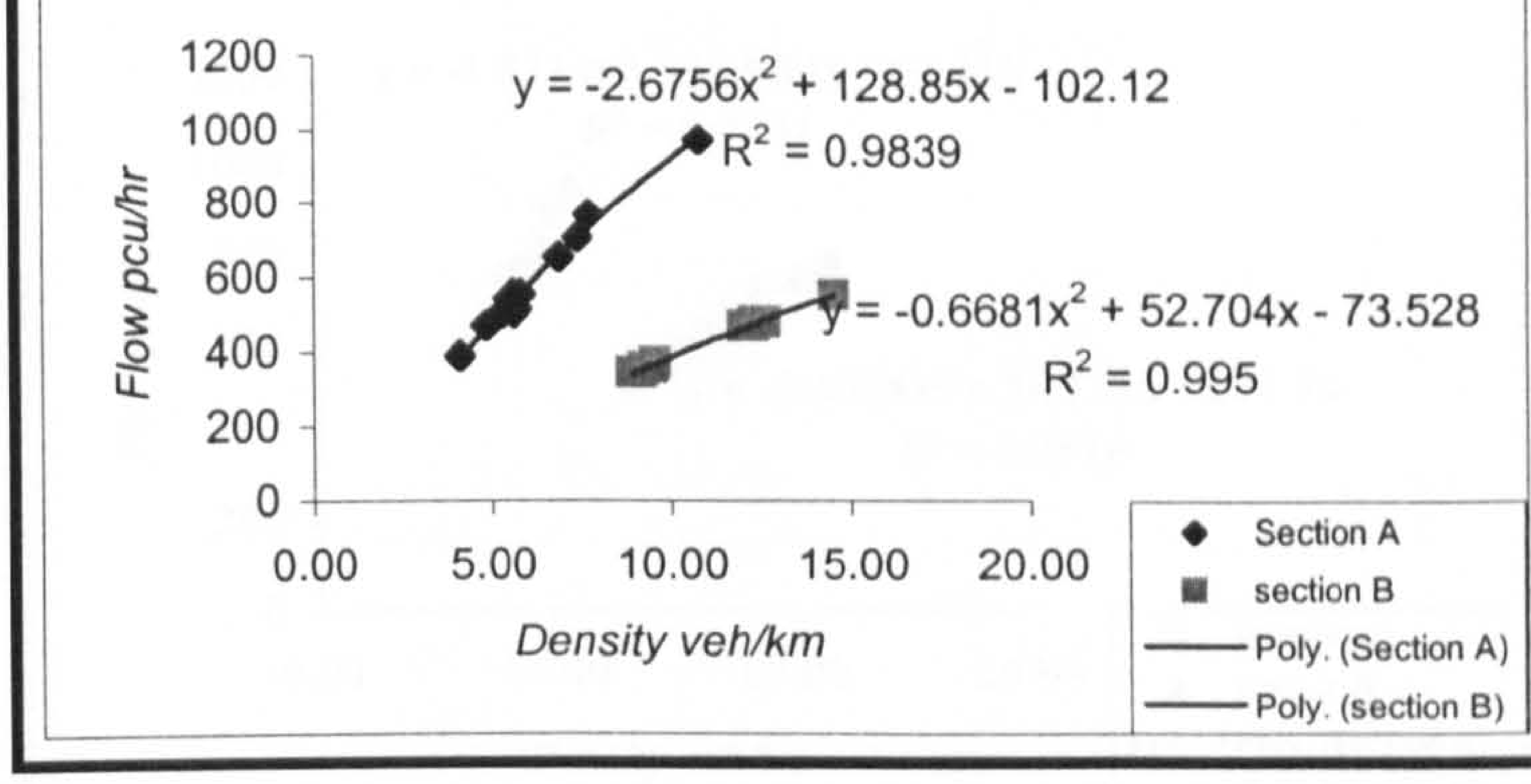


Figure 7.12 Flow / Density Curve (OG12)

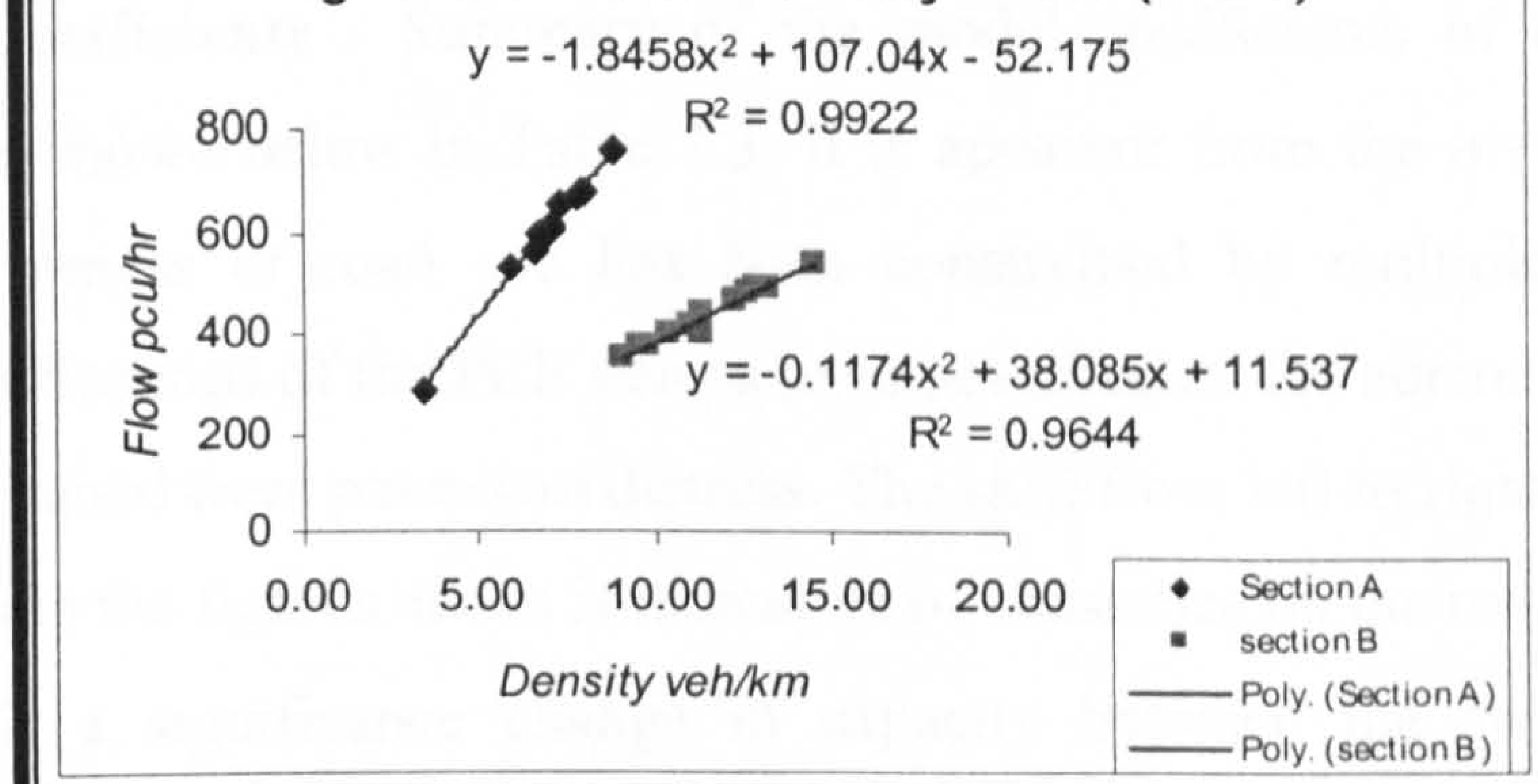


Figure 7.18 Flow / Density Curve (OY18)

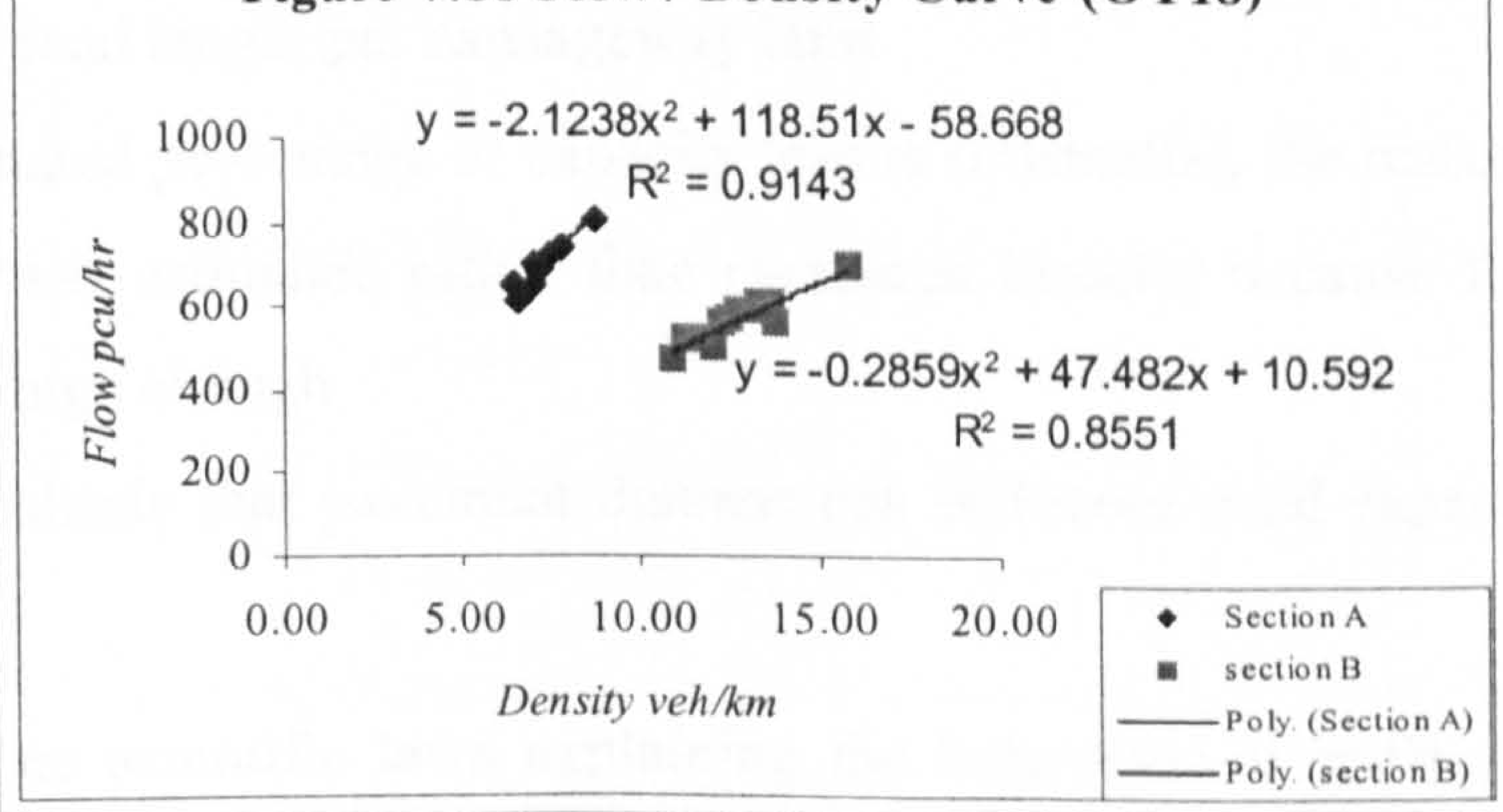
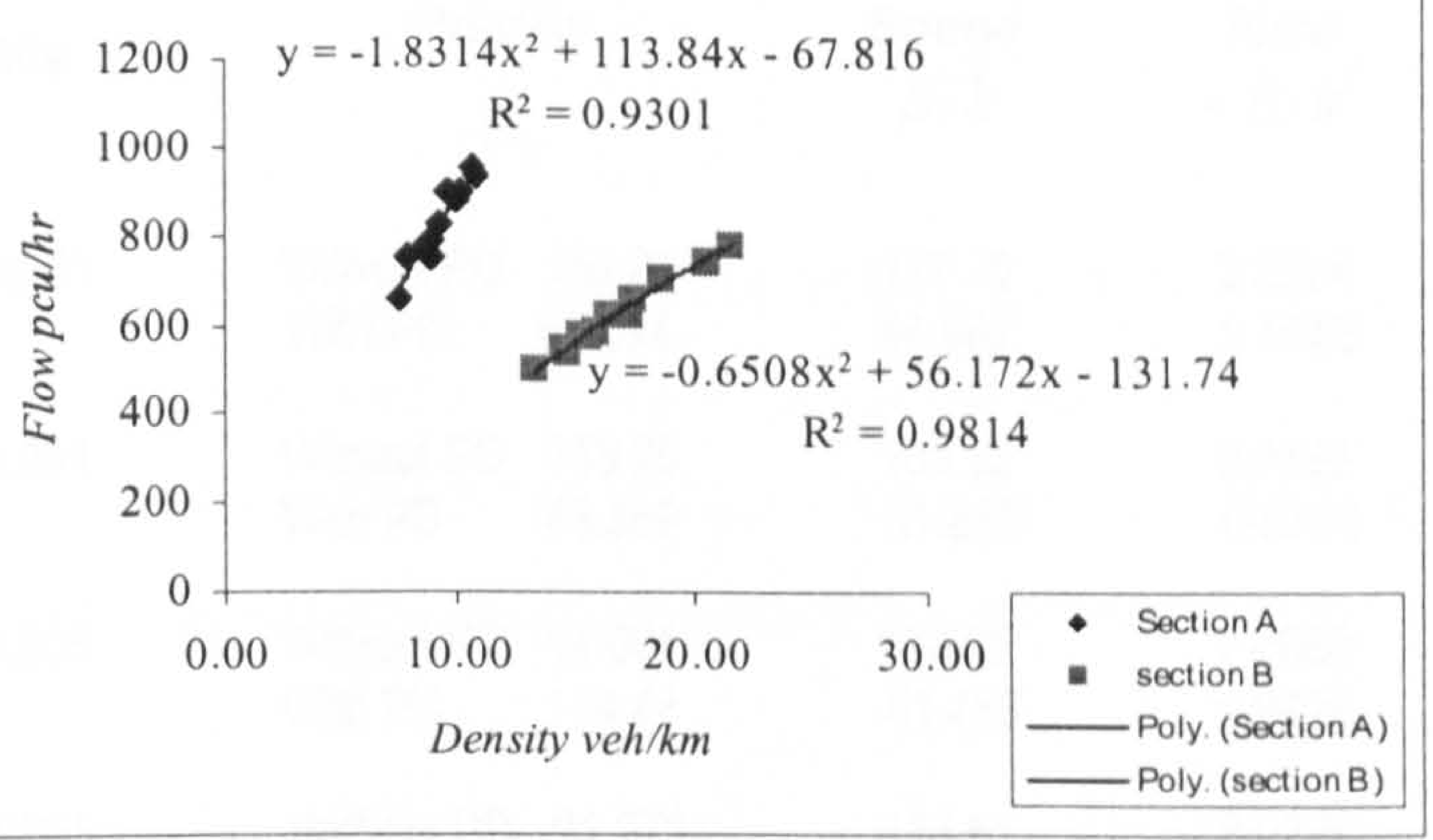


Figure 7.19 Flow / Density Curve (0Y19)



7.2.1 Model Coefficients - Summary of the model coefficients of all road sections investigated are shown below in Table 7.3. It is apparent from the investigations so far that the effectiveness of road use has been constrained by multiple road pavement distresses. Modifications of the PCE values have not affected the outcome of the result as capacity loss resulted from pavement distress. The shift from left to right in flow / density curve as shown in the figures above is indicative of constraint on the road, further that:

- There is a significance change in capacity between the 'with' and without pavement distress sections. There are no other factors other than pavement distress that affected the traffic flow loss between both link sections.
- Average loss of road capacity was attributed to pavement distress prevalent per surveyed road length per carriageway lane.
- The estimated percentage of capacity loss is substantial, the reason been that road capacity was estimated rather than measured directly because flows at the sites were not high enough
- The hypothesis that pavement distress can influence road capacity loss remains valid

Since there are no scientific laws explaining the behaviour of traffic, and in practice vehicles are not homogeneous, the concept of modified passenger car units was used to describe the effect of vehicles of different sizes.

Table 7.3 Summary of Model Coefficients

Site	Density $-\beta_o$		Speed $\beta_1 k$	Flow $-\beta_1 k^2$
AN001	Without PD	152.87	127.70	2.2384
	With PD	63.694	48.982	0.5563
DL004	Without PD	158.26	103.22	2.0398
	With PD	43.569	51.853	0.6396
DL005	Without PD	14.001	103.22	2.4680
	With PD	124.48	61.456	0.9628
ED006	Without PD	91.271	113.61	2.0224
	With PD	140.11	58.934	0.6886
ED008	Without PD	56.201	106.22	1.7856
	With PD	4.5358	46.901	0.6113
EK009	Without PD	52.064	111.86	1.9201
	With PD	107.66	57.765	0.8927
OG011	Without PD	102.12	128.85	2.6756
	With PD	73.528	52.704	0.6681
OY019	Without PD	67.816	113.84	1.8314
	With PD	131.74	56.172	0.6508

Source: Survey Data

7.2.2 Summary of Road Capacity Loss using Modified PCE - Road capacity losses resulted from pavement distress irrespective of whether the PCE values applied were standard or modified. Generally, the modified PCE values gave lower road capacities but higher road capacity loss because the modified PCE values were smaller and took account of the influence of pavement distress. The large increase in percentage road capacity loss resulted from reduction of PCE values of commercial vehicles to 1units, same as passenger cars. Hence passenger cars were more affected by the capacity loss. Where the small presence of commercial vehicles were recorded DL005, the difference in capacity loss was small regardless of whether the computation was based on standard or adjusted values. Also, where passenger car is the lead vehicle on road section with pavement distress, one would expect to record a higher loss time because this class of vehicle is the most affected by pavement distress. Table 7.4 below contains summary of road capacity loss analysis using modified PCE values. Critical densities have been found in Chapter 6 to be higher at the road sections with pavement distress; hence it follows that spacing would be smaller. However, speeds on this road section for all types of vehicles are the same because all the vehicles were constrained by the same road conditions with very little room for manoeuvrability. Thus, it can be argued that given smaller spacing, lower speed, and larger density, it's appropriate to expect the PCE values on the road sections with pavement distress to be somewhat lower than that of the section without pavement distress.

Table 7.4 Road Capacity Loss Using Modified PCE

1	2	3	4	5	6	7	8	9	10	11
ROAD CODE	SECTION WITHOUT DISTRESS				SECTION WITH DISTRESS				CAPACITY LOSS	
	Flow	Speed	Density	Capacity	Flow	Speed	Density	Capacity		
	Pcu/hr	Km/h	Veh/km	Pcu/hr	Pcu/hr	Km/h	Veh/km	Pcu/hr	Pcu/hr	%
AN001	1134	119	28	1668	624	46	44	1015	654	39
DL004	779	114	29	1650	540	50	40	1007	643	39
DL005	629	101	21	1065	624	53	32	856	644	39
ED006	1034	107	28	1504	744	50	43	1121	383	25
ED008	786	101	30	1523	516	47	38	895	628	41
EK009	959	109	29	1577	720	52	32	827	750	48
OG011	744	121	24	1449	720	49	39	966	483	33
OY019	950	110	31	1701	684	50	43	1080	620	36

Source: Survey Data

7.2.3 Comparative Summary - Table 7.5, below shows comparative summaries of the road capacity computed with standard Nigerian PCE and modified PCE values. Note that only flows and capacities from distressed road sections are shown in this table. The reason being, differences in flows and capacities are higher on this road section and can therefore be construed as the worst case scenario. By modifying the PCE values on Road section with pavement distress, we are implying that the performance advantage usually enjoyed by passenger car over other types of vehicles on level terrain has been eroded. In fact we are implying that HGVs will perform better than passenger cars overtime as the road condition worsen.

Table 7.5 Comparative Road Capacity Loss using both PCE values

1	2	3	4	5	6	7	8	9
ROAD CODE	ROAD CAPACITY USING STANDARD PCE VALUES				ROAD CAPACITY USING MODIFIED PCE VALUES			
	Distressed Flow Pcu/hr	Distressed Capacity Pcu/hr	Capacity Loss Pcu/hr	Loss %	Distressed Flow Pcu/hr	Distressed Capacity Pcu/hr	Capacity Loss Pcu/hr	Loss %
AN001	846	1328	518	28	624	1015	654	39
DL004	606	1204	315	23	540	1007	643	39
DL005	636	849	262	24	624	856	644	39
ED006	900	1468	338	12	744	1121	383	25
ED008	672	1122	584	34	516	895	628	41
EK009	930	1195	518	30	720	827	750	48
OG011	690	1244	316	20	720	966	483	33
OY019	816	1353	484	26	684	1080	620	36

Source: Survey Data

Over 50 percent commercial vehicles were accounted for in traffic composition at sites AN001, ED006, ED008 and EK009, while sites DL005 had 5 percent. Site DL005 has the lowest road capacity and capacity loss differences, the reason being, passenger cars accounted for 95% of traffic flow; hence the effect of PCE values was greatly reduced. By contrast site EK009 with a difference of +18% where traffic Composition (PC) 45%, (LGV) 52%, and (HGV) 03% is indicative of the significance of LGVs and HGVs in passenger car equivalency. The significance of LGVs and HGVs is further confirmed by site ED008 where traffic composition is (PC) 44%, (LGV) 51%, and (HGV) 05%. Sites AN001, ED006, ED008 and EK009 recorded substantial increase in road capacity loss when the PCE values were modified suggesting that PCE By using the headway method one is implying that the relative amount of space occupied by a vehicle in motion is the basis for calculating PCE values. The PCE values were given as a function of the type of terrain and level of service on the surveyed roads for passenger cars, light and heavy goods vehicles.

In estimating road capacity the fundamental relationship between flow, density and speed was used. Likewise the minimum desirable carriageway lane width according to DTp Advice Note 20/84 (*1997*) could be taken as 2.5m. Thus by implication road pavement distress width capable of reducing the carriageway lane width to less than 2.5m has adverse effect on traffic. As shown so far in this study, road pavement distress has significant effects on road capacity. That being so it can be argued that relationship exists between the two variables. We shall investigate this argument in the next section.

7.3 PAVEMENT DISTRESS AND ROAD CAPACITY LOSS RELATIONSHIP

Two variables road capacity loss and pavement distress are central to this study and the main thrust in this section is to investigate specifically the relationship between these variables. All selected sites exhibited pavement distress width greater than 1.15m on a two lane carriageway road. Even though literatures were not precise on how to relate the area of pavement distress to road section, we assumed a kilometre of road length would be useful for uniformity in measurements with other relevant traffic parameters like density and speed. So in considering the mechanisms by which pavement distress may possibly influence road capacity loss, two groups of factors seem most important: unpredictability associated with driver behaviour and of course the traffic mix.

Motorists may elect to travel at higher speeds given a certain traffic density because of good road condition; also they may keep shorter distances between vehicles ahead without lowering speed, or may even choose a different lane of the carriageway (multi-lanes). Also, drivers of heavy good vehicles may decide to take advantage of their larger tyre and twin axle, by maintaining above average speeds on road sections with poor surfacing condition. Based on the hypothesis that roadway capacity loss would result from pavement distress under daylight and dry weather conditions, it could be expected that a strong relationship exist between pavement distress and roadway capacity loss if the hypothesis were to hold.

Traditionally, regression techniques are employed for the development of functions that relate condition indices to the information recorded in the pavement management database. Where the sole aim of measurement of pavement distress is to model their influence on road capacity loss, then road capacity loss is taken as a function of pavement distress (PD). This could be written as:

$$Q_L = f(PD), \qquad \text{Equation 7.0}$$

However, in modelling for road capacity loss resulting from pavement distress, it is required that a satisfactory equilibrium between road capacity loss and the independent variables is reached and maintained in order to deliver effective road services. And for that to be meaningful, forecasting future capacity loss becomes essential to our problem solving approach. Therefore, this study will use the linear regression method that is capable of forecasting the future capacity loss satisfactorily. In order to check the relevance of the explanatory variables, a regression analysis was made applying the ordinary least squares estimation procedure to the survey-data. By applying least squares we assume among others that the explanatory variables are truly endogenous, that there is one-way causation between the dependent variable road capacity loss and the explanatory variables.

Structural equations express the endogenous variables as functions of other endogenous variables, predetermined variables and disturbances (random variables). Such information on types of inputs associated with types of outputs is invaluable for establishing more reliable capacity loss estimation.

Furthermore, we need to ascertain whether correlation exist between the independent variables so as to reduce the problem of multi co linearity. Multi colinearity may be view as a special case of weak identity. If some variables are strongly multi-co linear they are practically the same from the statistical point of view: either variable can be used as a proxy for the other. Such multi collinear variables cannot serve as two distinctly separate variables. Moreover, identified independent variables with weak coefficients were subsequently eliminated till satisfactory result is achieved. Three independent variables from Table 7.6 shown below are capable of been used equation 7.0 can be modified as:

$$Q_L = f(A/W, N, D) \qquad \text{Equation 7.1}$$

Table 7.6 Summaries of PD and Capacity Loss Variables

Site	$\%Q_L$	A / W m^2	Nos. (N)	Depth (D) mm	Length (L) m	Width (W) m
AN001	39	262.26	15	350	84.61	3.1
DL004	39	134.23	13	220	49.9	2.69
DL005	20	149.51	7	220	81.7	1.83
ED006	25	219.61	9	300	133.1	1.65
ED008	41	161.56	17	200	61.9	2.61
EK009	48	125.08	15	250	42.4	2.95
OG012	33	195.12	10	300	54.20	3.6
OY019	36	167.71	13	200	31.5	2.9

Source: Survey

By using Microsoft Linest function, we calculate the statistics for a line by using the 'least squares' method to calculate a straight line that best fits our data. The coefficients of different roadway capacity loss functions give us an indication of how efficient maximization could take place in various situations. The descriptions of important statistics used in the regression analysis are shown below:

't' statistic was used to determine whether each slope coefficient is useful in estimating the assessed value roadway capacity loss. For a variable to be considered useful the computed't' must be greater than 1.98 at 5% level of significance.

R^2 – coefficient of determination compares the estimated and actual roadway capacity loss values and was used to determine whether the regression equation could be used to predict roadway capacity loss values. It ranges in value is 0 to 1. Usually a value of 0.5 or higher will suffice for most regression equations.

F statistic was used to determine whether the model results with high coefficient of determination, occurred by chance. 'Alpha' was used for the probability of erroneously concluding that there was a relationship. There is a relationship among the variables if the F-observed statistic is greater than the F critical value. A benchmark value of 4.5 is a rough guide to F critical value. The F observed values in tables 8.04 and 8.05 are substantially greater than 4.5 therefore the regression equation is useful in predicting the assessed value of roadway capacity loss.

The starting point of this analysis is to plug the relevant variables in Table 7.18 into equation 7.1 then ordinary least squares estimation was performed employing the Microsoft Spreadsheet linear functions where road capacity Loss is a function of area of distress relative to lane width (*a/w*), number of potholes (*n*), and maximum depth (*d*) of potholes and written as:

$$Q_L = k_0 + \beta_0 (A / W) + \beta_1 N + \beta_2 D)$$

1. Make Null Hypothesis Ho; Correlation exists between the independent variables where, Calculated't' < 1.98 and $R^2 < 50\%$

2. Alternative Hypothesis Hi; Correlation does not exists between the variables where Calculated't' >1.98 and $R^2 > 50\%$. Where correlation does not exist among the independent variables and the test statistics are satisfactory, accept the relationship between the dependent and independent variables.

3 Test at 5% significance level.

The results are shown in Table 7.7

Table 7.7 Model Coefficients and Test Statistics

't' =	3.126043	8.833384	-3.551673	Constant
Coefficient	**0.095377**	**2.458311**	**-0.129343**	**3.261143**
Std. Error	0.03051	0.278298	0.036418	5.907299
R^2	0.956017	2.49664		
F *df*	28.98142	4		
Ssreg	541.9421	24.93285		

Source: Microsoft Excel Linest function

$$Q_L = 3.261 - 0.129A/W + 2.458N + 0.095D \quad \text{Equation. 7.2}$$

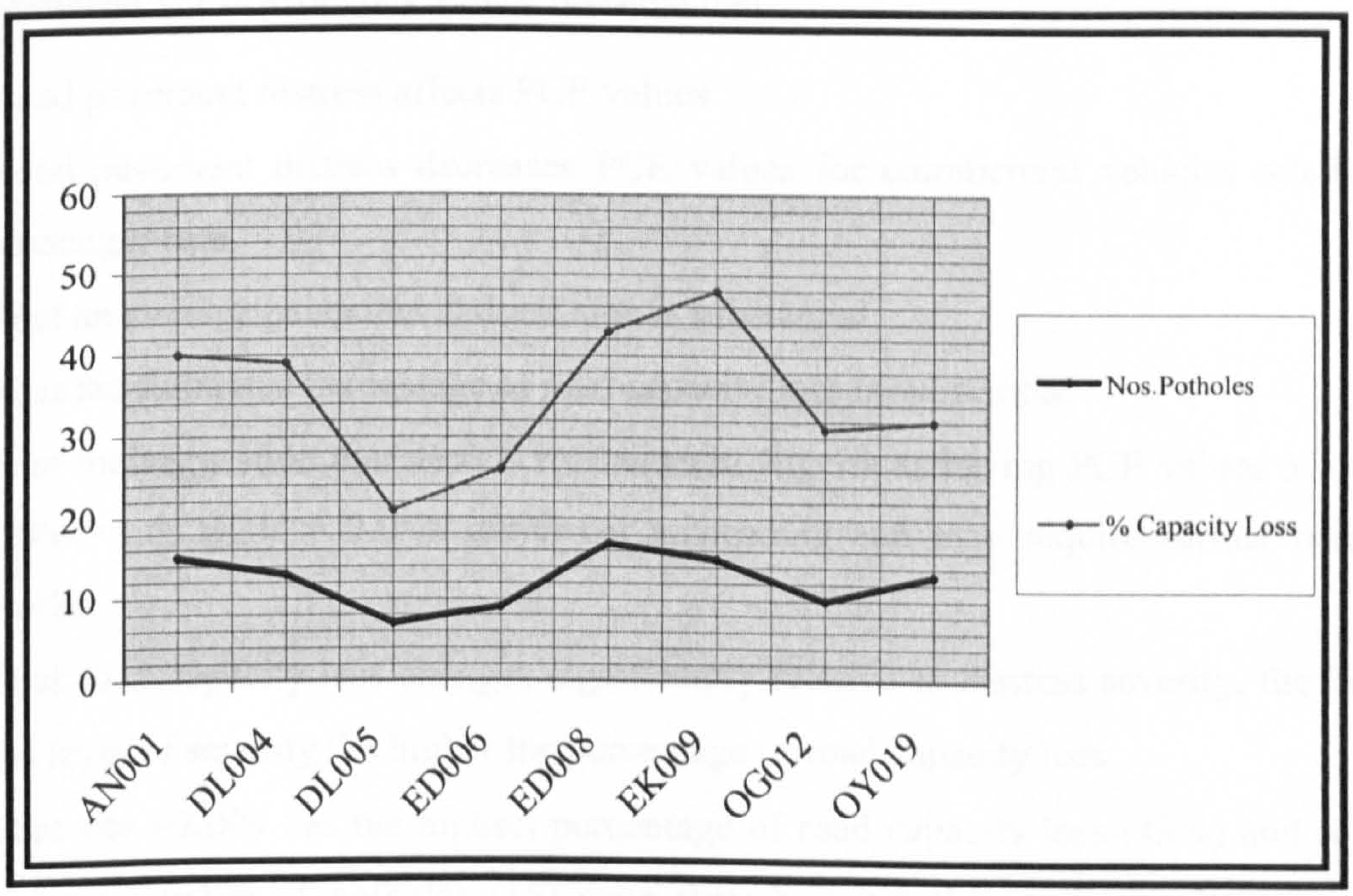
Where, t denotes t-statistics, t = Coefficient / std. error
Std. error denotes standard of error,
R^2 denotes coefficient of determination
F denotes F statistics, *df* denotes degree of freedom, and
ssreg denotes the regression sum of squares

Note: t - statistics was used to determine whether each slope coefficient is useful in estimating the assessed value of capacity loss where the t-critical single tail with 4 degrees of freedom and alpha = 0.05 = 1.98. Because the absolute values of 't' are greater than 1.98, Nos. of potholes, area of distress relative to lane width and maximum depth of surface distress are important variables when estimating the assessed value of capacity loss. We shall reject the null hypothesis – Ho, on the strength of the test statistics in Table

7.7, conclude that correlation do not exists between the independent variables and accept that relationship between the dependent and independent variables is valid. Therefore, we shall conclude that the model is capable of predicting road capacity loss in the presence of pavement distress surveyed in the study.

From Table 7.7, the 't' statistics show that the number of potholes is the most significant independent variable in the model. It's not surprising therefore (see Figure 7.20 below), that the sites with the most (EK009 ≥ 15 nos. of potholes) recorded the highest road capacity loss and least (DL005 with 7 nos. pothole) number of potholes recorded the lowest road capacity loss.

Figure 7.20 Nos. Potholes and Percentage Capacity Loss



7.4 SUMMARY

It has been shown so far that pavement distress has implications for PCE values, so the conclusion that pavement distress results in road capacity loss remains valid. It may be suggested that because of change in drivers attitude relative to pavement distress, and to some extent the need by heavy goods vehicle (HGV) operators to make profit, a description that depict passenger car equivalency value for HGV as substantially higher than one unit on distressed level terrain is somehow distorted. The estimated PCE values were found to be lower than those presently used for most of the standard capacity analysis in Nigeria and this may not be unconnected with the low level of traffic volume, the near mono modal transportation system and the dominant role of commercial vehicles in road transportation.

This will call to question the appropriateness of the standard PCE values (PC 1.0, LGV 1.5, and HGV 2.0) that is currently in use in Nigeria. However, the modified PCE values are preliminary findings and separate studies are needed on the relationship between traffic, traffic composition and the road itself in order to derive a true reflective PCE values for Nigeria. In any case, investigation into the implications of pavement distress for passenger car equivalency values revealed that:

- Road pavement distress affects PCE values
- Road pavement distress decreases PCE values for commercial vehicles relative to passenger cars.
- That an average pavement distress area is substantial.
- That the estimated percentage of road capacity loss is substantial.
- That the suggestion that depicts roadways in Nigeria as having PCE values of PC=1, LGV =1.5, HGV = 2.0 is somewhat misleading and may require further research works.
- That road capacity loss changes significantly relative to distress severity, the higher the level of severity the higher the percentage of road capacity loss.
- That site EK009 has the highest percentage of road capacity loss (48%) and second highest number of potholes (15) even though it has the smallest relative area of pavement distress. Thus suggesting that number of potholes is significant when measuring pavement distress.
- That site DL005 has the lowest percentage of road capacity loss (20%) and number of potholes (7) even though it has large relative area of pavement distress ($149m^2$) suggesting that number of potholes is significant when measuring pavement distress.

The study also shows that it is not only possible to formulate a model on road capacity loss resulting from pavement distress parameters but also that it is possible to verify the underlying hypotheses and assumptions of the model. Even though its not the focus of this study, by using historic database and the values of independent variables for similar highway, it can argued that road capacity loss can be predicted, however, care should be taken not to extrapolate beyond the range of the observed data in the study. Once the values of the explanatory variables have been established and tabulated, the ordinary least-squares estimation procedure was used to check the relevance of the variables. These values (independent variables) are then used as base for predictive computation of road capacity loss.

The conclusions we have drawn so far show that pavement distress has significant impact on road capacity loss. Should the road conditions be improved, road capacity loss would surely be reduced substantially.

8

CONCLUSIONS

This study is based on the hypothesis that the extent of road capacity loss resulting from pavement distress is significant. The aim behind this exercise is to establish the extent to which road capacity can be sustained in the presence of pavement distress and the relationship between the two variables.

Flexible road pavement consists of a series of structural layers and the surfacing without distress enables poor ride quality. Surface distress includes potholes, raveling, and cracking. Pothole was defined as open cavity in road surface with at least 150mm diameter and at 25mm depth. The state of some road sections at the time of survey suggest that road pavement distress is characterised by substantial potholes, edge damage, multiple cracks and wheel ruts. Many factors can be called to account for the occurrence of such vase pavement distress and they may include among others, poor design, poor construction, and poor maintenance.

Road capacity was defined as 'the maximum hourly rate at which vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period (usually 15 minutes) under prevailing roadway, traffic and control conditions'.

For the purpose of estimating road capacity the quadratic relationship between flow and density in a situation of free flow bearing in mind that flow, speed and density are fundamentally related. Two sets of Passenger Car Equivalent values were used in estimating traffic flows; the standard Nigeria values and the modified values based on empirical findings in this study. Regression techniques were employed for the development of functions that relate pavement distress to road capacity loss.

Within the purview of the study objectives, we set out two road sections: one with and the other without pavement distress. Both sections were surveyed and the empirical results investigated in the light of evidences obtained from the examination of survey data. The analytical findings for both road sections were compared. The empirical results from surveyed sites the highest recorded volume of vehicles was at site AN001 with 666 vehicles during the one-hour duration count while site DL003 recorded the lowest at 483 vehicles. AN001 with $262.26m^2$ has the largest area of pavement distress while EK009 with $22.96m^2$ has the smallest pavement distress area.ED008 with 17 holes has the most potholes while DL005 with 5 has the least. It was observed that HGVs are least affected by pavement distress from the three type of vehicles (passenger car, light goods vehicle, heavy goods vehicle) considered in this study and it is reasonable to suggest that increase in percentage of HGVs may affect the extent of road capacity loss.

Based on the synthesis of evidences obtained from the relationship between road capacity loss and pavement distress it is correct to conclude that no lasting solution to the challenges that face traffic flows will be found unless that solution addresses the issue of recurring pavement distress in Nigeria. In sum the study showed that:

1. Road capacity loss would result from pavement distress;
2. Computed PCE values were lower than the standard Nigerian PCE values;
3. Linear relationship exists between road capacity loss and pavement distress; and
4. Pothole is a significant contributor to road capacity loss

Pavement distress if allowed to continue, will present road transportation in Nigeria with a bottleneck situation and deprive it of the chance to produce basis for sustainable socio-economic growth. In the light of the discussion so far the remainder of this chapter is organised into four sections. Section 8.1 summarises the major findings of the road conditions while section 8.2 summarises the major findings of road capacity loss analyses. In Section 8.3 focuses on synthesis of evidences obtained from the relationship between road capacity loss and pavement distress, while section 8.4 focuses on the way forward.

8.1 Summary of Findings Based on Road Conditions - According to the Federal Ministry of Works and Housing *(1998)* over 70 per cent of the national road surfaces that are in poor condition are located in the southern region of the country, so the study on road pavement distress surveys was conducted in southern Nigeria. Twelve locations were investigated and four failed the quadratic concavity test at the analyses stages. Class 'B' roads with single 6.5m carriageway with 1.0m shoulder, 1,000 – 5000 annual daily traffic, design life of 15 years, design speed of 85 km/h on level terrain with and without pavement distressed sections were surveyed.

Traffic flows and vehicle speeds drop significantly, while density increases on road sections with pavement distress. Speed distribution fluctuates on the road section without distress, suggesting that drivers are not constrained by surface distress hence can choose speed. Whereas on the road section with pavement distress the speed distribution is almost flat suggesting that drivers were constrained by poor road surface condition.

From the study it was found that site DL004 has the lowest relative pavement distress area of $134m^2$ while site ED006 has the highest relative pavement distress area of $219m^2$. Site DL005 has the least nos. of pothole (7) while site ED008 has the highest nos. potholes (17). Road capacity loss of 48 percent resulted from $125m^2$ relative pavement distress in the presence of 15 Nos. potholes at Road AN001. At ED008 the road capacity loss of 41% resulted from $161m^2$ relative pavement distress in the presence of 17 Nos. of potholes, site DL005 road capacity loss of 20 percent resulted from $149m^2$ relative pavement distress area in the presence of 7 Nos. of potholes.

Interestingly, even though site ED006 had the second lowest road capacity loss of 25% with the second lowest level of pavement distress, the sites had the largest proportion of commercial vehicle suggesting that commercial vehicles suffer less from of pavement distress when compared to passenger cars and should be an area for further research. The fact that commercial vehicles with high axle clearance from road surface are extremely turn-around time sensitive hence more liable to drive aggressively irrespective of road condition cannot also be discounted. Nevertheless, all types of vehicles will suffer in the long run as road conditions continue to deteriorate.

8.2 Summary of Findings Based on Road Capacity Loss Analyses - Road capacity loss was estimated using the quadratic function and fundamental relationship between flow, speed and density. In the flow/density relationship density is used as the control parameter and flow is the objective function. In the ensuing model equations flows were differentiated with respect to densities for maximum value of flows and critical densities were estimated from the differential equations. Results of the road capacity loss analysis can best be summed as increase in density relative to increase in flow depicting a free flow situation where drivers can choose speeds, at this stage speed is relatively unaffected by flow until road capacity is reached and flow decreases relative to increase in density till a jam situation is reached.

Road capacity loss was analysed using standard Nigerian PCE values, PC = 1; LGV = 1.5 and HGV = 2.0 units for both sections of the surveyed road and the Modified values PCE values PCE values, PC = 1; LGV = 1.3 and HGV = 1.7 units for road section without pavement distress; PCE values, PC = 1; LGV = 1.0 and HGV = 1.0 unit for road section with pavement distress. Generally, the modified PCE values gave lower road capacities but higher capacity loss because the modified PCE values were smaller and took account of prevailing road and traffic conditions.

Modification of the PCE values did not affect the outcome of the study as road capacity loss resulted from pavement distress, with the standard PCE values road capacity loss ranged from 12 – 34 per cent, while the modified PCE values road capacity loss ranged from 25-48 per cent Sites AN001, ED006, ED008 and EK009 recorded substantial increase in road capacity loss when the PCE values were adjusted.

Since PCE values are central to road capacity calculation it follows that the problem of passenger car equivalency values in road capacity analysis cannot however be ignored. On the one hand it shows the potential of commercial vehicles gaining control of road by exploiting the presence of pavement distress. On the other hand it exposed the weakness of passenger cars as mode of transport on poor road surfaces.

8.3 Synthesis of Evidences Obtained from Road Capacity Loss and Pavement Distress Relationship - The effects of pavement distress on road capacity loss were observed to be particularly significant in cases where the percentage of passenger cars was high. Because the higher the level of pavement distress severity the slower the speed of passenger cars relative to commercial vehicles, it can be argued. At site ED006 where the highest percentage of pavement distress per km was recorded as 7.2%, traffic composition was PC 45%, LGV 50% and HGV 5% and the road capacity loss was the lowest being 12% especially when the commercial vehicles are platoon leaders. By contrast site EK009 with a road capacity loss of 48%, the traffic Compositions (PC) 45%, (LGV) 52%, and (HGV) 03% are indicative of the significance of LGVs and HGVs on road sections with pavement distress. The significance of LGVs and HGVs was further confirmed by site ED008 where traffic composition is (PC) 44%, (LGV) 51%, and (HGV) 05%.

In the model presented we have been able to relate road capacity loss to number of potholes, relative area of distress and maximum depth of pothole. Linear regression was used applying the least square method to determine the correlation among the parameters length of distress, width of distress and depth of distress. By applying least squares assumptions were made among others that the explanatory variables were truly endogenous; that there was one-way causation between the dependent variable and the explanatory variables.

Each slope coefficient was tested for usefulness in estimating the extent of pavement distress. The slope coefficient with the strongest indicator by way of t-statistic value was compared separately with the percentage of distress. Multiple regression analyses were performed a model equation capable of describing the relationship between dependent variable, road capacity loss and independent variables - maximum depth of potholes, number of potholes, and relative area of pavement distress, was established as:

$$Q_L = 3.26 - 0.13A/W + 2.46N + 0.09D$$

Statistical test of the model indicated number of potholes as the most significant factor affecting pavement distress in this study. So, based on the synthesis of evidences obtained from the relationship it is correct to conclude that no lasting solution to the challenges that face road transportation will be found unless that solution addresses the issue of recurring potholes in Nigeria.

8.4 The Way Forward - The study shows that significant road capacity loss will result from pavement distress and concluded that the estimated road capacity loss values are correct. It has long been clear that the problem of road maintenance is not one of engineering but policies and management. This implies that the development of effective road policy will be the way forward in Nigeria.

There has been a systematic neglect of appropriate planning, programming and financing of road maintenance in Nigeria, to the extent that the physical condition of virtually every category of road has deteriorated badly. The task of managing and operating effectively a road system is not without maintenance difficulties. Whether it is poor road maintenance or the lack of it that is responsible for road defects in Nigeria, pavement distress clearly has impact on road capacity loss as shown in the study.

It is often argued that the poor condition of roads in Nigeria can be partly attributable to lack of effective road maintenance system. But this has yet to be put to the test, as other factors, like poor design, badly executed contracts, inadequate funding, poor road management are also capable of giving rise to dysfunctional road system. It can also be argued that the vicious circle of road pavement distress derives largely from the prevalence of an uncoordinated road management system and defective road policy

Road management will require good planning for effectiveness and efficiency and good planning depends on relevant, timely and accurate data. At the moment approach to road management at best can be described as intuitive, short-term focused, and questionable The national road database is still partial, manual, ineffective and incomplete, and it may be extremely difficult if not impossible sometimes to locate reliable, updated and comprehensive documents on the road system.

The absence of road data would make accurate quantification, evaluation and planning decisions become questionable, short-termed and crisis oriented. The longer the problem of pavement distress remain unresolved the more entrenched poverty will become and the greater will be the degree of social instability, so much so that persistent social instability will adversely affect road sustainability.

This study gave an insight into some of the problems associated with conditions of roads in Nigeria. At the time of survey, there was no evident of road capacity manual at any level of governments. Barely sufficient information on road geometry and pavement conditions was available from Federal Ministry of Works and the Nigerian Road Research Institute; there is very little information concerning highway capacity in relation to road, traffic and control condition. This in itself would make roads very difficult to manage in Nigeria. As a result, some roads with pavement distress suffer substantial economic loss due to neglect especially as pavement distress has significant effects on road capacity loss. Road survey data from this study shows defects that include cracking, rutting, depression, edge subsidence, shoving, potholes and broken edges in disproportionate numbers.

Currently little is known about the strength behavior of road materials under dynamic loads and it would be useful if research would be undertaken in this area. In particular there is need to investigate comprehensively into the properties of the sub-grade soils that prevail in the tropics. There is further concern about the problem of bituminous surfacing with regards to cracking and potholing, under tropical climate. This is an area where research is needed in order to establish the effect of the tropical environment (in terms of rainfall, sunshine, temperatures and other ambient conditions) on the bitumen commonly used in the preparation of bituminous mixtures for road construction, so as to develop crack resistant bitumen material for construction. The softness of road surfacing after road construction is very common in Nigeria and equally disturbing, it is mainly indicative of wrong bituminous mixtures.

In Nigeria where local capability to manage road system is limited, assistance is generally needed, as successful outcome will require a fusion of foreign technology, investments and local inputs. The process of diffusion will generally involve new learning at a small price when compared to the costs of ignorance, primitive technology and outdated management techniques.

However, this study believes that of far more value to Nigeria is an understanding and experience of a systematic approach to road condition problem solving than the potential availability of particular technology and problem solving approach because of the diversity in culture and priority of needs.

While it is recognised that technology must be appropriate to the specific needs of a particular country, it can be argued that the depth of understanding and experience of systematic, objective approach to maintenance is more relevant and readily transferable than individual items of technology. Some of these technologies are not only inappropriate in the technological sense but are also inappropriate socially and economically as well. For example new technology in design, construction and maintenance programs could be feasible in Nigeria only if energy supply is not epileptic.

Funding of road works especially maintenance and rehabilitation remains a major problematic area in Nigeria. One reason among many others is the lack of information database for quality decision- making process. In cases where road construction cannot be justified a path to economic disaster would have been set. Justification is not rigidly in terms of number of vehicles plying the route but more in terms of economic reasoning and prudence.

It should no longer be permissible to institute costly out-of-programme emergency road repairs rather what is required is an ordered road maintenance programme able to distribute the money available to those areas where road deterioration and user requirements suggest a high priority.

At the moment Nigeria road system needs policy provision to promote road management learning and improve road maintenance performance. The road system is a capital-intensive investment, requiring thorough schematic framework that includes among others, technology, appraisal (traffic, economic, environmental / social), and funding. The expenditure on road networks between 1962 and 1985 was about $1.6 billion; in 1998 a total of $441 million was committed for investment in the development of road networks *(2000)*.

Despite all these investments in road building, road rehabilitation and expansion programmes, road conditions in Nigeria have remained poor; because once constructed the roads were often laid to waste because of the 'use to breakdown' culture in place at the moment. Departure from the 'use to breakdown' culture is the way forward and the cornerstone for any meaningful road policy in Nigeria.

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APPENDIX - A

A1.0 THE LAND, THE PEOPLE, AND THE ECONOMY: AN OVERVIEW

This section is intended to provide a descriptive account of the land, the people and the road system of Nigeria based on officially published facts and figures in general. The aim is to provide a background for more analytical and critical discussion in the subsequent sections of the chapter. Nigeria is the most populous nation in Africa (108million) and the 11th in the world. The country is endowed with vast human and natural resources, including oil and gas. Yet after 41 years of independence, Nigerians are unanimous in their conviction that the economic and political performance of their nation is far below her potential, and there own expectations and aspirations. The conviction that the country's poor economic and political performance is neither representative of her potential nor in consonance with the aspirations of her citizens, and their determination that their nation should occupy her rightful place in the comity of nations has inspired this research study.

A1.1 Location and Regional Geography

Nigeria is one of the West African countries made up of 36 States and a federal capital territory, with boundaries at the southern limits, set by Gulf of Guinea (bights of Benin and Biafra); inland frontiers shared with Cameroon (east), Chad (north-east) and Republic of Benin (west). Nigeria has five geographical divisions; low coastal zone along Gulf of Guinea; succeeded northward by hills and low plateaux; Niger-Benue river valley; broad steeped plateau stretching to northern border with highest elevations over 1,200 meters; mountainous zone along eastern border, which includes country's highest point (2,024 meters).

The climate is tropical with variations governed by interaction of moist Southwest monsoon and dry Northeast winds. Mean maximum temperatures of 30-32° C (north). There is high humidity in South between February-November, in the north, between June-September and low humidity during the dry season. Annual rainfall decreases northward: about 2,000 millimetres in coastal zone (Niger Delta averages over 3,550 millimetres): 500 to 750 millimetres in the North.

A1.2 Population and Road Administration

Nigeria with 108.4million people is largely a rural country, with 62 per cent of the population living in the rural areas. But the quality of life is very poor amongst this large population, due mainly too extremely inadequate infrastructure, lack of employment opportunities and social amenities. Social facilities are insufficient and dilapidated, access to land for agriculture is limited and, where available, productivity is low due to poor technology and lack of input, road network, communication facilities and markets are poorly developed. This account for the continuing poor quality of life in the rural areas in spite of an array of government programmes aimed at rural development.

Thirty eight per cent of Nigeria's population is urban. The main urban centres are Lagos with more than 4 million people, and Ibadan with more than 2 million people, others are Ogbomosho and Abeokuta in the West; Kano, Kaduna and Zaria in the North, and Port-Harcourt, Onitsha, Aba and Enugu in the South-East. Although urbanisation is a global phenomenon, Nigeria's urban growth rate of 5-7 per cent makes it one of the most rapidly urbanising countries in the world. By present trends, the proportion of urban population is estimated to reach over 50 per cent by the year 2010. This very rapid rate of growth has overwhelmed the capacity of urban management agencies, and compounded by cumbersome land allocation system, inappropriate planning techniques, and low resource allocation for provision and maintenance of infrastructure, roads in Nigeria have become chaotic.

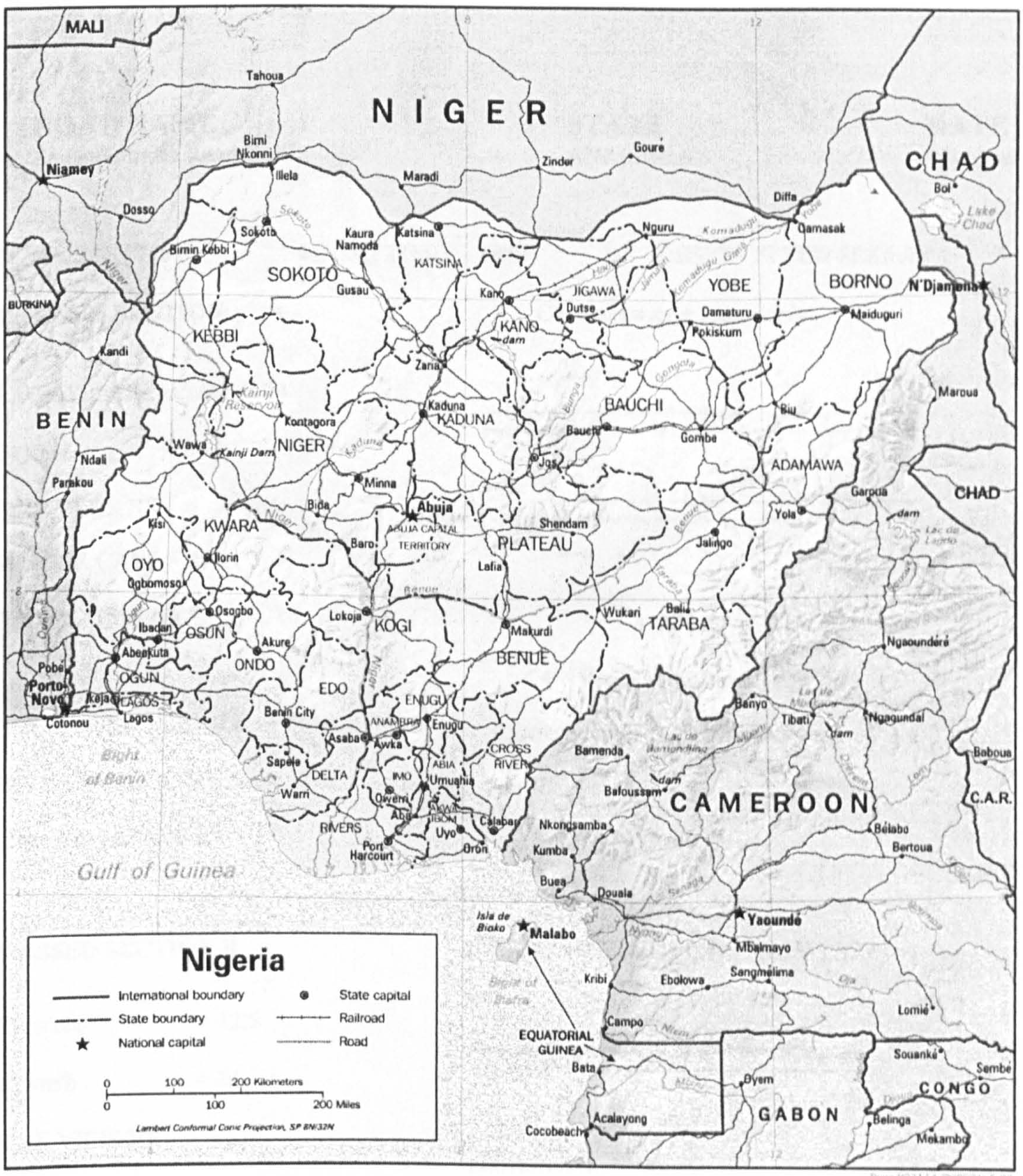
The current population growth of Nigeria is 2.5 percent. Life expectancy at birth in 1995 was 53. The infant mortality rate (per 1000 live births) has decreased from 99 in 1980 to 80 in 1995. Employment has been adversely affected since the 1980s. The number of unemployed professionals and executives has increased significantly over the years. The labour force growth rate, which was 2.6 percent during 1980-1990, has increased to 2.8 percent in 1990-1995. It has increased from an estimated 32.64 million in 1996 to 34.02 million in 1996, while total gainful employment rose from 30.22 million in 1996 to 31.55 million in 1998, which would represent a worsen of the employment situation.

In terms of road administration, the federal government, through the Federal Highway Department (FHD) in its Ministry of Works and Housing (FMWH) manages nearly 20% of the network. The state governments manage an equal proportion. Local governments manage the remaining 60%. Federal roads carry about half the traffic in terms of ton-km and vehicle km. However, government's effort at managing the road system so far appears to fall short of target and inadequate.

A1.3 The State of the Economy

Nigeria has per capital income of US$ 260 as reported in the 1997 World Development Report. The gross national product (GNP) had an annual average growth of 1.2 percent during the ten-year period from 1985-1995. The gross Domestic Product (GDP) had a growth rate of about 2.8% according to the Central bank of Nigeria statistics during the period 1990-1995. After falling to less than 2 per cent per annum in 1994, the growth rate of Gross Domestic Product (GDP) rose to 3.3 per cent in 1996. Inflation had also declined to about 30 per cent. The balance of payments deficit had declined significantly to less than $800 million, whilst external reserves had risen to about $4 billion. However, the structure of the economy remains unchanged.

The economy is still mono-cultural, the primary product now being crude oil (instead of agricultural produce as it was in the 60s and 70s). Production activities are still highly dependent on imports, as imported consumer goods as a proportion of total imports remain high at over 30 per cent. Oil accounts for about 95 per cent of the nation's total export earnings. The industrial sector had a negative growth rate while the agriculture and services had positive growth rates. In any case the next section will start by looking into road financing over time in Nigeria.


NIGER
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Birni Nkonni
Zinder
Gouré
Maradi
Dosso
Diffa
Bol
Lake Chad
N'Djamena
Maroua
Garoua
Ngaoundéré
Yaoundé
Douala
Malabo
Isla de Bioko
Bata
Kribi
Campo
Bertoua
Ebolowa
Sangmélima
Mbalmayo
Bamenda
Bafoussam
Kumba
Buea
Nkongsamba
Cotonou
Porto-Novo
Kandi
Ndali
Parakou
SOKOTO
KEBBI
KATSINA
KANO
JIGAWA
YOBE
BORNO
KADUNA
BAUCHI
NIGER
KWARA
ADAMAWA
OYO
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AKWA IBOM
ABUJA CAPITAL TERRITORY
Sokoto
Birnin Kebbi
Illela
Katsina
Kaura Namoda
Gusau
Kano
Dutse
Nguru
Damasak
Damaturu
Potiskum
Maiduguri
Zaria
Kaduna
Bauchi
Gombe
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Abuja
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Yola
Wukari
Makurdi
Lokoja
Ilorin
Ogbomosho
Oshogbo
Ibadan
Abeokuta
Akure
Ikeja
Lagos
Benin City
Asaba
Awka
Enugu
Sapele
Warri
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Umuahia
Aba
Uyo
Calabar
Oron
Port Harcourt
Kainji Reservoir
Kainji Dam
Gulf of Guinea
Bight of Benin
Bight of Biafra
Nigeria
International boundary
State boundary
National capital
State capital
Railroad
Road
0 100 200 Kilometers
0 100 200 Miles
Lambert Conformal Conic Projection, SP 8N/32N

APPENDIX - B

S/N	ROAD NAME	STATE	DATE
AN001	Enugu/Onitsha Road Onitsh	ANAMBRA	05-12-00

START TIME **1700** FINISH TIME **1800** DESIGN SPEED **85Km/hr**

NO-DISTRESS SECTION A

AVERAGE SPEED m/sec = 24

SPEED km/h = 86

VOLUME VEHS/HR = 666

PASSENGER CARS = 280

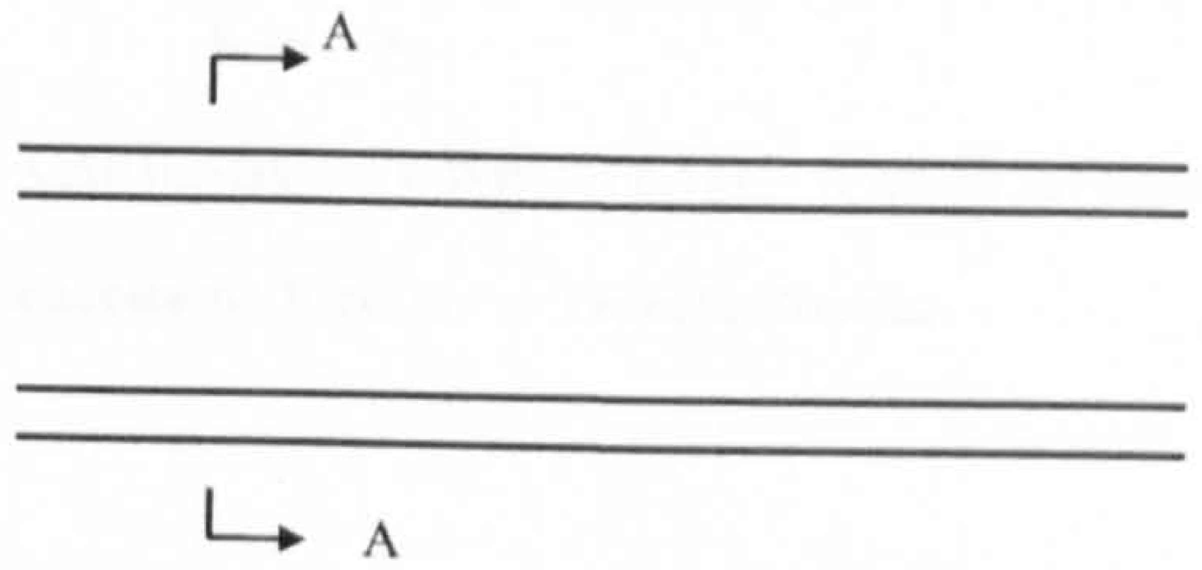
COMMERCIAL VEHICLES = 386

% LIGHT GOODS VEHCILE = 56%

% HEAVY GOODS VEHICLE = 2%

Time over 50m = 2.08secs.

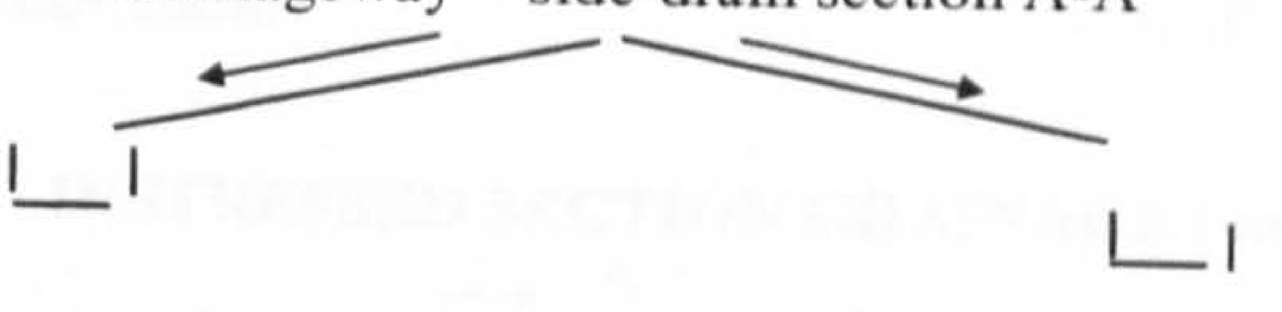
Carriageway + side-drain



CARRIAGEWAY WIDTH 6.5M
CLASS 'B' ROAD

Pavement: Flexible **Terrain:** Normal

Carriageway + side-drain section A-A



SIDE DRAIN SIDE DRAIN

DISTRESSED SECTION B

SPEED m/sec = 12.5

SPEED km/h = 24

VOLUME VEHS/HR = 519

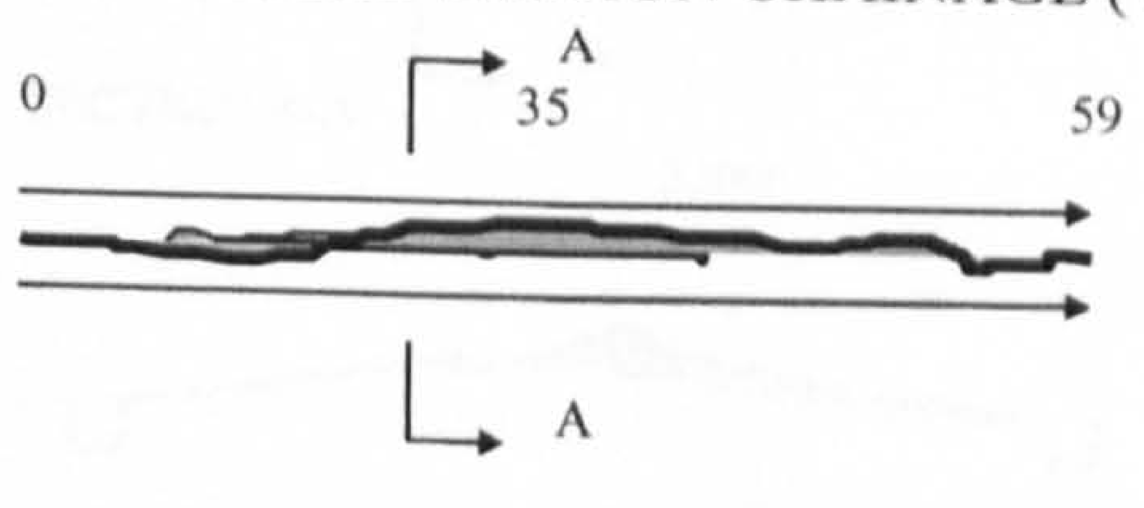
PASSENGER CARS = 218

COMMERCIAL VEHICLES = 301

% RSD = 22.2

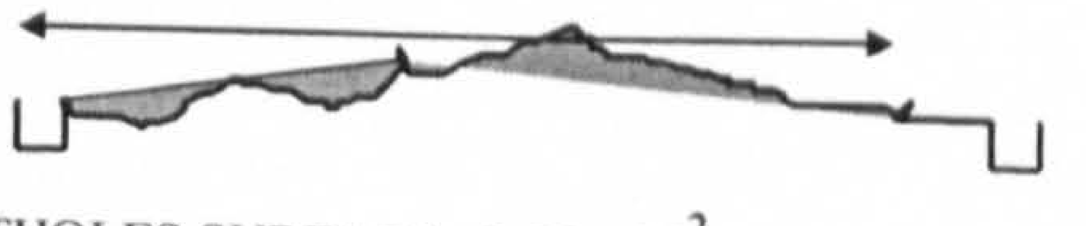
Time over 50m = 4.00secs.

DISTRESSED SECTION CHAINAGE (m)



SECTION A-A

5.8 – 3.65 = 2.15m



POTHOLES SURFACE: 2.55 > M^2 MAX. DEPTH > 0.25 M
Nos.>10

COMMENTS

S/N	ROAD NAME	STATE	DATE
DL002	Okere Road, Warri	DELTA	06-12-00

START TIME **0800** FINISH TIME **0900** DESIGN SPEED **85Km/hr**

NO-DISTRESS SECTION A

AVERAGE SPEED m/sec = 22

AVERAGE SPEED km/h = 80

VOLUME VEHS/HR = 480

PASSENGER CARS = 230

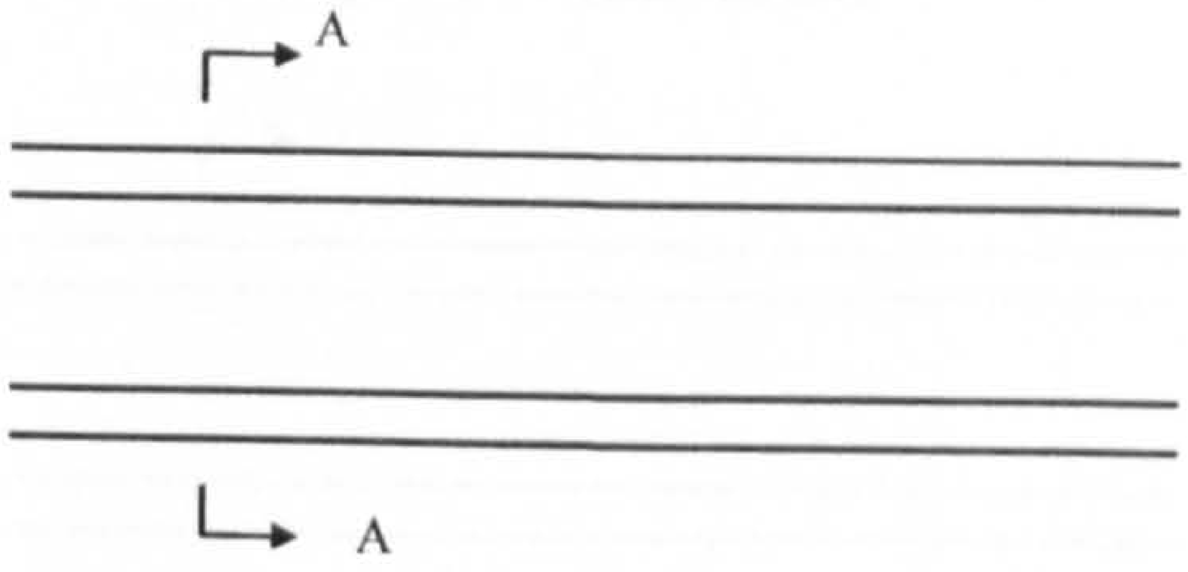
COMMERCIAL VEHICLE = 250

% LIGHT GOODS VEHCILE = 49%

% HEAVY GOODS VEHICLE = 3%

Time over 50m = 2.27secs.

Carriageway + side-drain



CARRIAGEWAY WIDTH 6.5M CLASS 'B' ROAD

Pavement: Flexible **Terrain:** Normal

Carriageway + side-drain section A-A

DISTRESSED SECTION B

AVERAGE SPEED Mm/sec = 10

AVERAGE SPEED km/h = 35

VOLUME VEHS/HR = 444

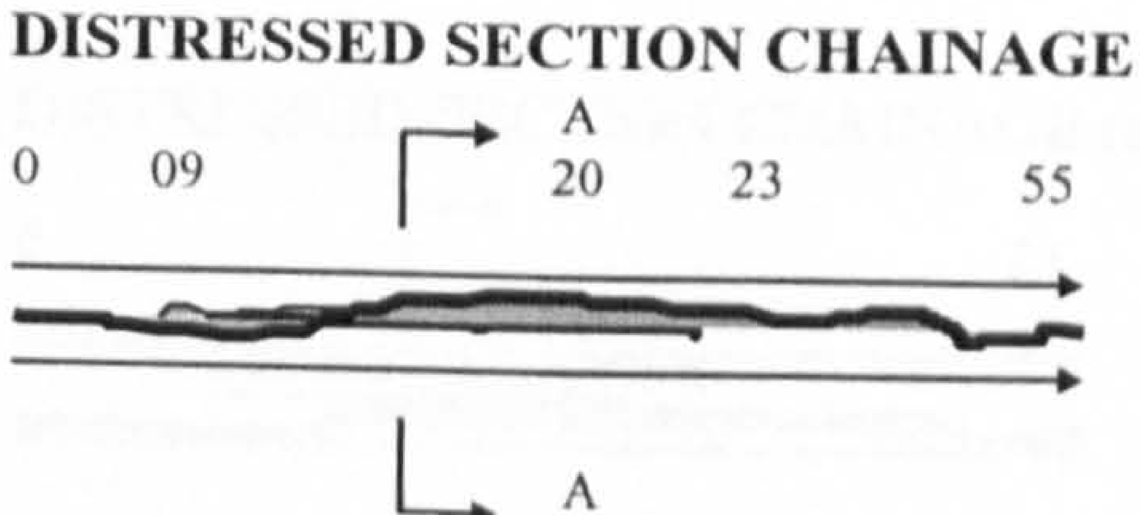
PASSENGER CARS = 213

COMMERCIAL VEHICLE = 231

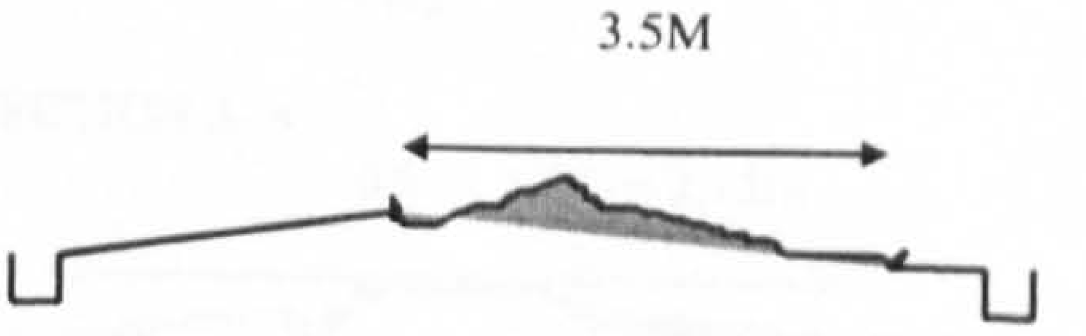
% RSD = 20.1

Time over 50m = 5.00secs.

DISTRESSED SECTION CHAINAGE (m)



SECTION A-A



POTHOLES SURFACE > 2.19 M^2 MAX. DEPTH > 0.2 M
Nos. > 10 (multiple)

COMMENTS

S/N	ROAD NAME	STATE	DATE
DL003	Esisi Road Warri	DELTA	06-12-00

START TIME **1700** FINISH TIME **1800** DESIGN SPEED **85Km/hr**

NO-DISTRESS SECTION A

AVERAGE SPEED m/sec = 24

AVERAGE SPEED km/h = 85

VOLUME VEHS/HR = 483

PASSENGER CARS = 449

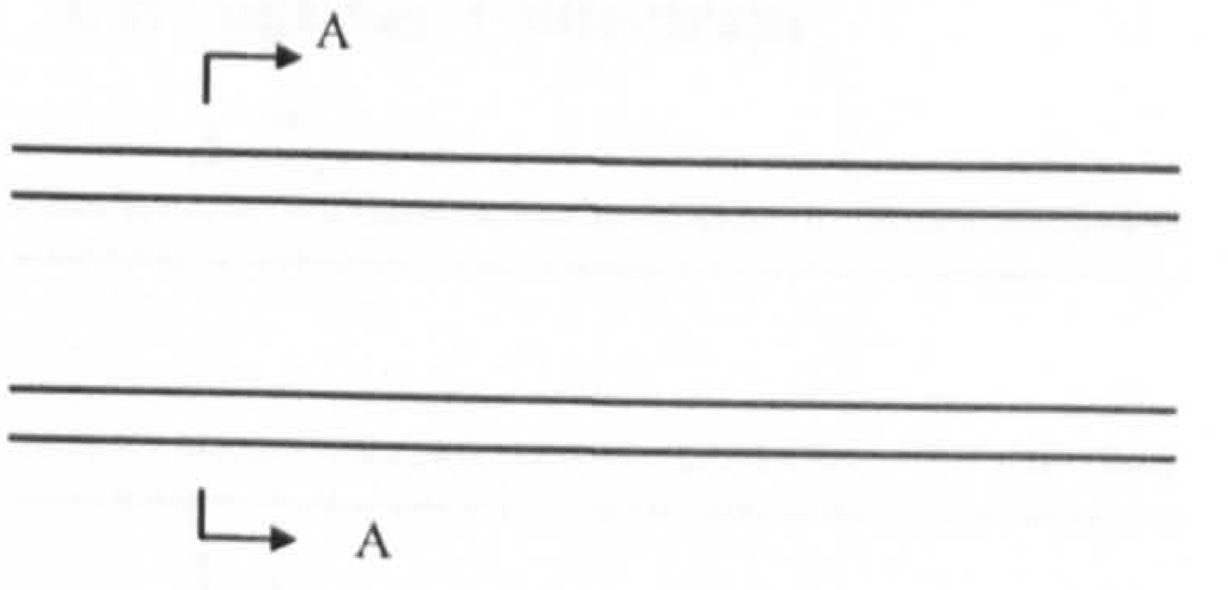
COMMERCIAL VEHICLES = 34

% LIGHT GOODS VEHCILE = 6%

% HEAVY GOODS VEHICLE = 1%

Time over 50m = 2.08secs.

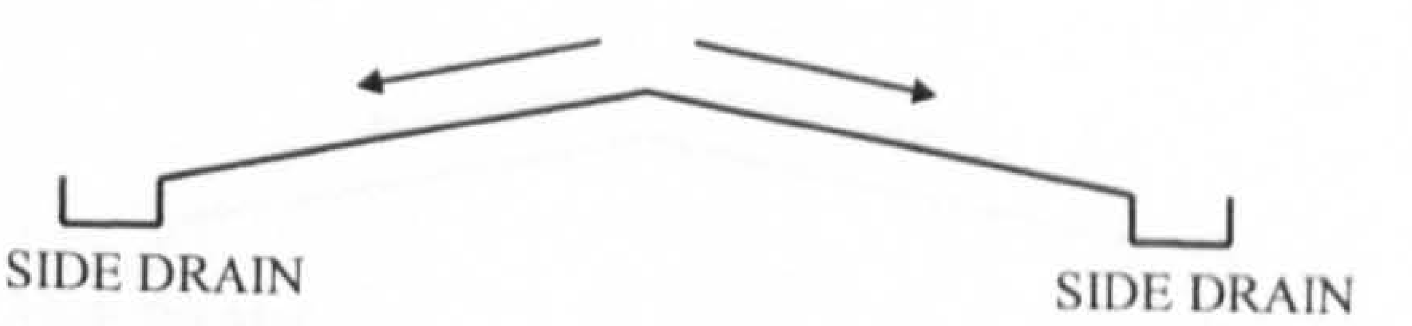
Carriageway + side-drain



CARRIAGEWAY WIDTH 7.3M CLASS 'B' ROAD

Pavement: Flexible **Terrain:** Normal

Carriageway + side-drain section A-A



DISTRESSED SECTION B

AVERAGE SPEED m/sec = 10

AVERAGE SPEED km/h = 36

VOLUME VEHS/HR = 448

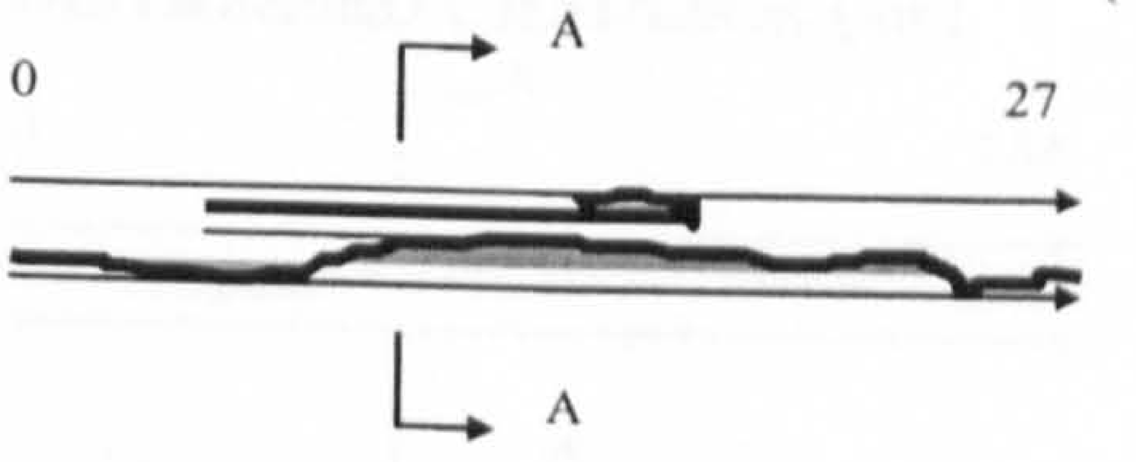
PASSENGER CARS = 417

COMMERCIAL VEHICLES = 31

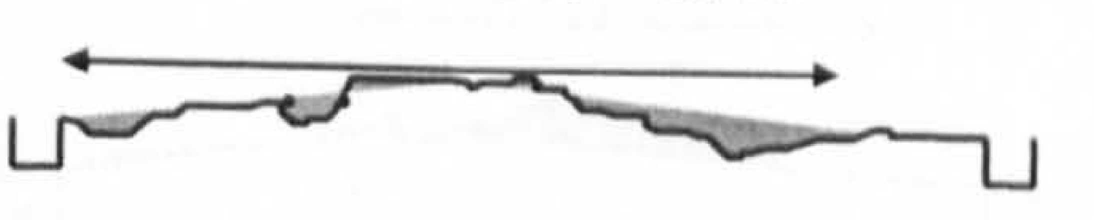
% RSD = 19.6

Time over 50m = 5.00secs.

DISTRESSED SECTION CHAINAGE (m)



SECTION A-A



POTHOLES: > 2.55M^2 MAX. DEPTH > 0.2M Nos. > 12

COMMENTS

S/N	ROAD NAME	STATE	DATE
DL004	Refinery Road	DELTA	07-12-00

START TIME **0800** FINISH TIME **0900** DESIGN SPEED **85Km/hr**

NO-DISTRESS SECTION A

AVERAGE SPEED m/sec = 21

AVERAGE SPEED km/h = 75

VOLUME VEHS/HR = 502

PASSENGER CARS = 467

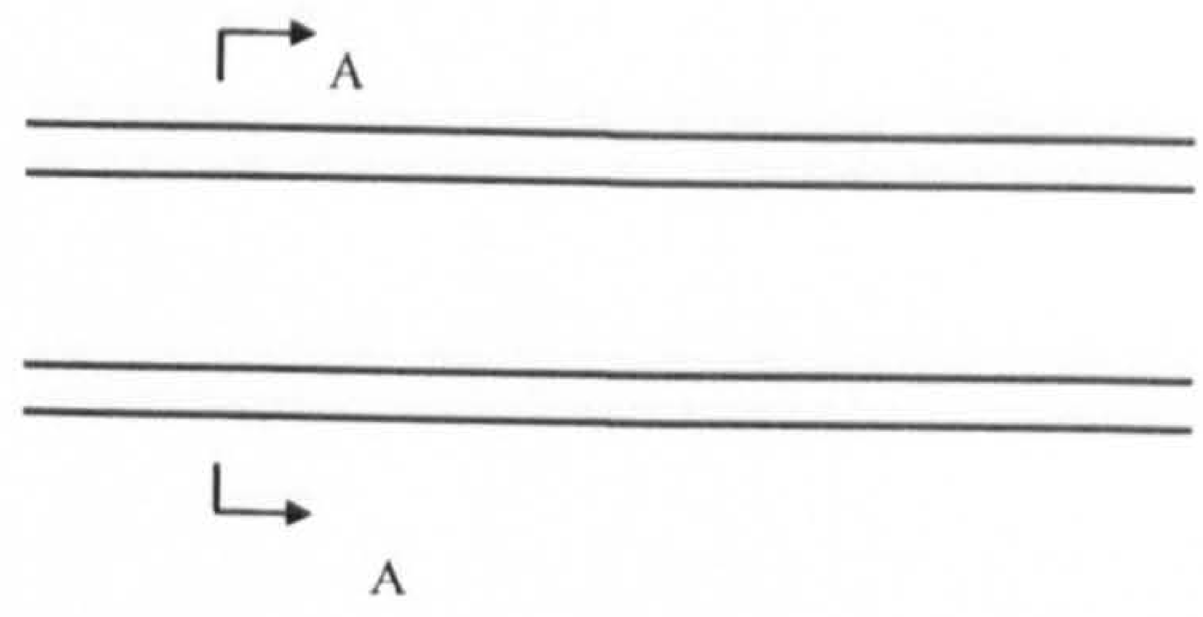
COMMERCIAL VEHICLES = 35

% LIGHT GOODS VEHCILE = 6%

% HEAVY GOODS VEHICLE = 1%

Time over 50m = 2.38secs.

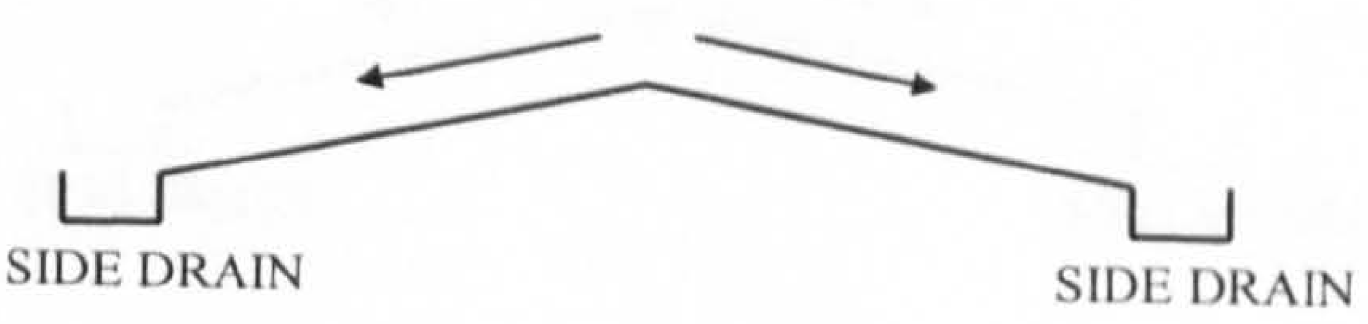
Carriageway + side-drain



CARRIAGEWAY WIDTH7.3M CLASS 'B' ROAD

Pavement: Flexible **Terrain:** Normal

Carriageway + side-drain section A-A



DISTRESSED SECTION (L=36 m)

AVERAGE SPEED m/sec = 11

AVERAGE SPEED km/h = 40

VOLUME VEHS/HR = 413

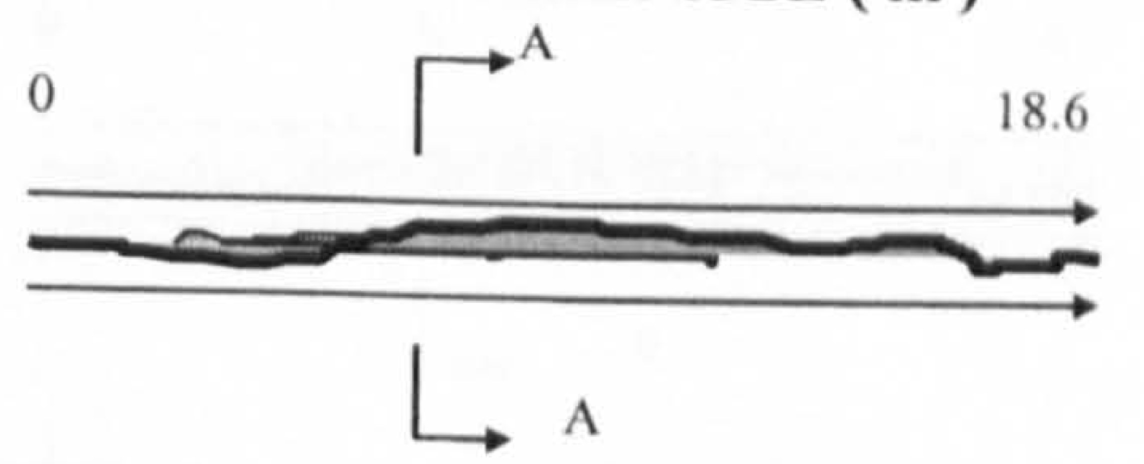
PASSENGER CARS = 304

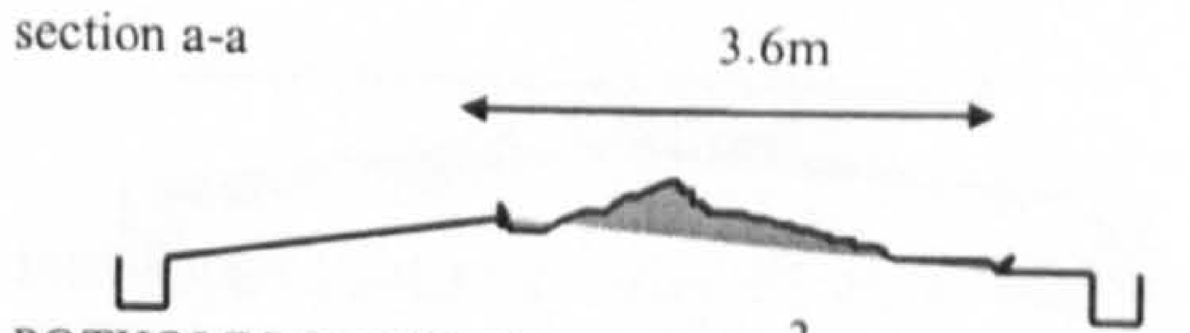
COMMERCIAL VEHICLES = 29

% RSD = 8.3

Time over 50m = 4.55secs.

DISTRESSED CHAINAGE (m)





POTHOLES SURFACE : >6.24 M^2 MAX. DEPTH >0.19 M
Nos. > 10 (Multiple)

COMMENTS

S/N	ROAD NAME	STATE	DATE
DL005	Warri / Sapele Road	DELTA	07-12-00

START TIME **1700** FINISH TIME **1800** DESIGN SPEED **85Km/hr**

NO-DISTRESS SECTION A

AVERAGE SPEED m/sec = 22

AVERAGE SPEED km/h = 80

VOLUME VEHS/HR = 490

PASSENGER CARS = 465

COMMERCIAL VEHICLES = 25

% LIGHT GOODS VEHICLE = 4

% HEAVY GOODS VEHICLE = 1

Time over 50m = 2.27secs.

DISTRESSED SECTION B

AVERAGE SPEED m/sec = 11

AVERAGE SPEED km/h = 38

VOLUME VEHS/HR = 468

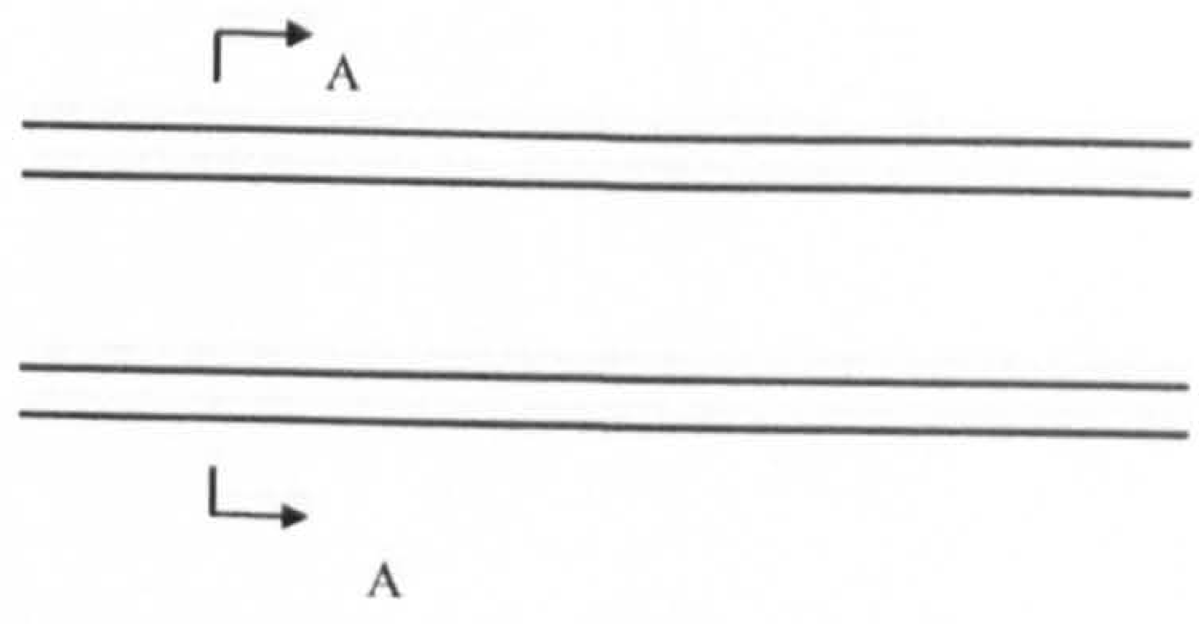
PASSENGER CARS = 445

COMMERCIAL VEHICLES = 23

% RSD = 13.6

Time over 50m = 4.55secs.

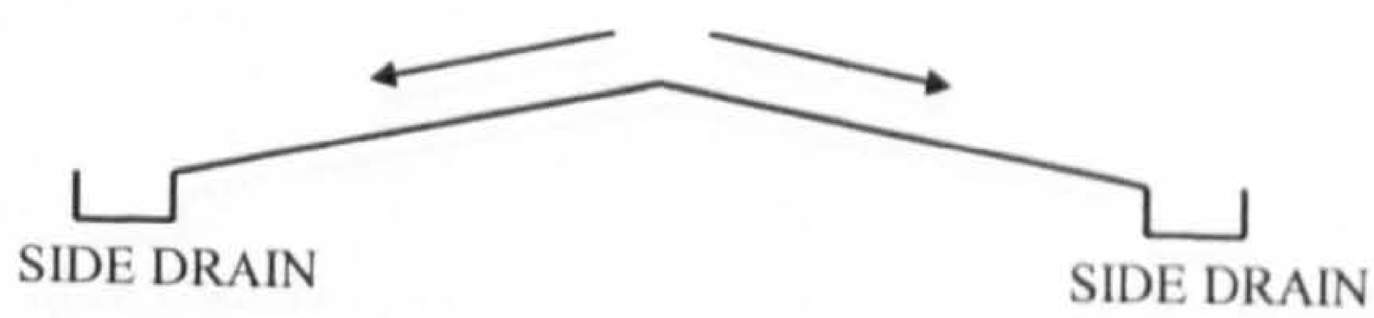
Carriageway + side-drain



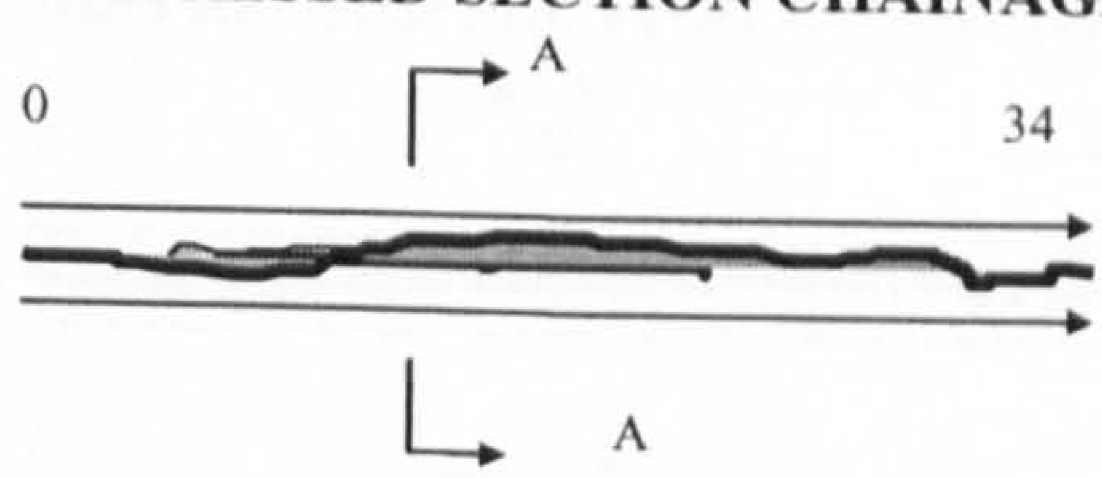
CARRIAGEWAY WIDTH 7.3M CLASS 'B' ROAD

Pavement: Flexible **Terrain:** Normal

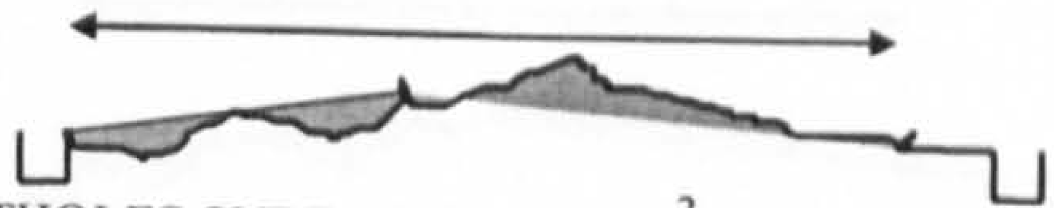
Carriageway + side-drain section A-A



DISTRESSED SECTION CHAINAGE (m)



section a-a 6.9 - 3.65 = 3.25 m



POTHOLES SURFACE: >1.35 M^2 MAX. DEPTH >0.3 M
Nos. > 10 (multiple)

COMMENTS

S/N	ROAD NAME	STATE	DATE
ED006	OGIDA ROAD	EDO	08-12-00

START TIME **0800** FINISH TIME **0900** DESIGN SPEED **85Km/hr**

NO-DISTRESS SECTION A

AVERAGE SPEED m/sec = 24

AVERAGE SPEED km/h = 88

VOLUME VEHS/HR = 674

PASSENGER CARS = 283

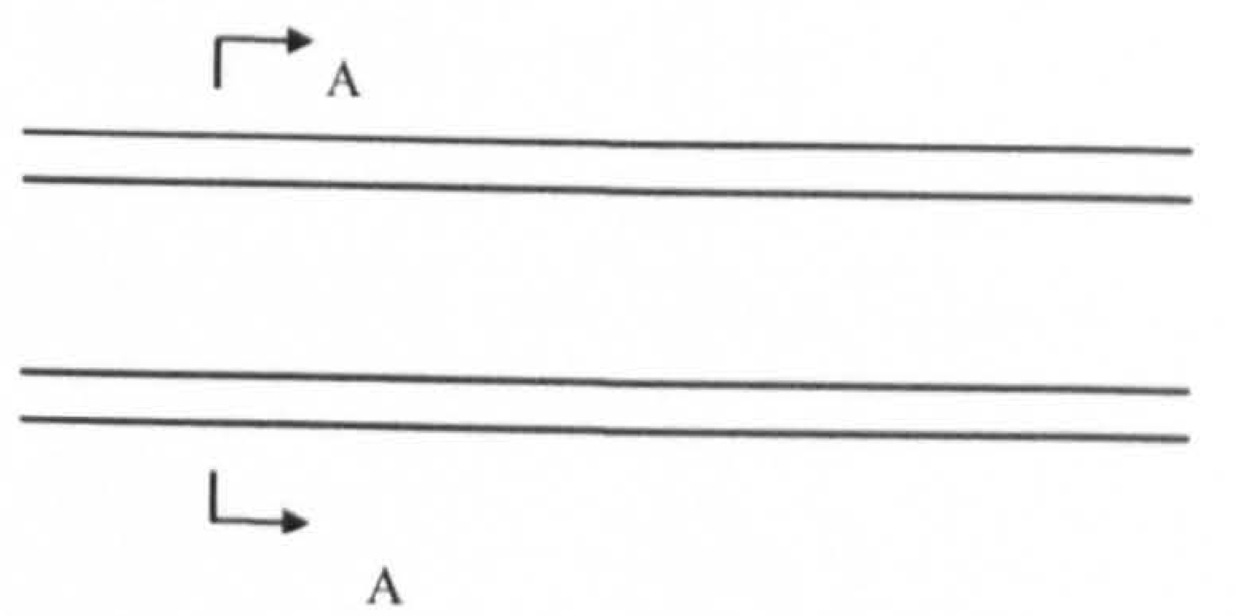
COMMERCIAL VEHICLES = 391

% LIGHT GOODS VEHCILE = 57

% HEAVY GOODS VEHICLE = 1

Time over 50m = 2.08secs.

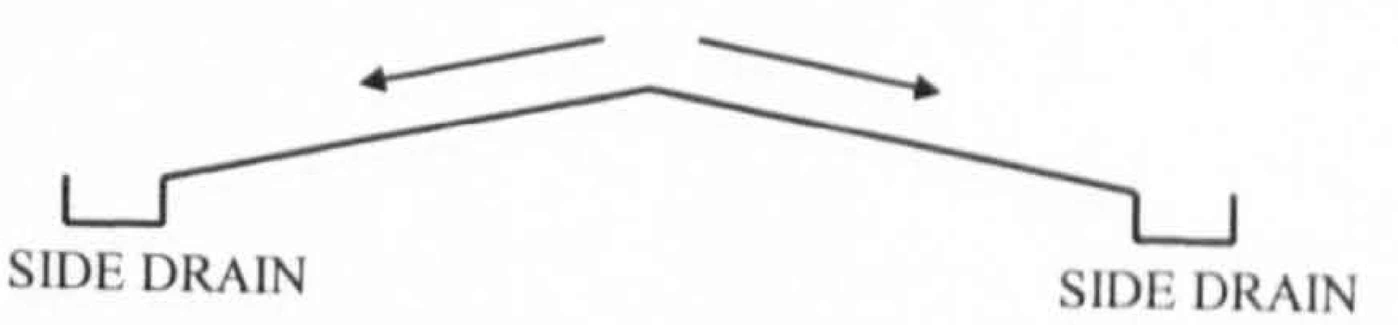
Carriageway + side-drain



CARRIAGEWAY WIDTH 7.3M CLASS 'B' ROAD

Pavement: Flexible **Terrain:** Normal

Carriageway + side-drain section A-A



DISTRESSED SECTION B

AVERAGE SPEED m/sec = 13

AVERAGE SPEED km/h = 46

VOLUME VEHS/HR = 590

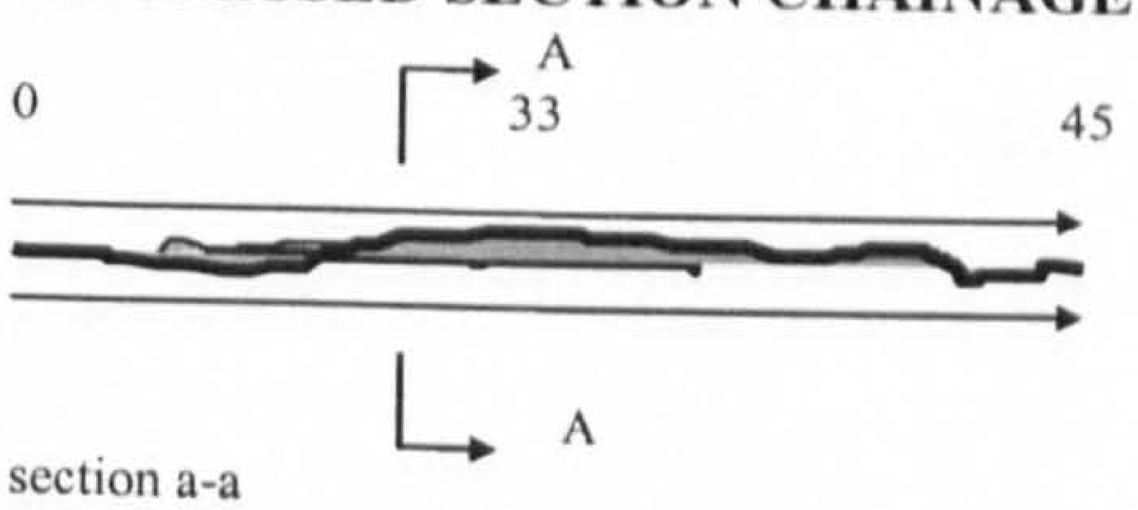
PASSENGER CARS = 248

COMMERCIAL VEHICLES = 342

% RSD = 11.7

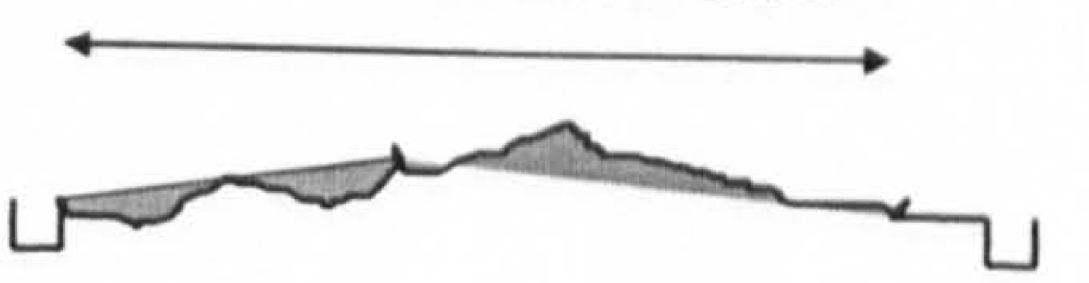
Time over 50m = 3.85secs.

DISTRESSED SECTION CHAINAGE (m)



section a-a

6.0 - 3.65 = 2.35m



POTHOLES SURFACE : > 1.2M^2 MAX. DEPTH > 0.2 M
Nos. > 10 (Multiple)

COMMENTS

S/N **ROAD NAME**
ED007 Upper Sakponba Road, Benin

STATE
EDO

DATE
08-12-00

START TIME **1700** FINISH TIME **1800** DESIGN SPEED **85Km/hr**

NO-DISTRESS SECTION A

AVERAGE SPEED m/sec = 21

AVERAGE SPEED km/h = 75

VOLUME VEHS/HR = 533

PASSENGER CARS = 224

COMMERCIAL VEHICLES = 309

% LIGHT GOODS VEHCILE = 56

% HEAVY GOODS VEHICLE = 3

Time over 50m = 2.38secs.

DISTRESSED SECTION B

AVERAGE SPEED m/sec = 11

AVERAGE SPEED km/h = 38

VOLUME VEHS/HR = 425

PASSENGER CARS = 178

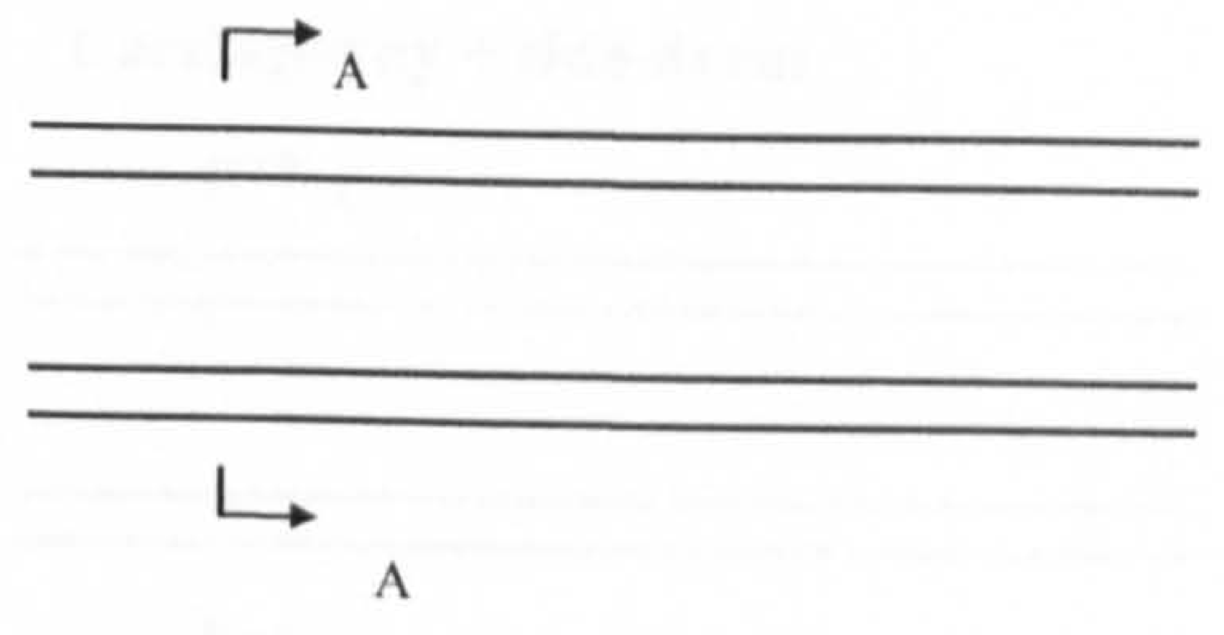
COMMERCIAL VEHICLES = 247

% RSD = 10.8

Time over 50m = 4.55secs.

COMMENTS

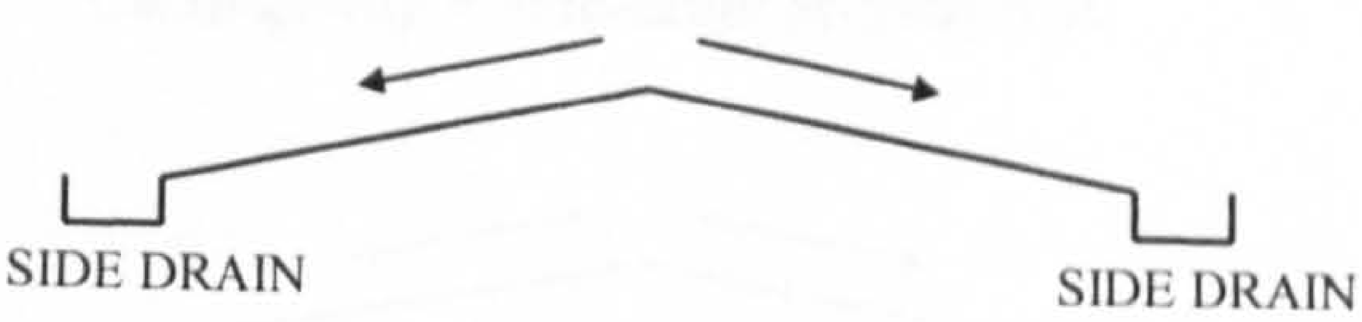
Carriageway + side-drain



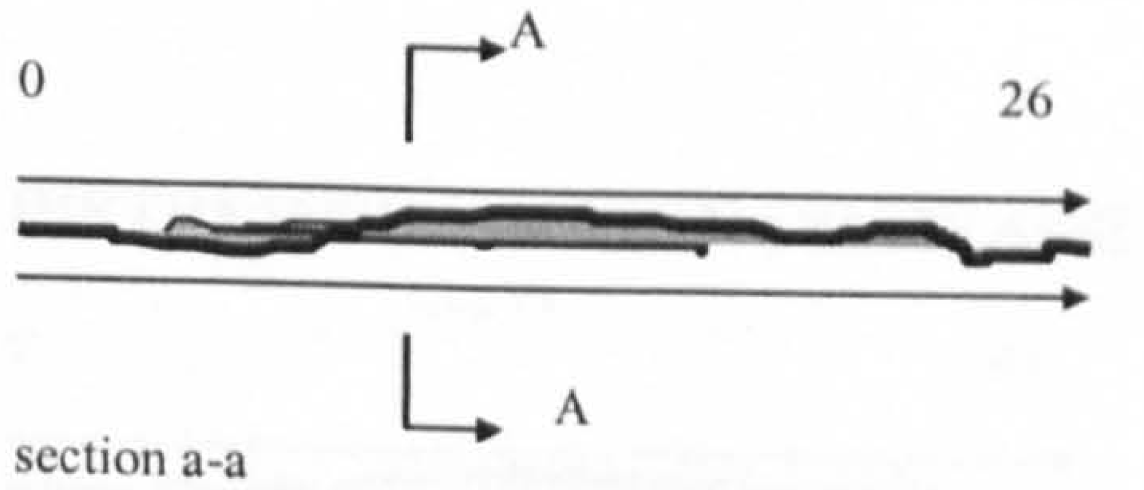
CARRIAGEWAY WIDTH 7.3M CLASS 'B' ROAD

Pavement: Flexible **Terrain :** Normal

Carriageway + side-drain section A-A

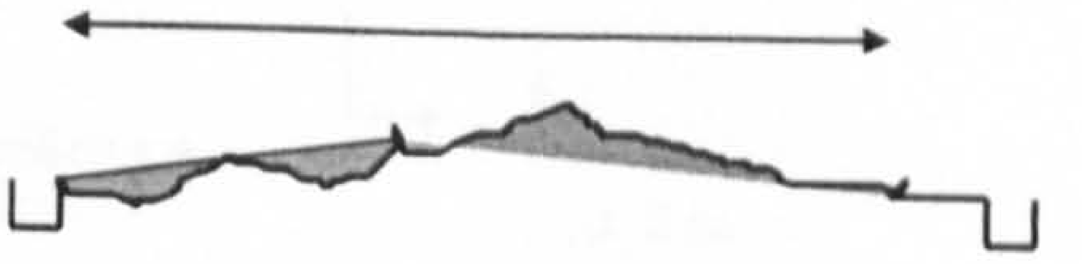


DISTRESSED SECTION CHAINAGE (m)



section a-a

5.69 – 3.65 = 2.04m



POTHOLES SURFACE: > 2.0M² MAX. DEPTH > 0.3 M
Nos. > 10 (Multiple)

S/N **ROAD NAME**
ED008 Upper Siliko Road Benin

STATE
EDO

DATE
11-12-00

START TIME **0800** FINISH TIME **0900** DESIGN SPEED **85Km/hr**

NO-DISTRESS SECTION A

AVERAGE SPEED m/sec = 22

AVERAGE SPEED km/h = 78

VOLUME VEHS/HR = 529

PASSENGER CARS = 233

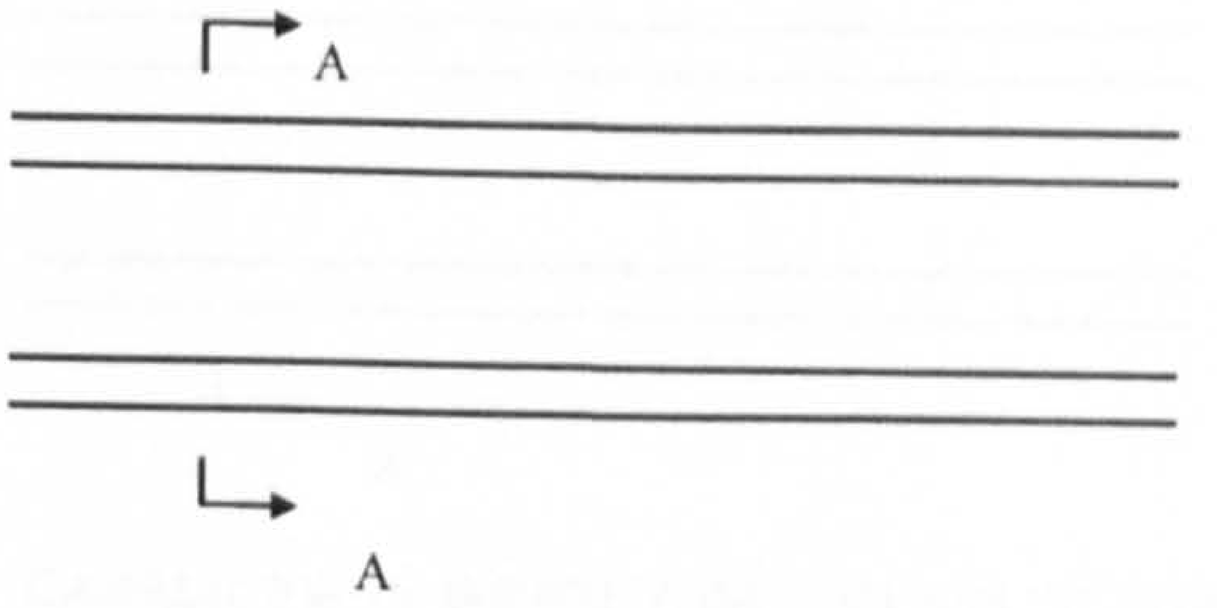
COMMERCIAL VEHICLES = 296

% LIGHT GOODS VEHCILE = 51

% HEAVY GOODS VEHICLE = 5

Time over 50m = 2.27secs.

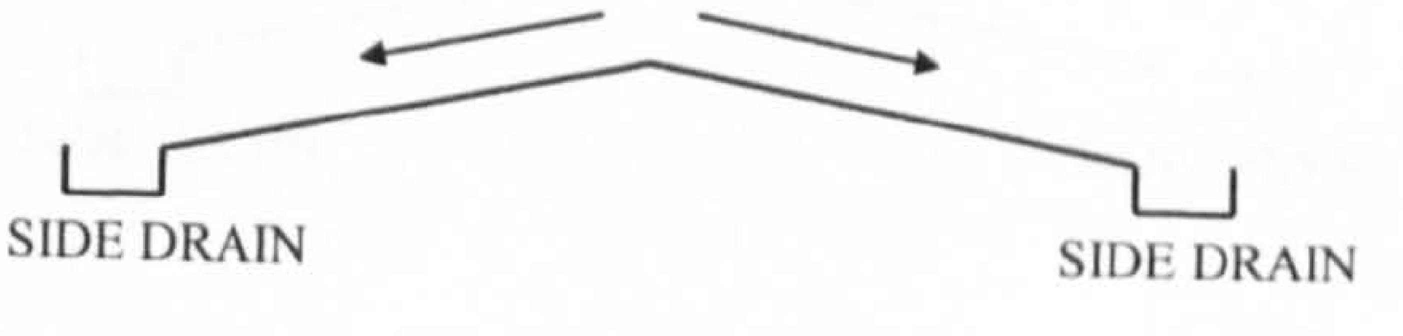
Carriageway + side-drain



CARRIAGEWAY WIDTH 7.3M CLASS 'B' ROAD

Pavement: Flexible **Terrain:** Normal

Carriageway + side-drain section A-A



DISTRESSED SECTION B

AVERAGE SPEED m/sec = 12

AVERAGE SPEED km/h = 42

VOLUME VEHS/HR = 393

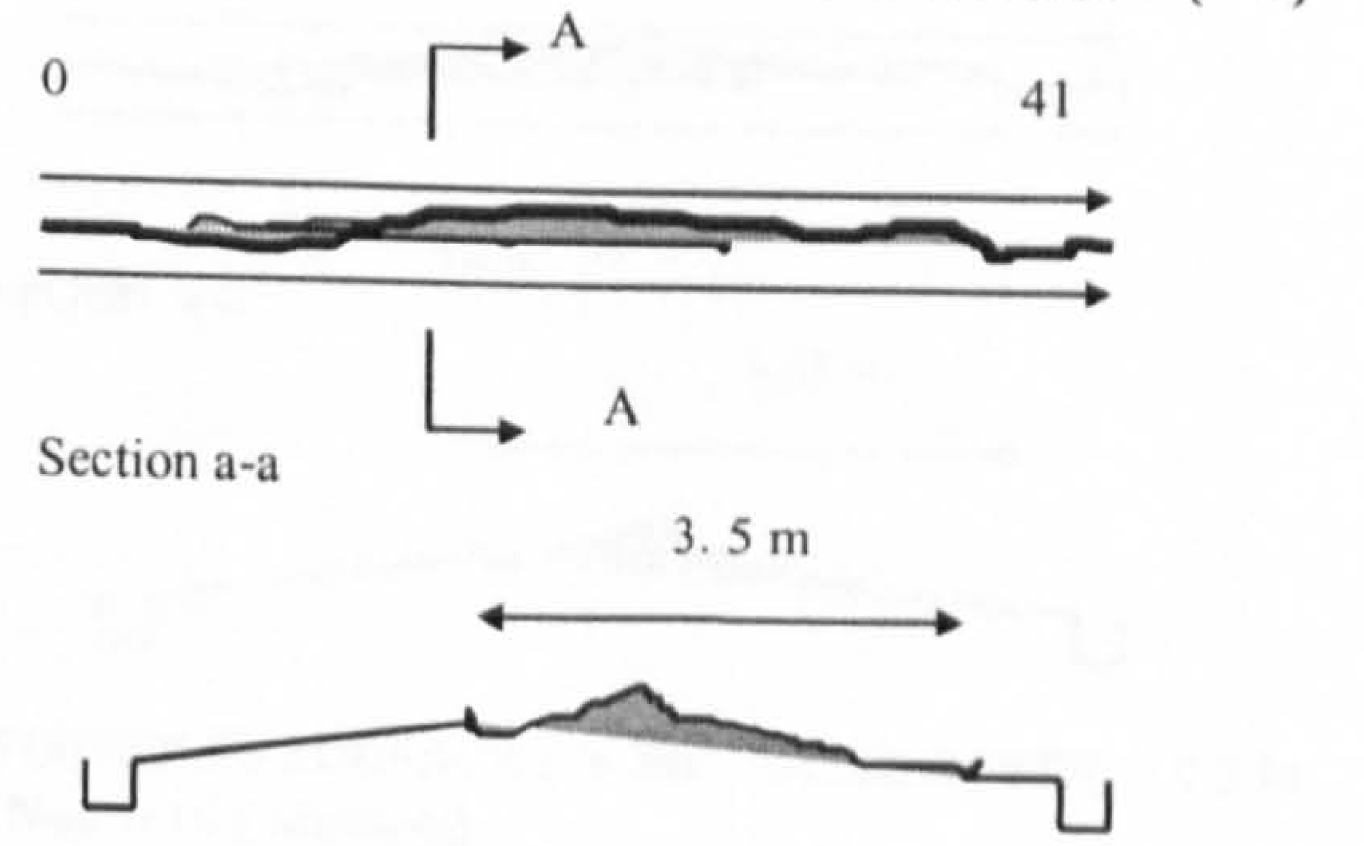
PASSENGER CARS = 173

COMMERCIAL VEHICLES = 220

% RSD = 16

Time over 50m = 4.17secs.

DISTRESSED SECTION CHAINAGE (m)



POTHOLES SURFACE: > $1.5M^2$ MAX. DEPTH >0.2 M
Nos. >10 (Multiple)

COMMENTS

S/N	ROAD NAME	STATE	DATE
EK009	Ajilosun Street, Ado-Ekiti	EKITI	16-10-00

START TIME 1700 FINISH TIME 1800 DESIGN SPEED 85Km/hr

NO-DISTRESS SECTION A

AVERAGE SPEED m/sec = 24

AVERAGE SPEED km/h = 85

VOLUME VEHS/HR = 613

PASSENGER CARS = 276

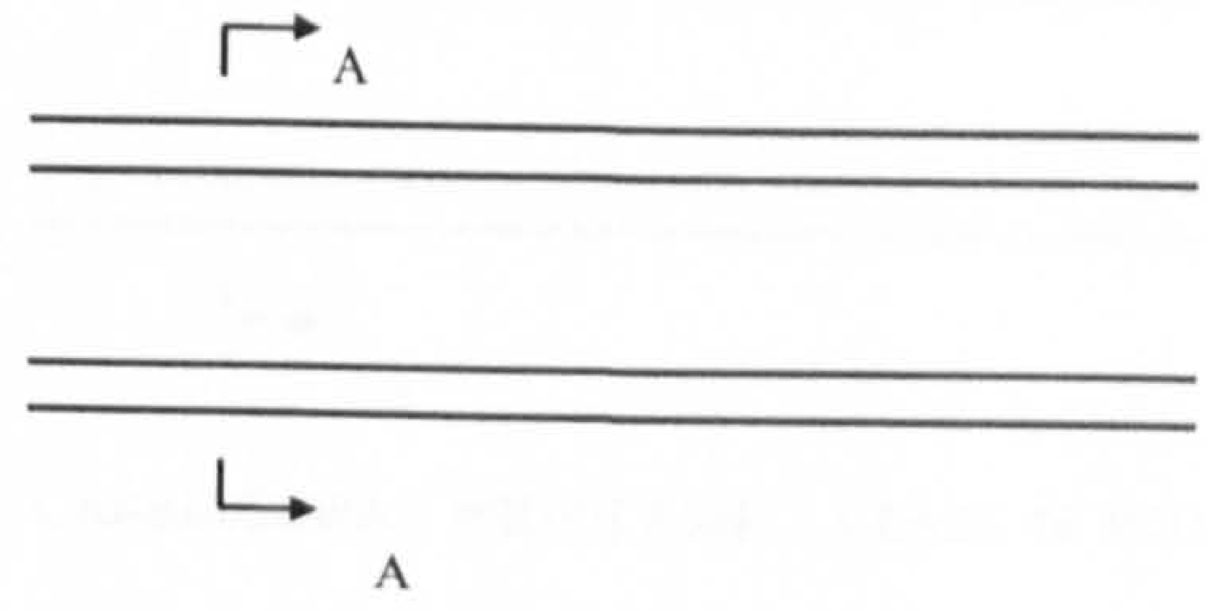
COMMERCIAL VEHICLES = 337

% LIGHT GOODS VEHCILE = 53

% HEAVY GOODS VEHICLE = 2

Time over 50m = 2.08secs.

Carriageway + side-drain



CARRIAGEWAY WIDTH 7.3M CLASS 'B' ROAD

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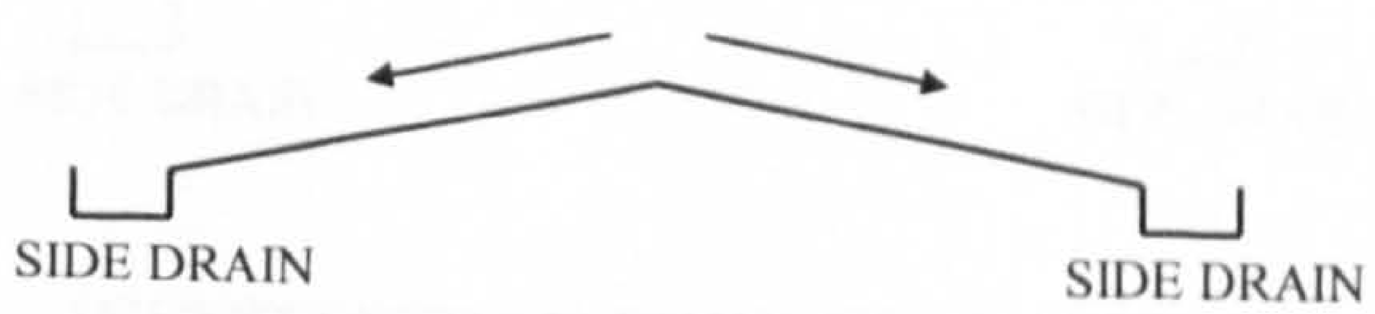
Pavement : Flexible **Terrain :** Normal

Carriageway + side-drain section A-A



DISTRESSED SECTION B

AVERAGE SPEED m/sec = 11

AVERAGE SPEED km/h = 40

VOLUME VEHS/HR = 547

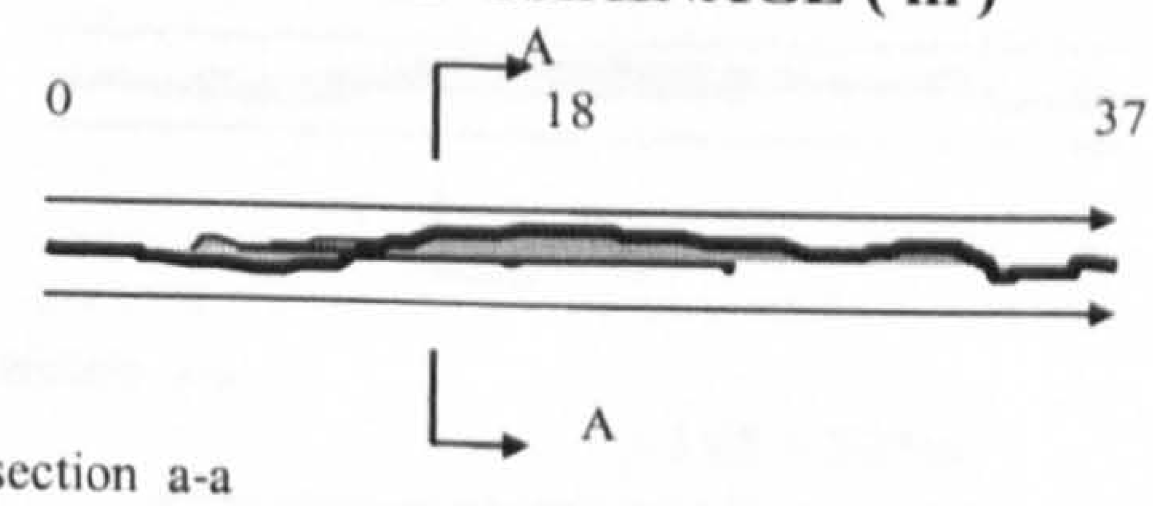
PASSENGER CARS = 246

COMMERCIAL VEHICLES = 301

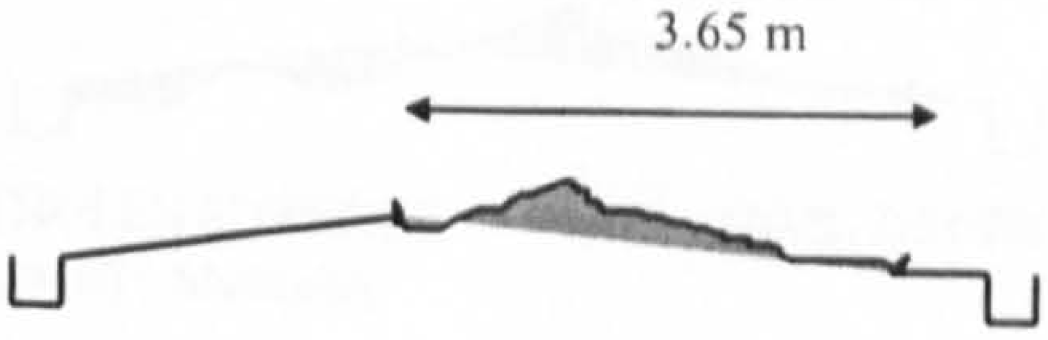
% RSD = 14.8

Time over 50m = 4.55secs.

DISTRESSED CHAINAGE (m)



section a-a



POTHOLES SURFACE : > $2M^2$ MAX. DEPTH > 0.2 M

Nos. > 10 (Multiple)

COMMENTS

S/N	**ROAD NAME**	**STATE**	**DATE**
OG010	Lantoro Road, Abeokuta	OGUN	09-10-00

START TIME **0800** FINISH TIME **0900** DESIGN SPEED **85Km/hr**

NO-DISTRESS SECTION A

AVERAGE SPEED m/sec = 25

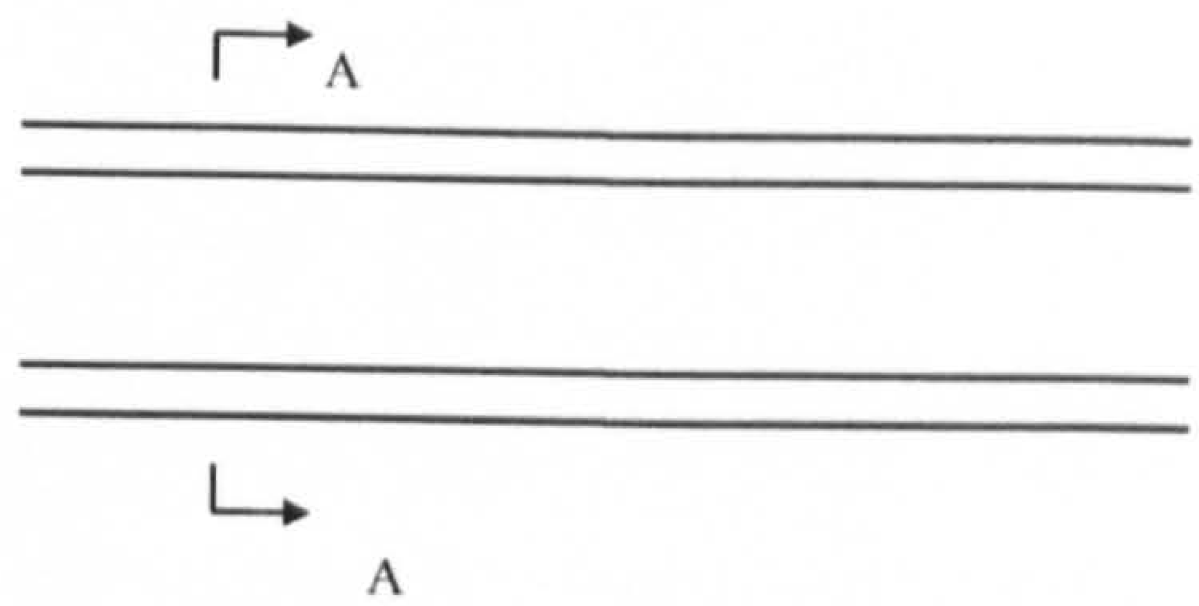
AVERAGE SPEED km/h = 90

VOLUME VEHS/HR = 640

PASSENGER CARS = 589

COMMERCIAL VEHICLES = 51

Carriageway + side-drain



CARRIAGEWAY WIDTH 7.3M CLASS 'B' ROAD

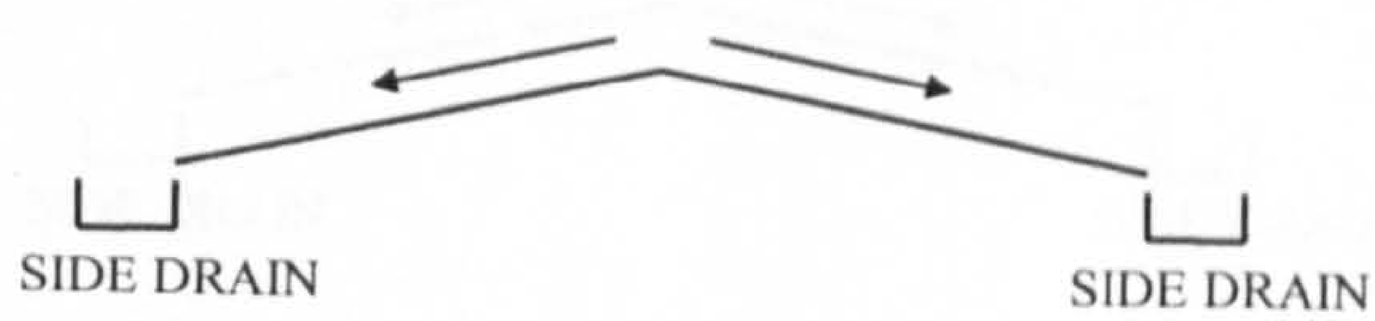
Pavement: Flexible **Terrain:** Normal

% LIGHT GOODS VEHCILE = 6

% HEAVY GOODS VEHICLE = 2

Time over 50m = 2.00secs.

Carriageway + side-drain section A-A



DISTRESSED SECTION B

AVERAGE SPEED m/sec = 11

AVERAGE SPEED km/h = 40

VOLUME VEHS/HR = 538

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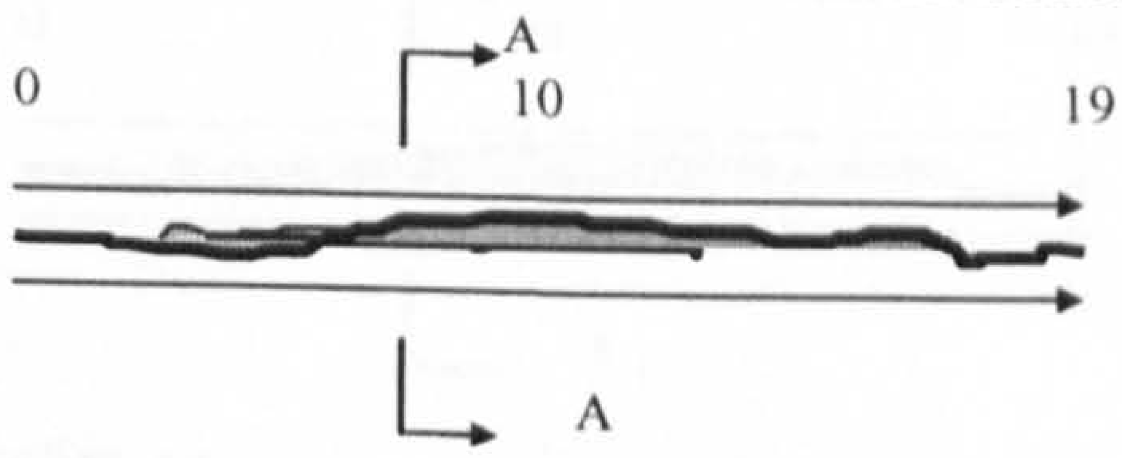
PASSENGER CARS = 495

COMMERCIAL VEHICLES = 43

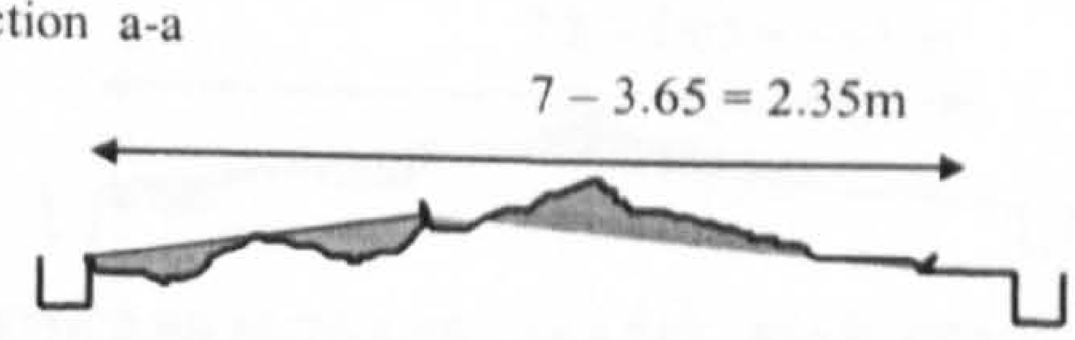
% RSD = 8.7

Time over 50m = 4.55secs.

DISTRESSED SECTION CHAINAGE (m)



section a-a



POTHOLES SURFACE > 3.0M^2 MAX. DEPTH > 0.2 M
Nos. > 10 (Multiple)

COMMENTS

S/N ROAD NAME | **STATE** | **DATE**
OG011 Oba Simolade Road, Shagamu | OGUN | 28-09-00

START TIME **0800** FINISH TIME **0900** DESIGN SPEED **85Km/hr**

NO-DISTRESS SECTION A

AVERAGE SPEED m/sec = 21

AVERAGE SPEED km/h = 75

VOLUME VEHS/HR = 511

PASSENGER CARS = 317

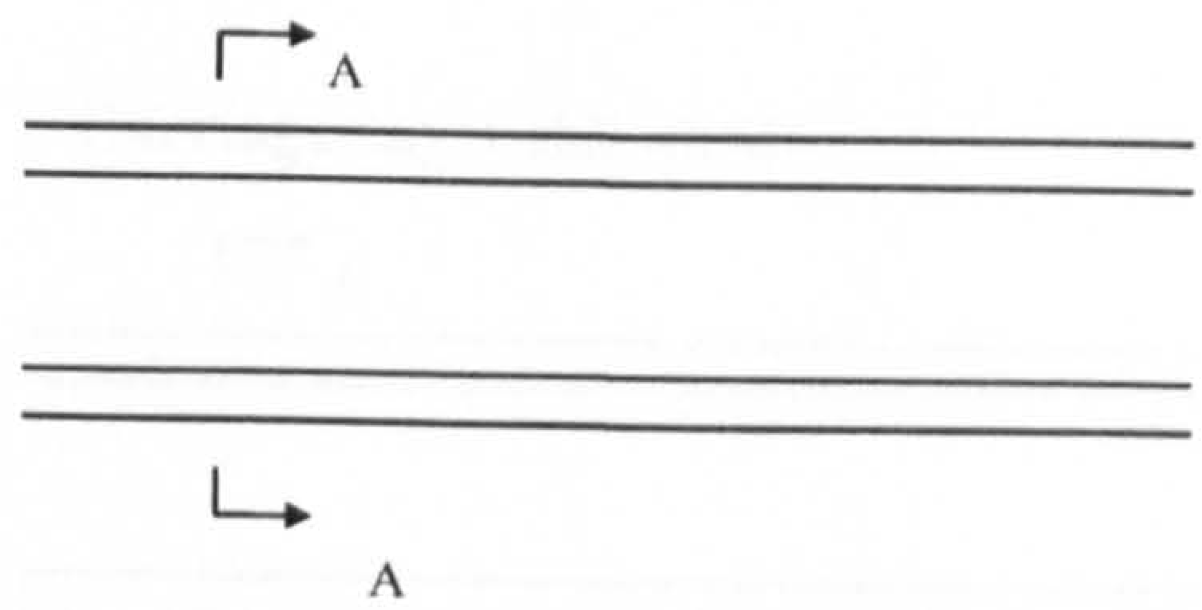
COMMERCIAL VEHICLES = 194

% LIGHT GOODS VEHICLE = 24

% HEAVY GOODS VEHICLE =14

Time over 50m = 2.38secs.

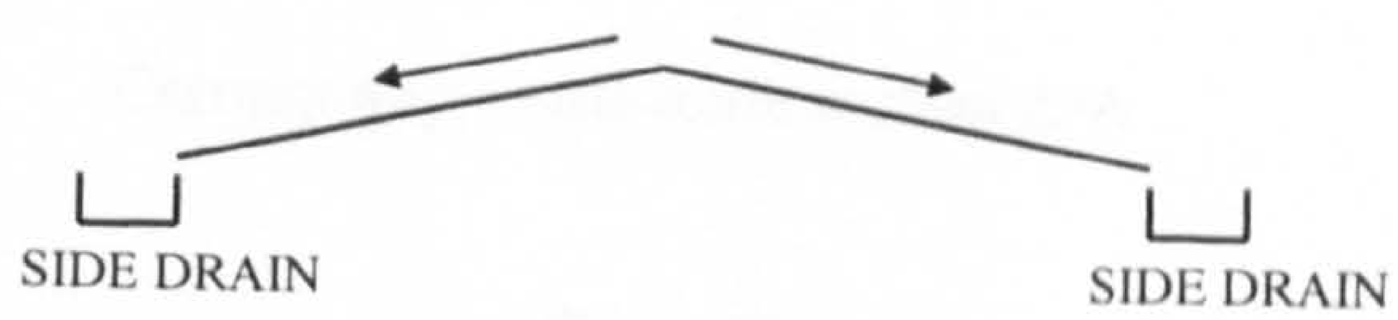
Carriageway + side-drain



CARRIAGEWAY WIDTH 14.30M CLASS ''A' ROAD

Pavement: Flexible **Terrain :** Normal

Carriageway + side-drain section A-A



DISTRESSED SECTION B

AVERAGE SPEED m/sec = 10

AVERAGE SPEED km/h = 35

VOLUME VEHS/HR = 412

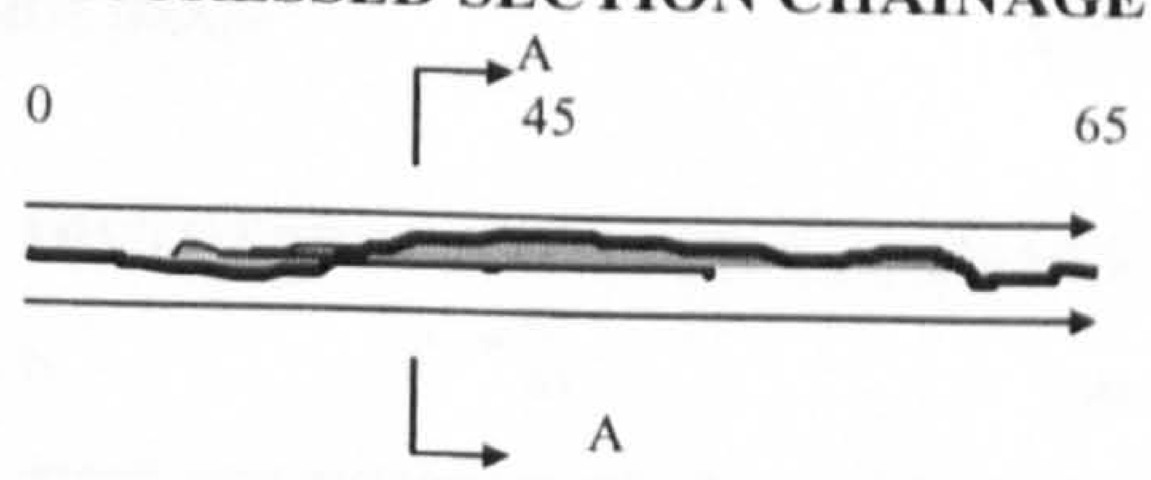
PASSENGER CARS = 255

COMMERCIAL VEHICLES = 155

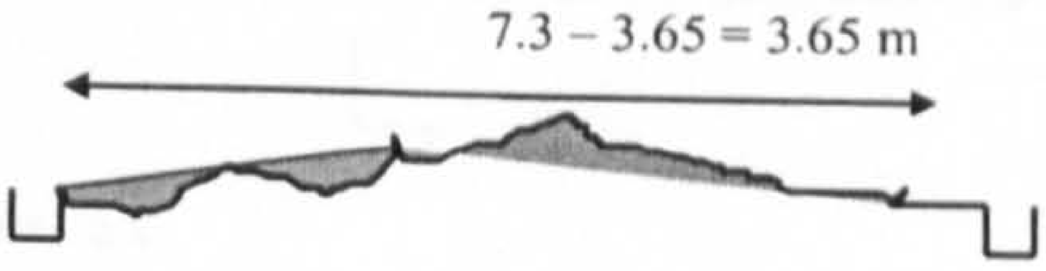
% RSD = 23.2

Time over 50m = 5.00secs.

DISTRESSED SECTION CHAINAGE (m)



Section a-a



POTHOLES SURFACE: >6.4 M^2 MAX. DEPTH >0.3 M
Nos. > 10 (Multiple)

COMMENTS

S/N	**ROAD NAME**	**STATE**	**DATE**
OG012	Ayetoro Road, Abeokuta	OGUN	28-09-00

START TIME **1700** FINISH TIME **1800** DESIGN SPEED **85Km/hr**

NO-DISTRESS SECTION B

AVERAGE SPEED m/sec = 24

AVERAGE SPEED km/h = 85

VOLUME VEHS/HR = 527

PASSENGER CARS = 379

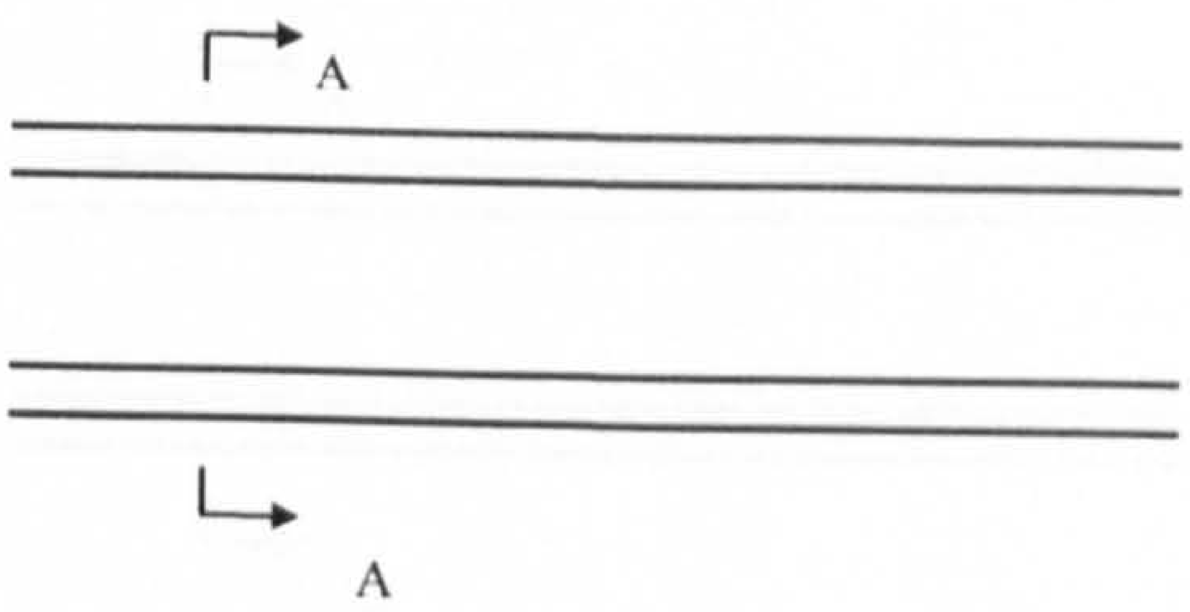
COMMERCIAL VEHICLES = 148

% LIGHT GOODS VEHCILE = 16

% HEAVY GOODS VEHICLE =12

Time over 50m = 2.08secs.

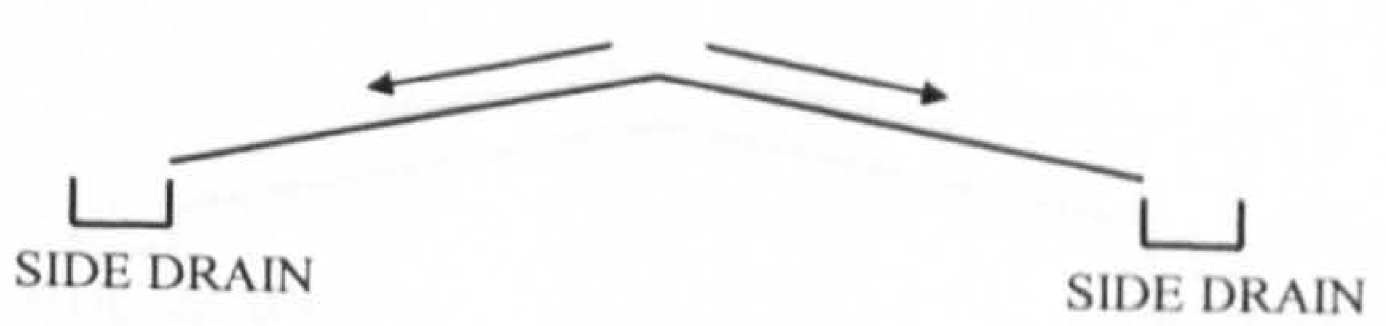
Carriageway + side-drain



CARRIAGEWAY WIDTH 7.3M CLASS 'B' ROAD

Pavement: Flexible **Terrain:** Normal

Carriageway + side-drain section A-A



DISTRESSED SECTION B

AVERAGE SPEED m/sec = 11

AVERAGE SPEED km/h = 38

VOLUME VEHS/HR = 431

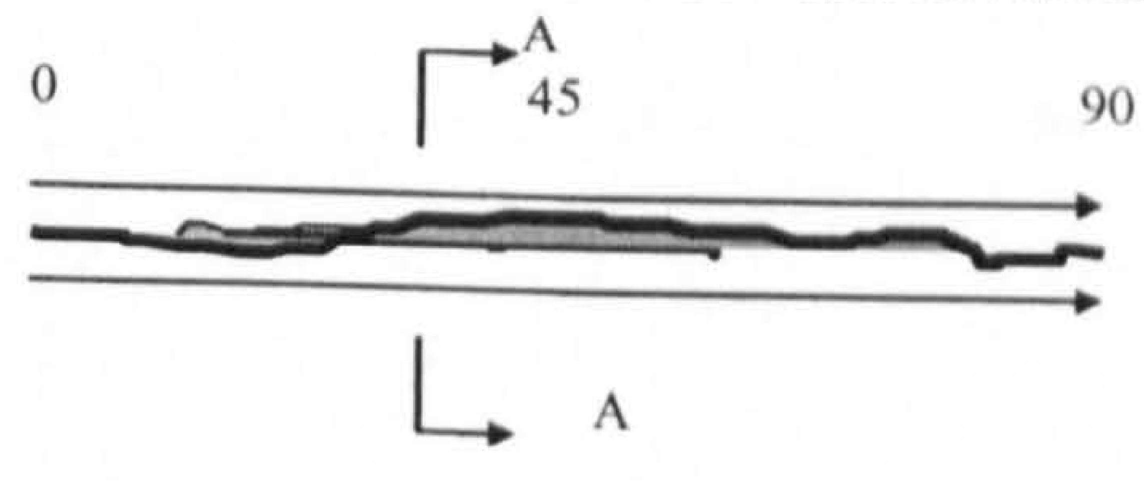
PASSENGER CARS = 410

COMMERCIAL VEHICLES = 121

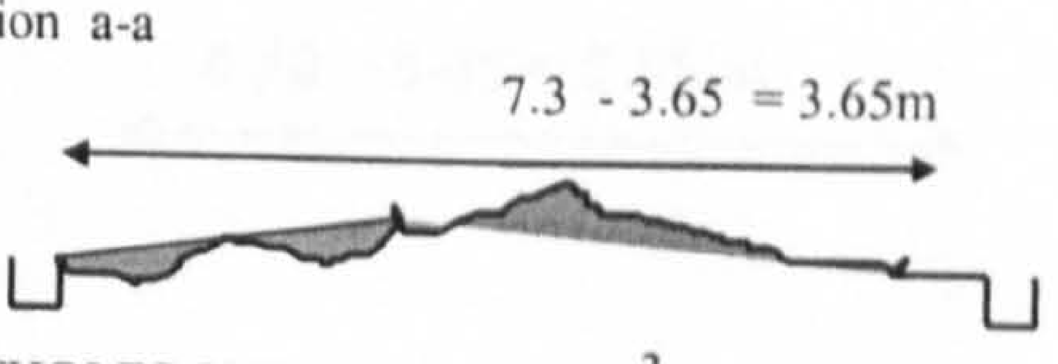
% RSD = 30

Time over 50m = 4.55secs.

DISTRESSED SECTION CHAINAGE (m)



section a-a



POTHOLES SURFACE: >4.0 M^2 MAX. DEPTH >0.3 M
Nos. > 10 (Multiple)

COMMENTS

S/N	**ROAD NAME**	**STATE**	**DATE**
OS013	Oranmiyan Road Ile Ife	OSUN	03-10-00

START TIME **0800** FINISH TIME 0900 DESIGN SPEED **85Km/hr**

NO-DISTRESS SECTION 1 (50M)

AVERAGE SPEED m/sec = 25

AVERAGE SPEED km/h = 89

VOLUME VEHS/HR = 546

PASSENGER CARS = 207

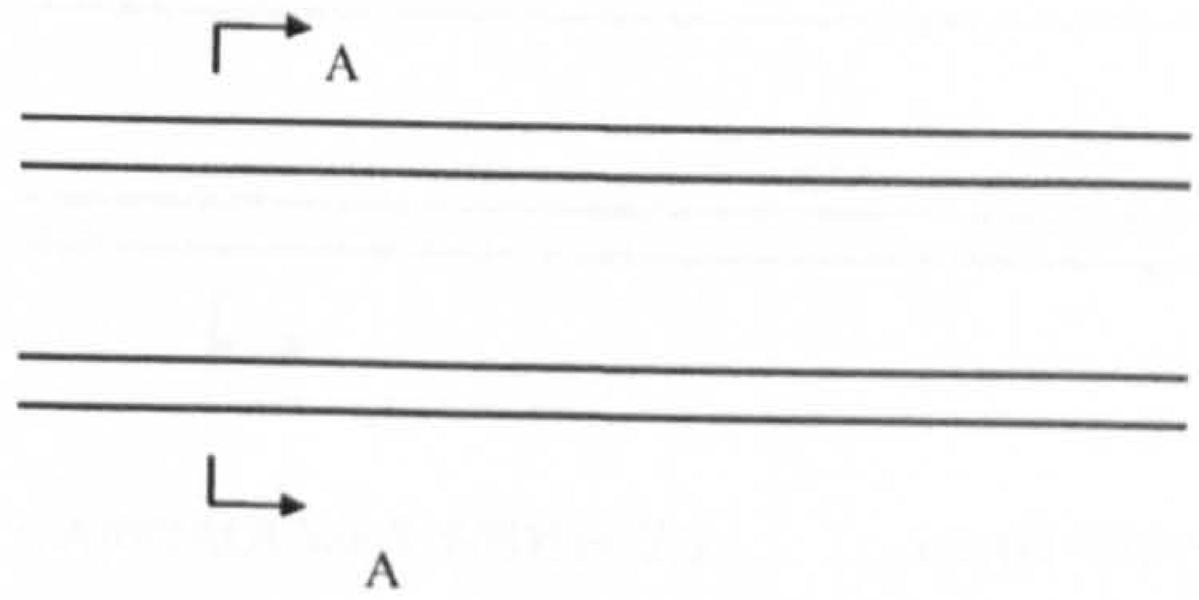
COMMERCIAL VEHICLES = 339

% LIGHT GOODS VEHCILE = 60

% HEAVY GOODS VEHICLE = 2

Time over 50m = 2.00secs.

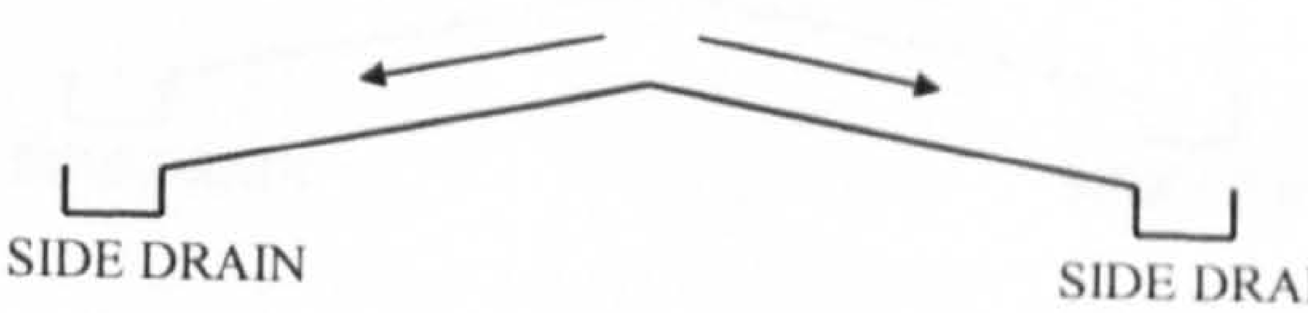
Carriageway + side-drain



CARRIAGEWAY WIDTH 7.3 ROAD TYPE B

Pavement: Flexible **Terrain:** Normal

Carriageway + side-drain section A-A



DISTRESSED SECTION B

AVERAGE SPEED m/sec = 11

AVERAGE SPEED km/h = 38

VOLUME VEHS/HR = 452

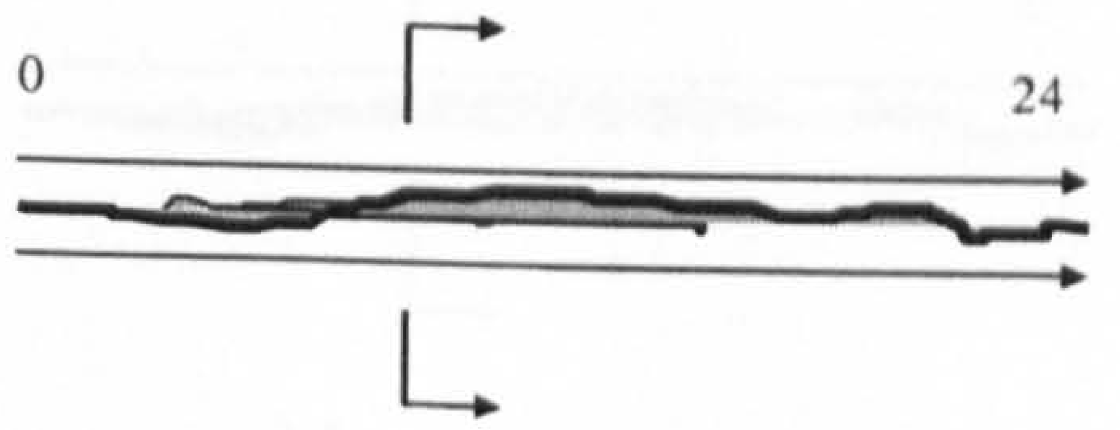
PASSENGER CARS = 172

COMMERCIAL VEHICLES = 280

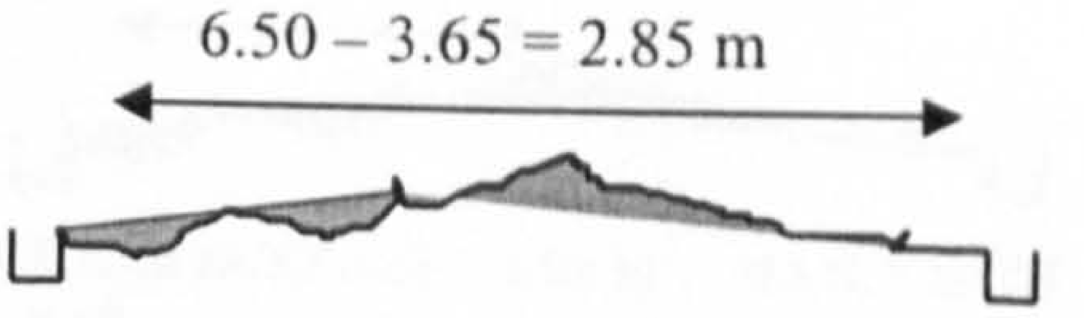
% RSD = 17.1

Time over 50m = 4.55secs.

DISTRESSED SECTION CHAINAGE (m)



6.50 – 3.65 = 2.85 m



POTHOLES SURFACE: > $1.5M^2$ MAX. DEPTH >0.15M
Nos. > 10

COMMENTS

S/N	ROAD NAME	STATE	DATE
OS015	Awolowo Road Ile Ife	OSUN	29-09-00

START TIME **0800** FINISH TIME 0900 DESIGN SPEED **85Km/hr**

NO-DISTRESS SECTION A

AVERAGE SPEED m/sec = 24

AVERAGE SPEED km/h = 87

VOLUME VEHS/HR = 513

PASSENGER CARS = 337

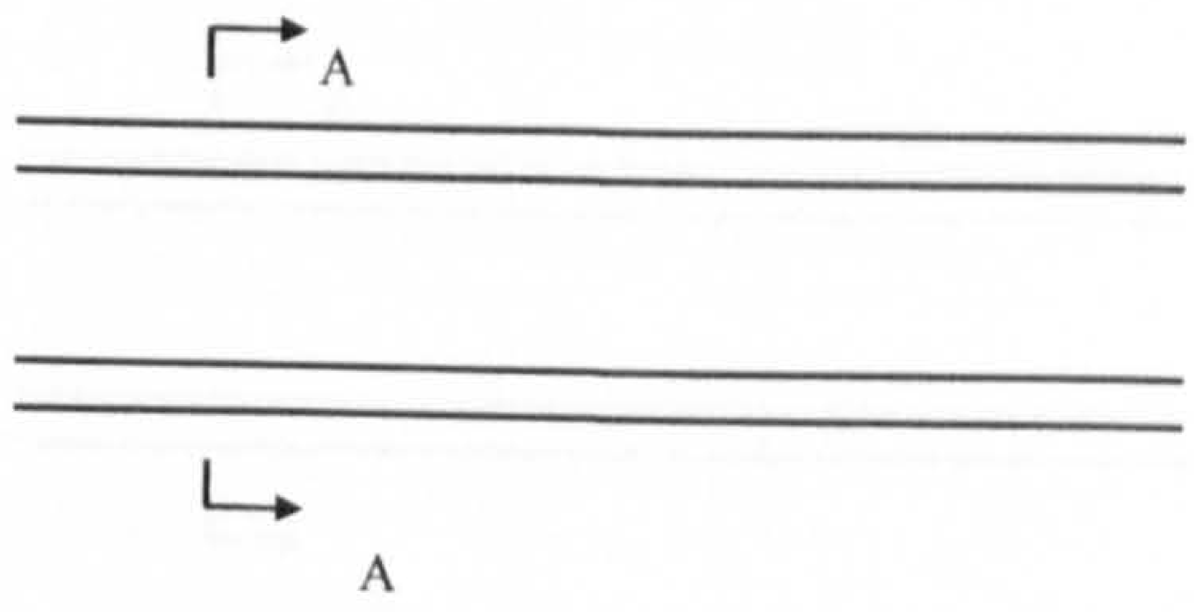
COMMERCIAL VEHICLES = 180

% LIGHT GOODS VEHCILE = 34

% HEAVY GOODS VEHICLE = 0.5

Time over 50m = 2.08secs.

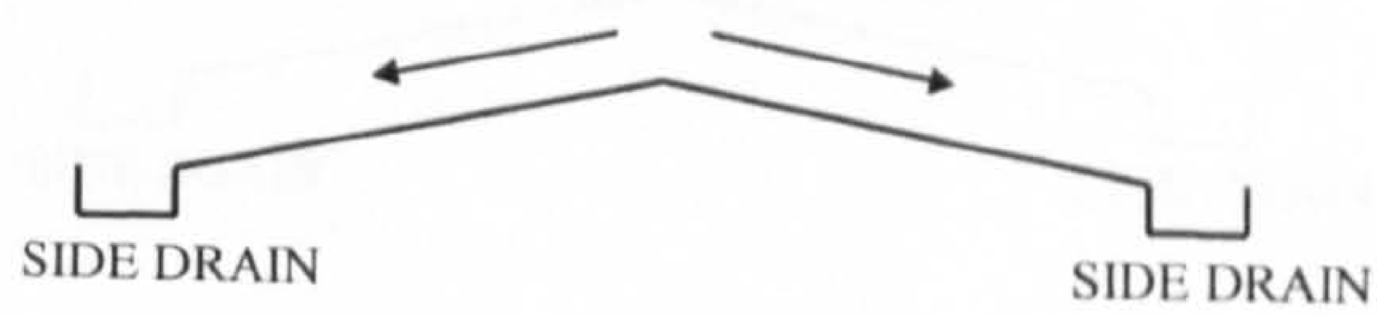
Carriageway + side-drain



CARRIAGEWAY WIDTH 7.3 ROAD TYPE B

Pavement: Flexible **Terrain :** Normal

carriageway + side-drain section A-A



DISTRESSED SECTION B

AVERAGE SPEED m/sec = 11

AVERAGE SPEED km/h = 38

VOLUME VEHS/HR = 417

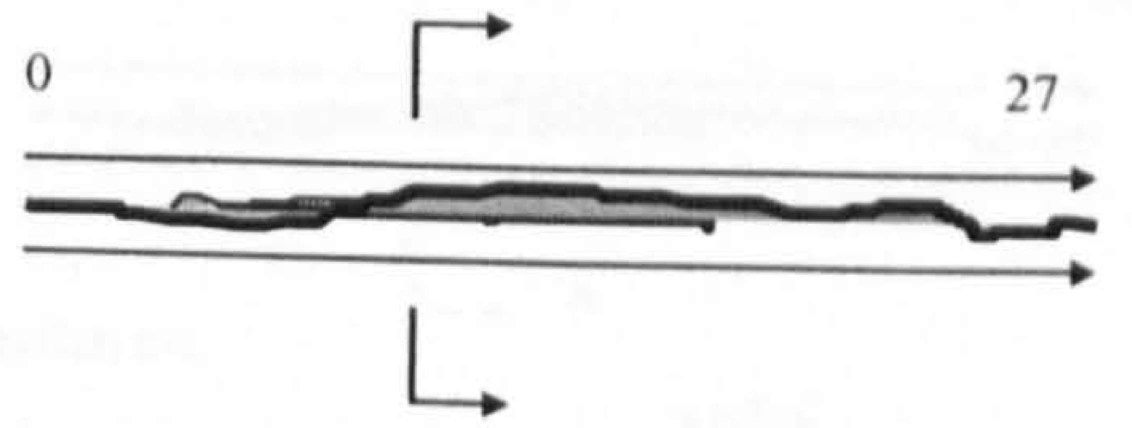
PASSENGER CARS = 271

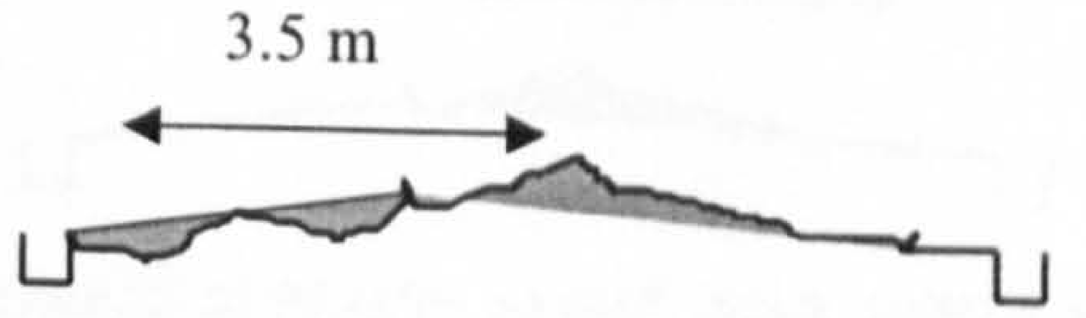
COMMERCIAL VEHICLES = 146

% RSD = 26.6

Time over 50m = 4.55secs.

DISTRESSED SECTION CHAINAGE (m)





POTHOLES SURFACE : 1.5> M^2 MAX. DEPTH >0.2 M
Nos. > 10

COMMENTS

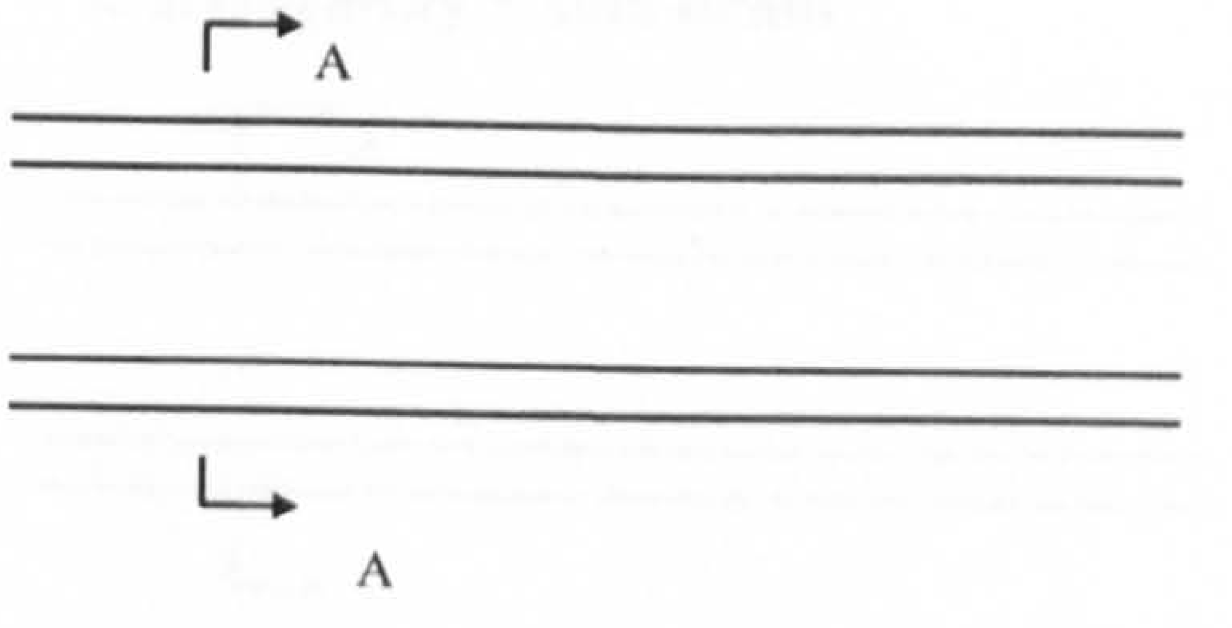
S/N **ROAD NAME** | **STATE** | **DATE**

OY018 Awolowo Ave. Bodija-Ibadan | OYO | 03-10-00

START TIME **1330** FINISH TIME **1430** DESIGN SPEED **85Km/hr**

NO-DISTRESS SECTION B

Carriageway + side-drain



AVERAGE SPEED m/sec = 24

AVERAGE SPEED km/h = 85

VOLUME VEHS/HR = 618

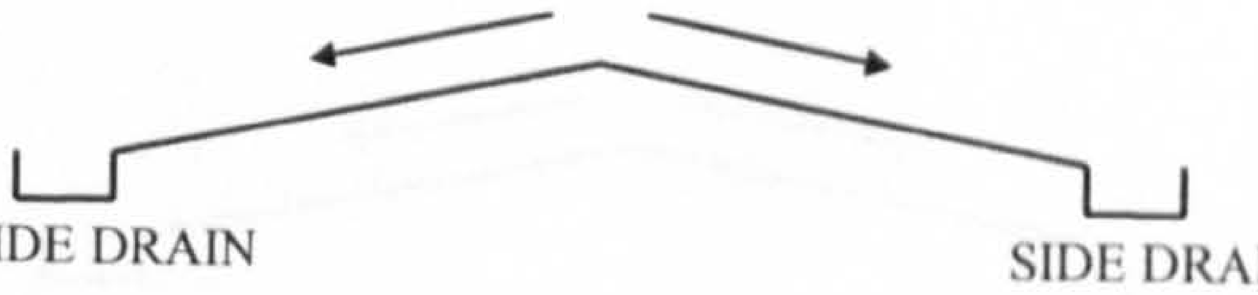
PASSENGER CARS = 463

COMMERCIAL VEHICLES = 155

CARRIAGEWAY WIDTH 7.3M CLASS 'B' ROAD

Pavement: Flexible **Terrain** Normal

Carriageway + side-drain section A-A



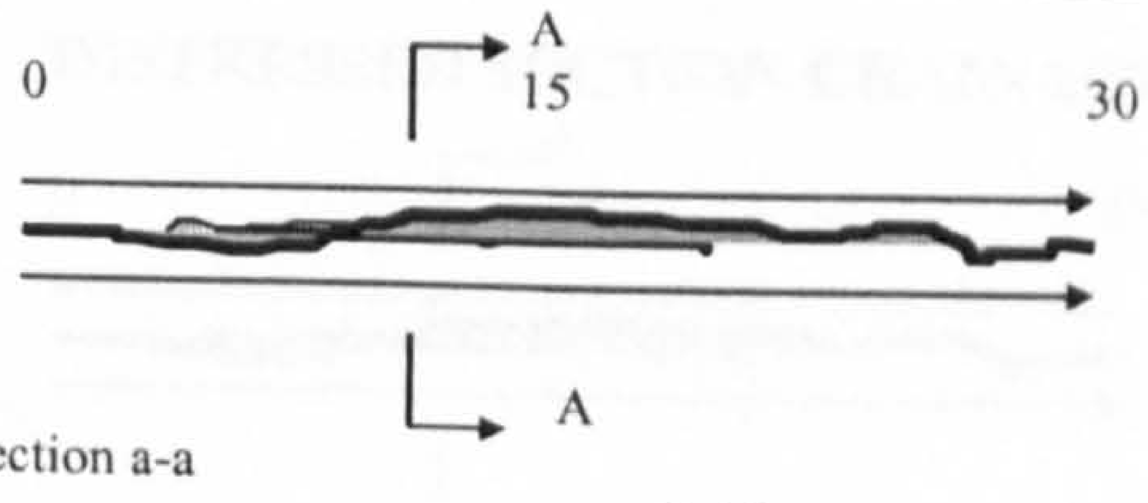
% LIGHT GOODS VEHCILE = 24

% HEAVY GOODS VEHICLE = 1

Time over 50m = 2.08secs.

DISTRESSED SECTION B

DISTRESSED SECTION CHAINAGE (m)



AVERAGE SPEED m/sec = 13

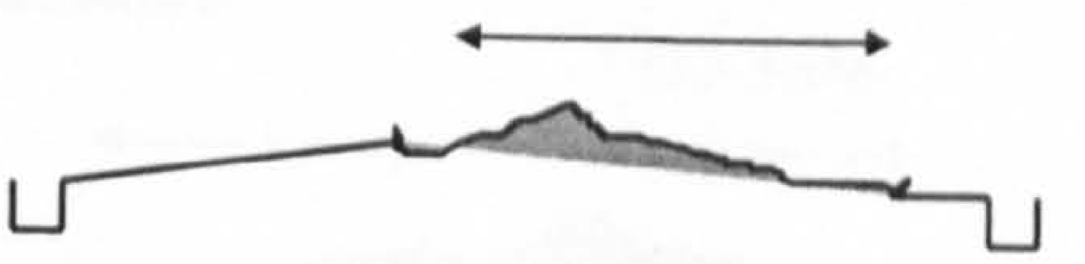
AVERAGE SPEED km/h = 48

VOLUME VEHS/HR = 567

PASSENGER CARS = 425

COMMERCIAL VEHICLES = 142

section a-a



% RSD = 12.5

POTHOLES SURFACE: >2.0M^2 MAX. DEPTH >0.15 M
Nos. >10 (Multiple)

Time over 50m = 3.84secs.

COMMENTS

S/N	ROAD NAME	STATE	DATE
OY019	Oyo Road Mokola-Ibadan	OYO	05-10-00

START TIME **1330** FINISH TIME **1530** DESIGN SPEED **85Km/hr**

NO-DISTRESS SECTION A

AVERAGE SPEED m/sec = 25

AVERAGE SPEED km/h = 89

VOLUME VEHS/HR = 637

PASSENGER CARS = 389

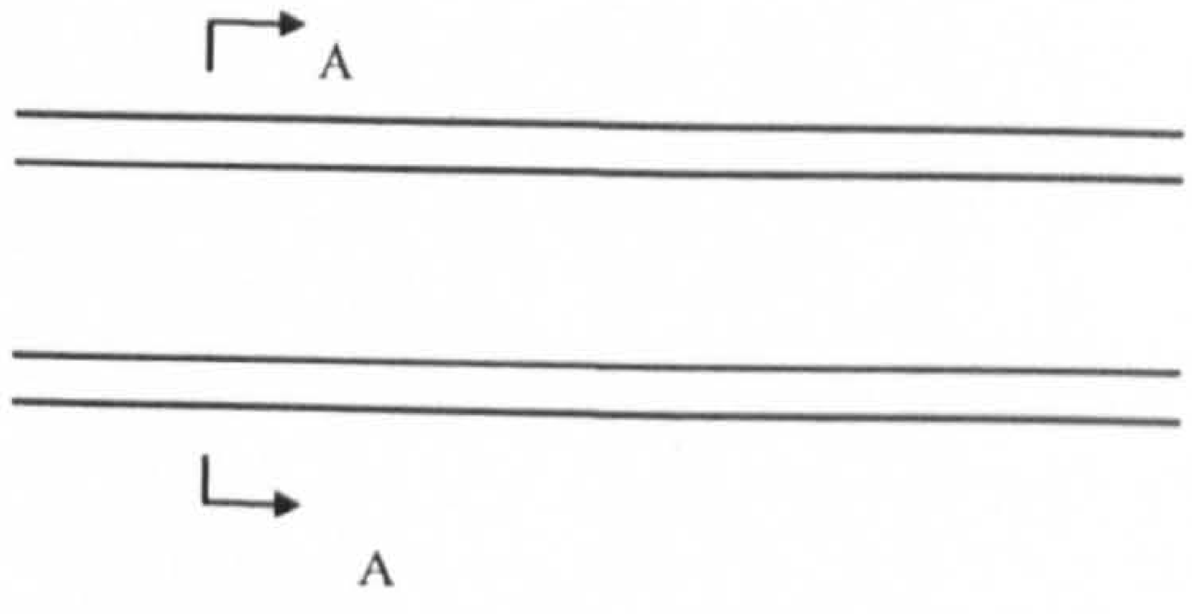
COMMERCIAL VEHICLES = 248

% LIGHT GOODS VEHCILE = 38

% HEAVY GOODS VEHICLE = 1

Time over 50m = 2.00secs.

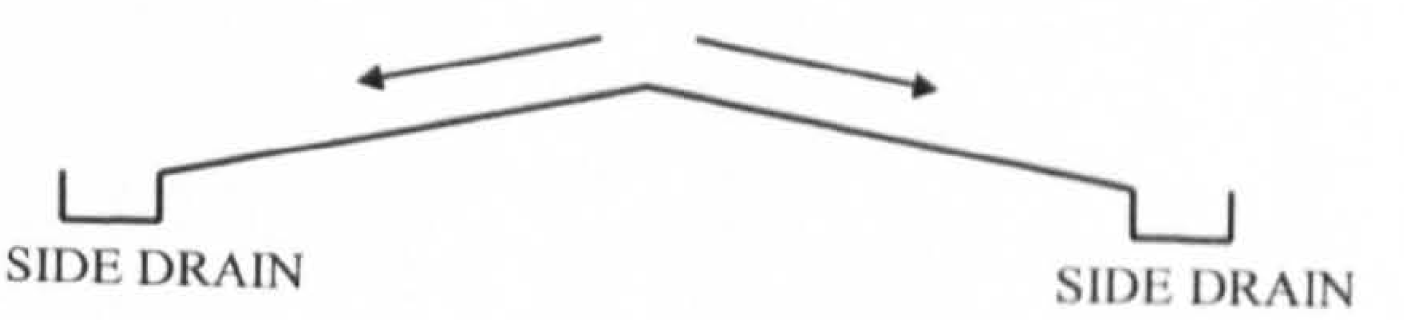
Carriageway + side-drain



CARRIAGEWAY WIDTH 7.3M CLASS 'B' ROAD

Pavement: Flexible **Terrain:** Normal

carriageway + side-drain section A-A



DISTRESSED SECTION B

AVERAGE SPEED m/sec = 12

AVERAGE SPEED km/h = 42

VOLUME VEHS/HR = 585

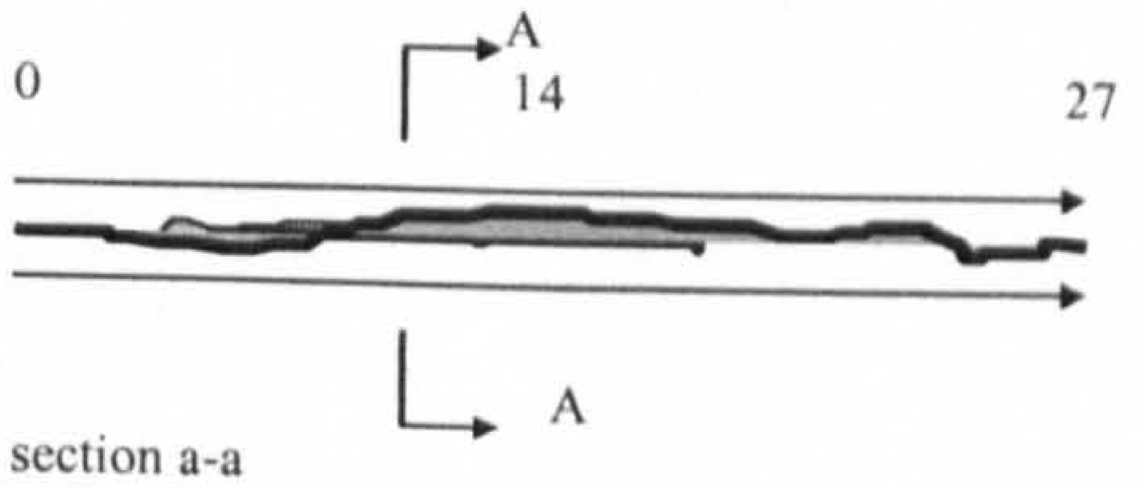
PASSENGER CARS = 357

COMMERCIAL VEHICLES = 228

% RSD = 11.3

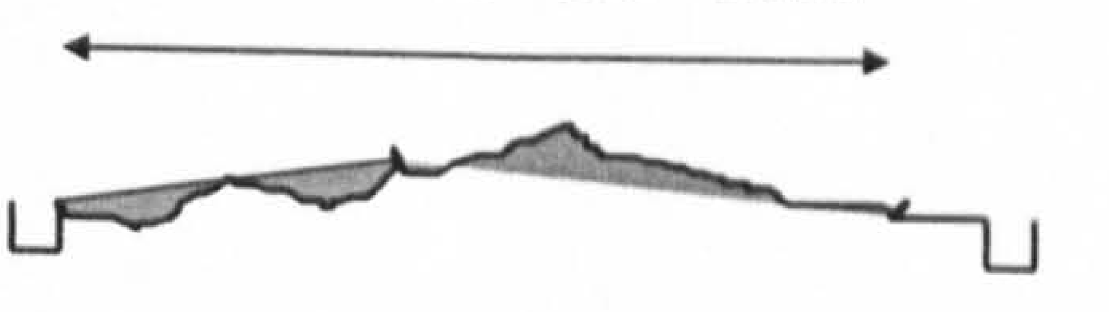
Time over 50m = 4.17secs.

DISTRESSED SECTION CHAINAGE (m)



section a-a

7.3 - 3.65 = 3.65m



POTHOLES SURFACE >2.0 M^2 MAX. DEPTH > 0.2 M
Nos. > 10 (Multiple)

COMMENTS

APPENDIX - C

SITE CODE AN001 DISTANCE 50M VEHICLE SPEED DATA

PERIOD	SECTION A TIME (Secs)	SECTION B TIME (Secs)
00-05	103, 82, 93, 93, 95, 97, 99, 92, 99, 97, 96, 92, 86, 86, 86, 88, 86,	44, 47, 47, 44, 45, 45 45, 45, 46, 45, 45, 45 44, 41, 37, 38, 46, 46
05-10	83, 82, 83, 93, 85, 87, 99, 92, 89, 87, 86, 92, 86, 86, 86, 88, 86	45, 42, 42, 44, 45, 45 45, 45, 46, 45, 45, 45 44, 41, 47, 41, 46, 46
10-15	93, 95, 97, 99, 92, 99, 97, 96, 92, 86, 86, 86, 88, 86, 86,93, 92 99	45, 45, 45, 44, 45, 45 45, 45, 46, 45, 45, 45 44, 41, 42, 43, 46, 46
15-20	93, 95, 97, 92, 99, 97, 96, 92, 86, 86, 86, 88, 86, 97, 96, 92, 86	45, 43, 43, 44, 45, 45 45, 45, 45, 46, 45, 45 45, 44, 41, 37, 44, 45
20-25	95, 97, 99, 92, 99, 86, 88, 86, 97, 96, 92, 86, 86, 93, 82, 93, 93	44, 47, 47, 44, 45, 45 38, 46, 46, 46, 45, 45 45, 45, 44, 41, 39, 38
25-30	93, 82, 93, 93, 95, 97, 99, 92, 99, 97, 96, 92, 86, 86, 86, 88, 86	44, 45, 47, 44, 45, 45 45, 45, 44, 45, 39, 48 48, 46, 46, 46, 45, 45
30-35	90, 82, 83, 93, 85, 97, 89, 92, 99, 97, 99, 82, 86, 86, 86, 88, 96	45, 47, 46, 44, 45, 46 45, 45, 44, 40, 37, 45 38, 46, 46, 46, 45, 45
35-40	100, 82, 83, 101, 95, 97, 99, 92, 99, 87, 86, 82, 86, 86, 86, 88, 86	44, 48, 48, 44, 45, 45 45, 45, 44, 40, 38, 46 39, 39, 46, 46, 46, 45
40-45	103, 82, 93, 93, 95, 97, 99, 92, 99, 97, 96, 92, 86, 86, 86, 88, 86	45, 47, 47, 44, 45, 45 45, 45, 44, 41, 37, 44 38, 46, 46, 46, 48, 44
45-50	97, 89, 92, 99, 97, 96, 92, 86, 86, 86, 88, 86, 103, 82, 93, 93, 95	46, 46, 47, 44, 45, 44 45, 45, 44, 41, 37, 46 44, 44, 45, 46, 45, 48
50-55	92, 99, 97, 96, 92, 86, 86, 86, 88, 86, 99, 82, 93, 93, 95, 97, 99	44, 43, 47, 44, 45, 45, 45, 45, 44, 41, 39, 48, 46, 46, 46, 45, 45, 45,
55-60	99, 92, 99, 97, 96, 92, 86, 86, 86, 88, 86, 100, 86, 83, 83, 95, 97	45, 45, 44, 41, 37, 38 44, 47, 47, 44, 45, 46 45, 45, 45, 46, 45, 46

SITE CODE DL002 DISTANCE 50M VEHICLE SPEED DATA

PERIOD	SECTION A TIME (Secs)	SECTION B TIME (Secs)
00-05	85, 81, 83, 73, 86, 88, 88, 80, 85, 83, 83, 86, 88, 86, 86,83, 82 79	33, 31, 33, 34, 35, 32 33, 31, 34, 33, 35, 32 32, 31, 32, 33, 36, 32
05-10	83, 85, 87, 89, 82, 88, 86, 86, 83, 82, 79, 87, 86, 82, 86, 86, 86	35, 35, 35, 34, 35, 31 35, 35, 36, 35, 35, 31 34, 31, 32, 33, 36, 33
10-15	83, 85, 87, 89, 82, 79, 87, 86, 82, 86, 86, 86, 88, 86, 86,83, 82 79	32, 32, 35, 34, 32, 32 33, 32, 30, 35, 32, 33 30, 31, 32, 33, 30, 33
15-20	83, 85, 87, 89, 82, 80, 87, 86, 79,82, 86, 86, 86, 88, 86, 86,83, 82	32, 33, 35, 34, 35, 31 32, 33, 36, 35, 35, 31 34, 33, 32, 33, 36, 33
20-25	79, 87, 86, 82, 86, 86, 86, 88, 86, 86,83, 82,83, 85, 87, 80, 82, 80	35, 30, 35, 34, 30, 31 35, 30, 32, 35, 30, 31 34, 31, 32, 33, 32, 33
25-30	83, 85, 87, 80, 82, 79, 87, 86, 82, 86, 86, 86, 88, 86, 86,83, 82 79	31, 31, 31, 34, 33, 31 35, 29, 29, 32, 35, 31 34, 31, 32, 33, 36, 33
30-35	87, 86, 82, 86, 86, 86, 88, 86, 86,83, 82,81, 83, 85, 87, 80, 82, 80	31, 35, 35, 34, 35, 31 30, 35, 36, 35, 33, 31 29, 31, 32, 33, 34, 33
35-40	83, 85, 87, 89, 82, 79, 87, 86, 82, 86, 86, 86, 83, 85, 87, 89, 82	35, 30, 30, 34, 35, 30 35, 31, 36, 30, 34, 30 34, 31, 32, 33, 34, 29
40-45	80, 85, 87, 88, 82, 79, 87, 86, 82, 80, 80, 86, 80, 86, 86,83, 82 79	30, 35, 35, 32, 31, 33 30, 35, 36, 33, 30, 34 32, 31, 32, 33, 26, 33
45-50	83, 85, 77, 79, 72, 79, 87, 86, 82, 86, 80, 86, 80, 86, 86,83, 82 79	32, 35, 34, 34, 35, 31 32, 35, 33, 25, 25, 31 32, 31, 32, 33, 36, 33
50-55	83, 85, 77, 79, 82, 79, 87, 86, 82, 86, 86, 86, 78, 80, 86,83, 82 85	32, 35, 35, 34, 35, 28 32, 30, 25, 35, 35, 30 34, 30, 30, 23, 36, 33
55-60	73, 85, 87, 89, 82, 79, 87, 86, 82, 86, 81, 81, 81, 85, 85,83, 82 89	32, 35, 33, 34, 30, 32 32, 35, 33, 32, 32, 32 30, 31, 32, 33, 36, 33

SITE CODE DL003 DISTANCE 50M VEHICLE SPEED DATA

PERIOD	SECTION A TIME (Secs)	SECTION B TIME (Secs)
00-05	82, 82, 85, 76, 75, 77, 81, 88, 86, 86, 83, 83, 83, 85, 75,83, 82 83	35, 35, 33, 36, 37, 36 36, 36, 37, 37, 37, 36 37, 37, 36, 36, 36, 37
05-10	86, 86, 83, 83, 83, 85, 75,83, 82 83, 82, 82, 75, 76, 74, 87, 81, 88,	35, 35, 33, 36, 37, 36 36, 36, 37, 37, 37, 36 37, 37, 36, 36, 36, 37
10-15	81, 88, 86, 86, 83, 83, 83, 85, 75, 83, 82, 83, 82, 82, 85, 76, 88	35, 35, 33, 36, 37, 36 36, 36, 37, 37, 37, 36 37, 37, 36, 36, 36, 37
15-20	82, 72, 75, 76, 75, 77, 81, 88, 85, 75,83, 82, 86, 86, 83, 83, 83 83	35, 35, 33, 36, 37, 36 36, 36, 37, 37, 37, 36 37, 37, 36, 36, 36, 37
20-25	72, 72, 85, 76, 75, 77, 81, 88, 76, 76, 80, 80, 73, 75, 75,83, 82 80	35, 35, 34, 36, 37, 36 35, 35, 33, 36, 37, 36 37, 37, 34, 36, 36, 37
25-30	80, 77, 77, 77, 77, 77, 81, 88, 76, 76, 77, 77, 77, 75, 75,73, 82 77	35, 35, 33, 36, 37, 36 36, 35, 37, 37, 37, 36 37, 37, 35, 36, 36, 37
30-35	81, 81, 81, 83, 85, 87, 88, 88, 81, 81, 81, 81, 81, 85, 75,83, 82 81	35, 35, 33, 36, 37, 36 37, 36, 35, 37, 37, 36 37, 36, 33, 36, 37, 36
35-40	88, 88, 85, 86, 85, 87, 81, 88, 86, 86, 88, 88, 88, 85, 85,83, 82 88	37, 35, 33, 36, 37, 36 37, 37, 34, 37, 37, 36 37, 37, 36, 36, 36, 37
40-45	86, 86, 86, 86, 85, 87, 86, 86, 86, 86, 86, 86, 86, 85, 85,86, 86 86	35, 35, 35, 36, 37, 36 36, 37, 37, 37, 37, 36 37, 37, 34, 36, 36, 37
45-50	86, 86, 86, 86, 85, 87, 86, 86, 86, 86, 86, 86, 86, 86, 75,86, 86 85	35, 35, 33, 36, 37, 36 37, 35, 38, 37, 37, 36 37, 37, 36, 36, 36, 37
50-55	82, 82, 85, 76, 75, 77, 81, 88, 86, 86, 83, 83, 83, 85, 75,83, 82 83	36, 36, 39, 36, 37, 36 36, 36, 37, 37, 37, 36 36, 36, 49, 36, 36, 37
55-60	83, 82, 83, 83, 84, 86, 89, 80, 83, 83, 83, 83, 83, 85, 73,83, 82 83	35, 34, 36, 36, 37, 36 36, 36, 40, 37, 37, 36 35, 36, 37, 37, 36, 37

SITE CODE DL004 DISTANCE 50M VEHICLE SPEED DATA

PERIOD	SECTION A TIME (Secs)	SECTION B TIME (Secs)
00-05	70, 80, 80, 70, 80, 80, 80, 65, 73, 70, 73, 75, 73, 70, 73,70, 70 70	40, 40, 43, 43, 40, 42 40, 42, 40, 47, 43, 42 42, 40, 43, 43, 40, 40
05-10	80, 80, 80, 80, 80, 80, 80, 85, 83, 80, 83, 85, 83, 80, 83,80, 85 83	40, 40, 43, 43, 40, 42 40, 42, 40, 47, 43, 42 42, 40, 43, 43, 40, 40
10-15	81, 81, 81, 80, 90, 81, 80, 75, 83, 82, 81, 81, 81, 81, 83,80, 80 81	40, 40, 43, 43, 40, 42 40, 40, 40, 47, 40, 42 42, 40, 40, 43, 40, 40
15-20	77, 70, 70, 77, 83, 81,72, 95, 77, 77, 77, 77, 77, 79, 77,78, 78 77	40, 40, 40, 43, 40, 42 40, 42, 40, 47, 43, 42 42, 40, 40, 43, 40, 40
20-25	89, 88, 88, 85, 88, 88, 88, 85, 88, 88, 83, 85, 83, 88, 83,88, 88 88	40, 40, 43, 43, 40, 42 40, 42, 40, 40, 43, 42 42, 40, 43, 40, 40, 40
25-30	88, 88, 88, 80, 88, 88, 88, 85, 78, 78, 83, 85, 83, 88, 83,88, 89 88	40, 40, 43, 43, 40, 42 40, 42, 40, 40, 43, 42 42, 40, 40, 40, 40, 40
30-35	89, 89, 88, 89, 88, 88, 88, 89, 79, 89, 89, 89, 89, 88, 89,88, 89 89	40, 40, 43, 43, 40, 42 40, 42, 40, 47, 43, 42 42, 40, 43, 43, 40, 40
35-40	65, 70, 65, 65, 70, 70, 65, 73, 60, 63, 65, 73, 65, 65,67, 67, 66 65	40, 40, 43, 43, 40, 42 40, 42, 40, 47, 43, 42 42, 40, 43, 43, 40, 40
40-45	74, 74, 78, 73, 70, 70, 70, 85, 73, 73, 73, 75, 73, 70, 73,70, 70 73	40, 40, 43, 43, 40, 42 40, 42, 40, 47, 43, 42 42, 40, 43, 43, 40, 40
45-50	73, 81, 70, 70, 80, 80, 80, 73, 73, 70, 74, 75, 73, 70, 73,70, 70 73	40, 40, 43, 43, 40, 40 40, 42, 40, 47, 43, 42 42, 40, 43, 43, 40, 40
50-55	74, 74, 74, 74, 60, 70, 70, 74, 73, 74, 74, 74, 74, 90, 73,70, 70 74	40, 40, 43, 43, 40, 42 40, 42, 40, 47, 43, 42 42, 40, 43, 43, 40, 40
55-60	73, 74, 73, 70, 73, 73, 73, 73, 73, 74, 73, 74, 73, 70, 73,70, 70 73	40, 40, 43, 43, 40, 42 40, 42, 40, 47, 43, 4 40, 40, 40, 43, 40, 40

SITE CODE DL005 DISTANCE 50M VEHICLE SPEED DATA

PERIOD	SECTION A TIME (Secs)	SECTION B TIME (Secs)
00-05	82, 82, 82, 80, 82, 82, 80, 82, 83, 83, 83, 82, 83, 88, 83,82, 82 82	39, 39, 40, 40, 40, 40 38, 39, 39, 38, 39, 39 38, 37, 38, 38, 39, 39
05-10	82, 82, 82, 80, 82, 82, 82, 82, 82, 82, 82, 82, 83, 82, 83,82, 82 82	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38
10-15	80, 80, 80, 80, 82, 82, 80, 80, 80, 80, 80, 82, 80, 80, 83,82, 80 80	39, 39, 39, 39, 39, 39 39, 39, 39, 38, 39, 39 38, 39, 38, 38, 39, 39
15-20	89, 88, 89, 88, 89, 89, 89, 89, 89, 88, 83, 88, 83, 88, 83,82, 89 89	40, 40, 40, 40, 40, 40 40, 40, 41, 41, 38, 40 40, 40, 41, 39, 38, 38
20-25	78, 81, 78, 78, 79, 78, 78, 78, 78, 78, 78, 78, 78, 78, 73,78, 78 78	39, 39, 39, 39, 39, 39 39, 39, 39, 38, 39, 39 38, 39, 38, 38, 39, 39
25-30	86, 85, 85, 86, 86, 86, 86, 86, 86, 85, 85, 86, 86, 84, 87,85, 86 86	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38
30-35	79, 81, 78, 78, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79,79, 79 79	38, 38, 38, 39, 39, 38 38, 38, 38, 38, 39, 38 38, 38, 38, 38, 39, 38
35-40	79, 81, 78, 78, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79,79, 79 79	38, 38, 38, 39, 39, 38 38, 38, 38, 38, 39, 38 38, 38, 38, 38, 39, 38
40-45	80, 80, 80, 80, 82, 82, 80, 80, 80, 80, 80, 82, 80, 80, 83,82, 80 80	37, 37, 38, 39, 37, 37 37, 37, 36, 38, 36, 37 37, 37, 38, 38, 37, 37
45-50	81, 81, 81, 79, 81, 82, 79, 81, 81, 81, 81, 81, 80, 80, 79,82, 81 81	39, 39, 39, 39, 39, 39 39, 39, 39, 38, 39, 39 38, 39, 38, 38, 39, 39
50-55	83, 83, 83, 83, 85, 83, 83, 83, 83, 83, 84, 83, 85 84, 83,85, 83 83	39, 39, 39, 39, 38, 38 39, 39, 39, 38, 39, 38 39, 39, 38, 38, 39, 38
55-60	83, 83, 83, 83, 85, 83, 83, 83, 83, 83, 84, 83, 85 84, 83,85, 83 83	39, 39, 39, 39, 38, 38 39, 39, 39, 38, 39, 38 39, 39, 38, 38, 39, 38

SITE CODE ED006 DISTANCE 50M VEHICLE SPEED DATA

PERIOD	SECTION A TIME (Secs)	SECTION B TIME (Secs)
00-05	79, 78, 79, 78, 79, 79, 79, 79, 79, 78, 80, 78, 80, 78, 80,80, 79 79	55, 55, 50, 50, 50, 55 55, 55, 51, 51, 48, 55 55, 55, 51, 59, 48, 48
05-10	74, 74, 74, 74, 74, 74, 74, 74, 74, 74, 75, 75, 81, 74, 73,74, 74 74	50, 50, 50, 50, 50, 50 50, 50, 51, 51, 50, 50 50, 50, 51, 49, 50, 50
10-15	86, 86, 86, 86, 89, 86, 86, 86, 86, 86, 85, 68, 86, 85, 83,86, 86 86	50, 50, 50, 50, 50, 50 50, 50, 51, 51, 50, 50 50, 50, 51, 49, 50, 50
15-20	79, 78, 79, 78, 79, 79, 79, 79, 79, 78, 80, 78, 80, 78, 80,80, 79 79	45, 45, 45, 44, 45, 45 45, 45, 45, 44, 46, 45 45, 45, 45, 45, 46, 45
20-25	80, 80, 80, 80, 80, 83, 82, 80, 80, 80, 80, 80, 80, 82, 83,82, 80 80	45, 45, 45, 44, 45, 45 45, 45, 45, 44, 46, 45 45, 45, 45, 45, 46, 45
25-30	85, 85, 86, 85, 85, 85, 85, 85, 85, 85, 85, 85, 86, 85, 85,85, 85 85	46, 46, 46, 46, 46, 46 46, 46, 45, 46, 46, 46 46, 46, 45, 46, 46, 46
30-35	86, 86, 86, 86, 89, 86, 86, 86, 86, 86, 85, 68, 86, 85, 83,86, 86 86	48, 47, 48, 48, 48, 48 48, 47, 48, 48, 48, 48 48, 47, 48, 48, 46, 48
35-40	86, 86, 86, 86, 89, 86, 86, 86, 86, 86, 85, 68, 86, 85, 83,86, 86 86	50, 50, 50, 50, 50, 50 50, 50, 51, 51, 50, 50 50, 50, 51, 49, 50, 50
40-45	85, 85, 86, 85, 85, 85, 85, 85, 85, 85, 85, 85, 86, 85, 85,85, 85 85	50, 50, 50, 50, 50, 50 50, 50, 51, 51, 50, 50 50, 50, 51, 49, 50, 50
45-50	86, 86, 86, 86, 89, 86, 86, 86, 86, 86, 85, 68, 86, 85, 83,86, 86 86	50, 50, 50, 50, 50, 50 50, 50, 51, 51, 50, 50 50, 50, 51, 49, 50, 50
50-55	86, 86, 86, 86, 89, 86, 86, 86, 86, 86, 85, 68, 86, 85, 83,86, 86 86	50, 50, 50, 50, 50, 50 50, 50, 51, 51, 50, 50 50, 50, 51, 49, 50, 50
55-60	85, 85, 86, 85, 85, 85, 85, 85, 85, 85, 85, 85, 86, 85, 85,85, 85 85	50, 50, 50, 50, 50, 50 50, 50, 51, 51, 50, 50 50, 50, 51, 49, 50, 50

SITE CODE ED007 DISTANCE 50M VEHICLE SPEED DATA

PERIOD	SECTION A TIME (Secs)	SECTION B TIME (Secs)
00-05	80, 80, 80, 80, 80, 83, 82, 80, 80, 80, 80, 80, 80, 82, 83,82, 80 80	40, 42, 42, 40, 40, 40 40, 40, 40, 44, 40, 40 40, 41, 40, 40, 40, 40
05-10	85, 85, 85, 85, 83, 85, 84, 85 85, 85, 85, 85, 83, 85, 85,85, 85 85	40, 42, 42, 40, 40, 40 40, 40, 40, 44, 40, 40 40, 41, 40, 40, 40, 40
10-15	75, 75, 75, 75, 78, 75, 74, 75 75, 75, 75, 78, 78, 75, 75,75, 75 75	40, 40, 40, 40, 40, 40 40, 40, 40, 40, 40, 40 40, 41, 40, 40, 40, 40
15-20	80, 80, 80, 80, 80, 83, 82, 80, 80, 80, 80, 80, 80, 82, 83,82, 80 80	45, 45, 45, 44, 45, 45 45, 45, 45, 44, 46, 45 45, 45, 45, 45, 46, 45
20-25	85, 85, 85, 85, 83, 85, 84, 85 85, 85, 85, 85, 83, 85, 85,85, 85 85	45, 45, 45, 44, 45, 45 45, 45, 45, 44, 46, 45 45, 45, 45, 45, 46, 45
25-30	75, 75, 75, 75, 78, 75, 74, 75 75, 75, 75, 78, 78, 75, 75,75, 75 75	40, 40, 40, 40, 40, 40 40, 40, 40, 40, 40, 40 40, 41, 40, 40, 40, 40
30-35	80, 80, 80, 80, 80, 83, 82, 80, 80, 80, 80, 80, 80, 82, 83,82, 80 80	45, 45, 45, 44, 45, 45 45, 45, 45, 44, 46, 45 45, 45, 45, 45, 46, 45
35-40	80, 80, 80, 80, 80, 83, 82, 80, 80, 80, 80, 80, 80, 82, 83,82, 80 80	45, 45, 45, 44, 45, 45 45, 45, 45, 44, 46, 45 45, 45, 45, 45, 46, 45
40-45	80, 80, 80, 80, 80, 83, 82, 80, 80, 80, 80, 80, 80, 82, 83,82, 80 80	44, 44, 44, 44, 44, 44 44, 45, 45, 44, 44, 44 44, 45, 45, 45, 44, 44
45-50	75, 75, 75, 75, 78, 75, 74, 75 75, 75, 75, 78, 78, 75, 75,75, 75 75	39, 39, 40, 40, 40, 39 39, 39, 40, 40, 40, 39 39, 39, 39, 40, 40, 39
50-55	75, 75, 75, 75, 78, 75, 74, 75 75, 75, 75, 78, 78, 75, 75,75, 75 75	39, 39, 39, 40, 40, 39 39, 39, 39, 40, 40, 39 39, 39, 39, 40, 40, 39
55-60	75, 75, 75, 75, 78, 75, 74, 75 75, 75, 75, 78, 78, 75, 75,75, 75 75	39, 39, 40, 40, 40, 39 39, 39, 40, 40, 40, 39 39, 39, 39, 39, 39, 39

SITE CODE ED008 DISTANCE 50M VEHICLE SPEED DATA

PERIOD	SECTION A TIME (Secs)	SECTION B TIME (Secs)
00-05	79, 79, 79, 78, 78, 75, 79, 79 79, 78, 75, 78, 78, 79, 78,78, 79 79	39, 39, 38, 39, 39, 39 39, 39, 38, 39, 37, 39 39, 39, 39, 39, 39, 39
05-10	78, 78, 77, 77, 78, 78, 79, 78 78, 78, 77, 78, 78, 78, 78,78, 78 78	39, 39, 38, 39, 39, 39 39, 39, 38, 39, 37, 39 39, 39, 39, 39, 39, 39
10-15	75, 75, 75, 75, 78, 75, 74, 75 75, 75, 75, 78, 78, 75, 75,75, 75 75	40, 40, 40, 40, 40, 40 40, 40, 40, 40, 40, 40 40, 41, 40, 40, 40, 40
15-20	77, 75, 75, 75, 78, 75, 74, 77 77, 75, 75, 78, 78, 75, 75,75, 77 77	40, 40, 40, 40, 40, 40 40, 40, 40, 40, 40, 40 40, 41, 40, 40, 40, 40
20-25	75, 85, 79, 90, 78, 73, 74, 7 75, 75, 79, 78, 78, 75, 76,75, 73, 74 75	42, 42, 41, 43, 42, 42 42, 42, 41, 42, 42, 42 42, 42, 42, 42, 40, 42
25-30	75, 75, 75, 75, 78, 75, 74, 75 75, 75, 75, 78, 78, 75, 75,75, 75 75	40, 40, 40, 40, 40, 40 40, 40, 40, 40, 40, 40 40, 41, 40, 40, 40, 40
30-35	79, 79, 79, 80, 80, 79, 79, 79, 79, 79, 80, 79, 80, 79, 79,79, 79 79	42, 42, 41, 43, 42, 42 42, 42, 41, 42, 42, 42 42, 42, 42, 42, 40, 42
35-40	81, 80, 80, 80, 80, 83, 82, 81, 81, 80, 80, 80, 80, 82, 83,82, 81 81	40, 40, 40, 40, 40, 40 40, 40, 40, 40, 40, 40 40, 41, 40, 40, 40, 40
40-45	76, 76, 77, 75, 78, 75, 77, 76 76, 76, 78, 78, 78, 75, 75,77, 78 76	42, 42, 41, 43, 42, 42 42, 42, 41, 42, 42, 42 42, 42, 42, 42, 40, 42
45-50	78, 80, 80, 80, 80, 83, 82, 80, 78, 80, 80, 80, 80, 82, 83,82, 80 78	39, 39, 38, 39, 39, 39 39, 39, 38, 39, 37, 39 39, 39, 39, 39, 39, 39
50-55	80, 78, 78, 80, 80, 83, 82, 78, 80, 78, 78, 80, 80, 82, 83,82, 78 80	40, 40, 40, 40, 40, 40 40, 40, 40, 40, 40, 40 40, 41, 40, 40, 40, 40
55-60	78, 79, 78, 77, 78, 76, 78, 78 78, 75, 75, 78, 78, 78, 78,78, 78 78	39, 39, 38, 39, 39, 39 39, 39, 38, 39, 37, 39 39, 39, 39, 39, 39, 39

SITE CODE EK009 DISTANCE 50M VEHICLE SPEED DATA

PERIOD	SECTION A TIME (Secs)	SECTION B TIME (Secs)
00-05	89, 89, 89, 87, 89, 86, 86, 89, 89, 86, 89, 88, 88, 89, 89,89, 89 89	35, 35, 35, 35, 35, 35 35, 35, 35, 35, 36, 35 35, 35, 35, 35, 35, 35
05-10	82, 82, 82, 82, 82, 82, 82, 82, 82, 82, 82, 78, 86, 82, 83,82, 82 82	35, 35, 35, 35, 35, 35 35, 35, 35, 35, 36, 35 35, 35, 35, 35, 35, 35
10-15	82, 82, 82, 82, 82, 82, 82, 82, 82, 82, 82, 78, 86, 82, 83,82, 82 82	35, 35, 35, 35, 35, 35 35, 35, 35, 35, 36, 35 35, 35, 35, 35, 35, 35
15-20	89, 89, 89, 87, 89, 86, 86, 89, 89, 86, 89, 88, 88, 89, 89,89, 89 89	36, 36, 36, 36, 36, 36 36, 36, 36, 36, 36, 36 36, 36, 36, 36, 36, 36
20-25	82, 82, 82, 82, 85, 82, 82, 82, 82, 82, 82, 82, 82, 83, 83,85, 82 82	39, 39, 39, 39, 39, 39 39, 39, 38, 39, 39, 39 39, 39, 38, 39, 39, 39
25-30	82, 82, 82, 82, 85, 82, 82, 82, 82, 82, 82, 82, 82, 83, 83,85, 82 82	39, 39, 39, 39, 39, 39 39, 39, 38, 39, 39, 39 39, 39, 38, 39, 39, 39
30-35	84, 84, 84, 85, 84, 84, 84, 84, 84, 84, 85, 88, 84, 85, 83,84, 84 84	36, 36, 36, 36, 36, 36 36, 36, 36, 36, 36, 36 36, 36, 36, 36, 36, 36
35-40	84, 84, 84, 85, 84, 84, 84, 84, 84, 84, 85, 88, 84, 85, 83,84, 84 84	36, 36, 36, 36, 36, 36 36, 36, 36, 36, 36, 36 36, 36, 36, 36, 36, 36
40-45	84, 84, 84, 85, 84, 84, 84, 84, 84, 84, 85, 88, 84, 85, 83,84, 84 84	36, 36, 36, 36, 36, 36 36, 36, 36, 36, 36, 36 36, 36, 36, 36, 36, 36
45-50	89, 89, 89, 87, 89, 86, 86, 89, 89, 86, 89, 88, 88, 89, 89,89, 89 89	36, 36, 36, 36, 36, 36 36, 36, 36, 36, 36, 36 36, 36, 36, 36, 36, 36
50-55	89, 89, 89, 87, 89, 86, 86, 89, 89, 86, 89, 88, 88, 89, 89,89, 89 89	40, 40, 40, 40, 40, 40 40, 40, 40, 40, 40, 40 40, 41, 40, 40, 40, 40
55-60	89, 89, 89, 87, 89, 86, 86, 89, 89, 86, 89, 88, 88, 89, 89,89, 89 89	40, 40, 40, 40, 40, 40 40, 40, 40, 40, 40, 40 40, 41, 40, 40, 40, 40

SITE CODE OG010 DISTANCE 50M VEHICLE SPEED DATA

PERIOD	SECTION A TIME (Secs)	SECTION B TIME (Secs)
00-05	106, 100, 106, 106, 100, 106, 106, 99, 106, 100, 100, 98, 108, 106, 99,109, 106	45, 45, 45, 44, 45, 45 45, 45, 45, 44, 46, 45 45, 45, 45, 45, 46, 45
05-10	90, 90, 90, 96, 90, 90, 90, 99, 91, 90, 90, 90, 95, 90, 90,90, 91 90	45, 45, 45, 44, 45, 45 45, 45, 45, 44, 46, 45 45, 45, 45, 45, 46, 45
10-15	100, 100, 100, 106, 100, 100, 100, 99, 101, 100, 100, 100, 108, 100, 100,100, 101	44, 44, 44, 44, 44, 44 44, 45, 45, 44, 44, 44 44, 45, 45, 45, 44, 44
15-20	100, 100, 100, 106, 100, 100, 100, 99, 101, 100, 100, 100, 108, 100, 100,100, 101	48, 48, 48, 46, 48, 48 48, 48, 48, 46, 48, 48 48, 48, 48, 48, 48, 48
20-25	95, 95, 95, 95, 95, 95, 96, 99, 95, 95, 95, 95, 95, 94, 95,95, 91 95	44, 44, 44, 44, 44, 44 44, 45, 45, 44, 44, 44 44, 45, 45, 45, 44, 44
25-30	106, 100, 106, 106, 100, 106, 106, 99, 106, 100, 100, 98, 108, 106, 99,109, 106	44, 44, 44, 44, 44, 44 44, 45, 45, 44, 44, 44 44, 45, 45, 45, 44, 44
30-35	99, 99, 99, 99, 98, 98, 98, 99, 99, 95, 99, 99, 99, 98, 99,99, 98 99	45, 45, 45, 44, 45, 45 45, 45, 45, 44, 46, 45 45, 45, 45, 45, 46, 45
35-40	90, 90, 90, 96, 90, 90, 90, 99, 91, 90, 90, 90, 95, 90, 90,90, 91 90	45, 45, 45, 44, 45, 45 45, 45, 45, 44, 46, 45 45, 45, 45, 45, 46, 45
40-45	90, 90, 90, 96, 90, 90, 90, 99, 91, 90, 90, 90, 95, 90, 90,90, 91 90	48, 48, 48, 46, 48, 48 48, 48, 48, 46, 48, 48 48, 48, 48, 48, 48, 48
45-50	95, 95, 95, 95, 95, 95, 96, 99, 95, 95, 95, 95, 95, 94, 95,95, 91 95	48, 48, 48, 46, 48, 48 48, 48, 48, 46, 48, 48 48, 48, 48, 48, 48, 48
50-55	90, 90, 90, 96, 90, 90, 90, 99, 91, 90, 90, 90, 95, 90, 90,90, 91 90	46, 46, 45, 46, 45, 46 46, 46, 45, 46, 46, 46 46, 46, 45, 46, 46, 46
55-60	90, 90, 90, 96, 90, 90, 90, 99, 91, 90, 90, 90, 95, 90, 90,90, 91 90	46, 46, 45, 46, 45, 46 46, 46, 45, 46, 46, 46 46, 46, 45, 46, 46, 46

SITE CODE OG011 DISTANCE 50M VEHICLE SPEED DATA

PERIOD	SECTION A TIME (Secs)	SECTION B TIME (Secs)
00-05	77, 70, 70, 77, 83, 81,72, 95, 77, 77, 77, 77, 77, 79, 77,78, 78 77	39, 39, 39, 39, 39, 39 39, 39, 39, 38, 39, 39 38, 39, 38, 38, 39, 39
05-10	75, 75, 75, 75, 73, 71,72, 75, 75, 75, 77, 75, 75, 75, 77,75, 77 75	39, 39, 39, 39, 39, 39 39, 39, 39, 38, 39, 39 38, 39, 38, 38, 39, 39
10-15	75, 75, 75, 75, 73, 71,72, 75, 75, 75, 77, 75, 75, 75, 77,75, 77 75	39, 39, 39, 39, 39, 39 39, 39, 39, 38, 39, 39 38, 39, 38, 38, 39, 39
15-20	75, 75, 75, 75, 73, 71,72, 75, 75, 75, 77, 75, 75, 75, 77,75, 77 75	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38
20-25	79, 79, 79, 79, 79, 79,78, 79, 79, 79, 79, 79, 75, 79, 79,78 79 79	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38
25-30	79, 79, 79, 79, 79, 79,78, 79, 79, 79, 79, 79, 75, 79, 79,78 79 79	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38
30-35	79, 79, 79, 79, 79, 79,78, 79, 79, 79, 79, 79, 75, 79, 79,78 79 79	39, 39, 39, 39, 39, 39 39, 39, 39, 38, 39, 39 38, 39, 38, 38, 39, 39
35-40	79, 79, 79, 79, 79, 79,78, 79, 79, 79, 79, 79, 75, 79, 79,78 79 79	39, 39, 39, 39, 39, 39 39, 39, 39, 38, 39, 39 38, 39, 38, 38, 39, 39
40-45	77, 70, 70, 77, 83, 81,72, 95, 77, 77, 77, 77, 77, 79, 77,78, 78 77	39, 39, 39, 39, 39, 39 39, 39, 39, 38, 39, 39 38, 39, 38, 38, 39, 39
45-50	77, 70, 70, 77, 83, 81,72, 95, 77, 77, 77, 77, 77, 79, 77,78, 78 77	39, 39, 39, 39, 39, 39 39, 39, 39, 38, 39, 39 38, 39, 38, 38, 39, 39
50-55	77, 70, 70, 77, 83, 81,72, 95, 77, 77, 77, 77, 77, 79, 77,78, 78 77	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38
55-60	77, 70, 70, 77, 83, 81,72, 95, 77, 77, 77, 77, 77, 79, 77,78, 78 77	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38

SITE CODE OG012 DISTANCE 50M VEHICLE SPEED DATA

PERIOD	SECTION A TIME (Secs)	SECTION B TIME (Secs)
00-05	85, 85, 85, 85, 83, 85, 84, 85, 85, 85, 85, 85, 83, 85, 85,85, 85 85	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38
05-10	85, 85, 85, 85, 83, 85, 84, 85, 85, 85, 85, 85, 83, 85, 85,85, 85 85	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38
10-15	85, 85, 85, 85, 83, 85, 84, 85, 85, 85, 85, 85, 83, 85, 85,85, 85 85	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38
15-20	80, 80, 80, 80, 80, 83, 82, 80, 80, 80, 80, 80, 80, 82, 83,82, 80 80	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38
20-25	85, 85, 85, 85, 83, 85, 84, 85, 85, 85, 85, 85, 83, 85, 85,85, 85 85	39, 39, 39, 39, 39, 39 39, 39, 39, 38, 39, 39 38, 39, 38, 38, 39, 39
25-30	85, 85, 85, 85, 83, 85, 84, 85, 85, 85, 85, 85, 83, 85, 85,85, 85 85	36, 36, 36, 36, 36, 36 36, 36, 36, 36, 36, 36 36, 37, 36, 36, 36, 36
30-35	85, 85, 85, 85, 85, 85, 82, 85, 85, 85, 85, 85, 85, 85, 83,82, 85 85	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38
35-40	84, 84, 84, 85, 84, 84, 84, 84, 84, 84, 85, 88, 84, 85, 83,84, 84 84	39, 39, 39, 39, 39, 39 39, 39, 39, 38, 39, 39 38, 39, 38, 38, 39, 39
40-45	86, 89, 89, 87, 89, 86, 86, 89, 86, 86, 89, 88, 88, 89, 89,89, 89 86	39, 39, 39, 39, 39, 39 39, 39, 39, 38, 39, 39 38, 39, 38, 38, 39, 39
45-50	87, 89, 89, 87, 89, 86, 86, 89, 87, 86, 89, 88, 88, 89, 89,89, 89 87	37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37
50-55	85, 85, 85, 85, 83, 85, 84, 85, 85, 85, 85, 85, 83, 85, 85,85, 85 85	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38
55-60	85, 85, 85, 85, 83, 85, 84, 85, 85, 85, 85, 85, 83, 85, 85,85, 85 85	37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37

SITE CODE OS013 DISTANCE 50M VEHICLE SPEED DATA

PERIOD	SECTION A TIME (Secs)	SECTION B TIME (Secs)
00-05	89, 89, 89, 87, 89, 86, 86, 89, 89, 86, 89, 88, 88, 89, 89,89, 89 89	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38
05-10	86, 89, 89, 87, 89, 86, 86, 89, 86, 86, 89, 88, 88, 89, 89,89, 89 86	39, 39, 39, 39, 39, 39 39, 39, 39, 38, 39, 39 38, 39, 38, 38, 39, 39
10-15	87, 89, 89, 87, 89, 86, 86, 89, 87, 86, 89, 88, 88, 89, 89,89, 89 87	39, 39, 39, 39, 39, 39 39, 39, 39, 38, 39, 39 38, 39, 38, 38, 39, 39
15-20	89, 89, 89, 87, 89, 86, 86, 89, 89, 86, 89, 88, 88, 89, 89,89, 89 89	37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37
20-25	89, 89, 89, 87, 89, 86, 86, 89, 89, 86, 89, 88, 88, 89, 89,89, 89 89	39, 39, 39, 39, 39, 39 39, 39, 39, 38, 39, 39 38, 39, 38, 38, 39, 39
25-30	85, 85, 85, 85, 83, 85, 84, 85, 85, 85, 85, 85, 83, 85, 85,85, 85 85	39, 39, 39, 39, 39, 39 39, 39, 39, 38, 39, 39 38, 39, 38, 38, 39, 39
30-35	85, 85, 85, 85, 85, 85, 82, 85, 85, 85, 85, 85, 85, 85, 83,82, 85 85	37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37
35-40	84, 84, 84, 85, 84, 84, 84, 84, 84, 84, 85, 88, 84, 85, 83,84, 84 84	37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37
40-45	86, 89, 89, 87, 89, 86, 86, 89, 86, 86, 89, 88, 88, 89, 89,89, 89 86	39, 39, 39, 39, 39, 39 39, 39, 39, 38, 39, 39 38, 39, 38, 38, 39, 39
45-50	87, 89, 89, 87, 89, 86, 86, 89, 87, 86, 89, 88, 88, 89, 89,89, 89 87	39, 39, 39, 39, 39, 39 39, 39, 39, 38, 39, 39 38, 39, 38, 38, 39, 39
50-55	90, 90, 90, 96, 90, 90, 90, 99, 91, 90, 90, 90, 95, 90, 90,90, 91 90	39, 39, 39, 39, 39, 39 39, 39, 39, 38, 39, 39 38, 39, 38, 38, 39, 39
55-60	89, 89, 89, 87, 89, 86, 86, 89, 89, 86, 89, 88, 88, 89, 89,89, 89 89	39, 39, 39, 39, 39, 39 39, 39, 39, 38, 39, 39 38, 39, 38, 38, 39, 39

SITE CODE OS015 DISTANCE 50M VEHICLE SPEED DATA

PERIOD	SECTION A TIME (Secs)	SECTION B TIME (Secs)
00-05	86, 89, 89, 87, 89, 86, 86, 89, 86, 86, 89, 88, 88, 89, 89,89, 89 86	36, 36, 36, 36, 36, 37 36, 36, 36, 37, 38, 36 36, 36, 36, 37, 36, 36
05-10	87, 89, 89, 87, 89, 86, 86, 89, 87, 86, 89, 88, 88, 89, 89,89, 89 87	37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37
10-15	89, 89, 89, 87, 89, 86, 86, 89, 89, 86, 89, 88, 88, 89, 89,89, 89 89	37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37
15-20	86, 89, 89, 87, 89, 86, 86, 89, 86, 86, 89, 88, 88, 89, 89,89, 89 86	35, 35, 35, 35, 35, 35 35, 35, 35, 36, 36, 35 35, 35, 35, 36, 36, 35
20-25	87, 89, 89, 87, 89, 86, 86, 89, 87, 86, 89, 88, 88, 89, 89,89, 89 87	36, 36, 36, 36, 36, 37 36, 36, 36, 37, 38, 36 36, 36, 36, 37, 36, 36
25-30	87, 89, 89, 87, 89, 86, 86, 89, 87, 86, 89, 88, 88, 89, 89,89, 89 87	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38
30-35	89, 89, 89, 87, 89, 86, 86, 89, 89, 86, 89, 88, 88, 89, 89,89, 89 89	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38
35-40	86, 89, 89, 87, 89, 86, 86, 89, 86, 86, 89, 88, 88, 89, 89,89, 89 86	37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37
40-45	87, 89, 89, 87, 89, 86, 86, 89, 87, 86, 89, 88, 88, 89, 89,89, 89 87	36, 36, 36, 36, 36, 37 36, 36, 36, 37, 38, 36 36, 36, 36, 37, 36, 36
45-50	87, 89, 89, 87, 89, 86, 86, 89, 87, 86, 89, 88, 88, 89, 89,89, 89 87	37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37
50-55	86, 89, 86, 86, 86, 86, 86, 86, 86, 86, 86, 86, 88, 87, 87,87, 88 86	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38
55-60	88, 89, 89, 87, 88, 86, 86, 89, 88, 86, 89, 88, 88, 89, 88,89, 89 88	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38

SITE CODE OY018 DISTANCE 50M VEHICLE SPEED DATA

PERIOD	SECTION A TIME (Secs)	SECTION B TIME (Secs)
00-05	87, 89, 89, 87, 89, 86, 86, 89, 87, 86, 89, 88, 88, 89, 89,89, 89 87	48, 48, 48, 46, 48, 48 48, 48, 48, 46, 48, 48 48, 48, 48, 48, 48, 48
05-10	87, 89, 89, 87, 89, 86, 86, 89, 87, 86, 89, 88, 88, 89, 89,89, 89 87	48, 48, 48, 48, 48, 48 48, 48, 47, 47, 48, 48 48, 48, 48, 47, 48, 48
10-15	88, 89, 89, 87, 88, 86, 86, 89, 88, 86, 89, 88, 88, 89, 88,89, 89 88	48, 48, 48, 46, 48, 48 48, 48, 48, 46, 48, 48 48, 48, 48, 48, 48, 48
15-20	88, 89, 89, 87, 88, 86, 86, 89, 88, 86, 89, 88, 88, 89, 88,89, 89 88	45, 45, 45, 45, 45, 45 45, 45, 45, 46, 45, 45 45, 45, 45, 45, 45, 45
20-25	86, 89, 89, 87, 89, 86, 86, 89, 86, 86, 89, 88, 88, 89, 89,89, 89 86	46, 46, 45, 46, 45, 46 46, 46, 45, 46, 46, 46 46, 46, 45, 46, 46, 46
25-30	87, 89, 89, 87, 89, 86, 86, 89, 87, 86, 89, 88, 88, 89, 89,89, 89 87	47, 47, 46, 47, 47, 47 47, 47, 47, 47, 48, 47 47, 47, 46, 48, 48, 47
30-35	86, 89, 89, 87, 89, 86, 86, 89, 86, 86, 89, 88, 88, 89, 89,89, 89 86	46, 46, 45, 46, 45, 46 46, 46, 45, 46, 46, 46 46, 46, 45, 46, 46, 46
35-40	87, 89, 89, 87, 88, 86, 86, 87, 87, 86, 89, 88, 88, 87, 87,87, 88 87	46, 46, 45, 46, 45, 46 46, 46, 45, 46, 46, 46 46, 46, 45, 46, 46, 46
40-45	87, 89, 89, 87, 89, 86, 86, 87, 87, 86, 89, 88, 88, 89, 89,89, 87 87	48, 47, 48, 48, 48, 48 48, 48, 48, 48, 47, 48 49, 48, 48, 47, 48, 48
45-50	89, 89, 88, 87, 88, 86, 86, 88, 87, 86, 88, 88, 88, 88, 88,87, 87 85	49, 49, 48, 49, 49, 49 49, 49, 49, 49, 49, 49 49, 49, 49, 49, 49, 49
50-55	85, 85, 87, 87, 85, 86, 86, 89, 85, 85, 86, 86, 88, 85, 85,85, 87 85	48, 48, 48, 46, 48, 48 48, 48, 48, 46, 48, 48 48, 48, 48, 48, 48, 48
55-60	87, 89, 89, 87, 89, 86, 86, 89, 87, 86, 89, 88, 88, 89, 89,89, 89 87	48, 48, 48, 46, 48, 48 48, 48, 48, 46, 48, 48 48, 48, 48, 48, 48, 48

SITE CODE OY019 DISTANCE 50M VEHICLE SPEED DATA

PERIOD	SECTION A TIME (Secs)	SECTION B TIME (Secs)
00-05	87, 89, 89, 87, 88, 86, 86, 87, 87, 86, 89, 88, 88, 87, 87,87, 88 87	36, 36, 36, 36, 36, 37 36, 36, 36, 37, 38, 36 36, 36, 36, 37, 36, 36
05-10	87, 89, 89, 87, 89, 86, 86, 87, 87, 86, 89, 88, 88, 89, 89,89, 87 87	36, 36, 36, 36, 36, 37 36, 36, 36, 37, 38, 36 36, 36, 36, 37, 36, 36
10-15	89, 89, 88, 87, 88, 86, 86, 88, 87, 86, 88, 88, 88, 88, 88,87, 87 85	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38
15-20	85, 85, 87, 87, 85, 86, 86, 89, 85, 85, 86, 86, 88, 85, 85,85, 87 85	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38
20-25	87, 89, 89, 87, 89, 86, 86, 89, 87, 86, 89, 88, 88, 89, 89,89, 89 87	37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37
25-30	86, 89, 89, 87, 89, 86, 86, 89, 86, 86, 89, 88, 88, 89, 89,89, 89 86	36, 36, 36, 36, 36, 37 36, 36, 36, 37, 38, 36 36, 36, 36, 37, 36, 36
30-35	87, 89, 85, 87, 85, 85, 86, 86, 87, 86, 85, 85, 85, 89, 86,85, 86 87	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38
35-40	86, 89, 85, 87, 89, 86, 86, 86, 86, 86, 84, 88, 84, 85, 85,86, 86 86	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38
40-45	86, 89, 89, 87, 89, 86, 86, 86, 86, 86, 89, 88, 88, 88, 88,89, 86 86	39, 39, 39, 39, 39, 39 39, 39, 39, 39, 39, 39 39, 39, 39, 39, 39, 39
45-50	87, 89, 89, 87, 88, 86, 86, 87, 87, 86, 89, 88, 88, 88, 89,89, 87 87	38, 38, 39, 39, 38, 38 38, 38, 39, 38, 39, 38 38, 38, 38, 38, 39, 38
50-55	88, 88, 88, 85, 89, 86, 86, 88, 88, 86, 89, 88, 88, 89, 89,89, 87 87	37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37
55-60	87, 87, 87, 87, 87, 86, 86, 87, 87, 87, 87, 88, 88, 87, 89,89, 87 87	37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37 37, 37, 37, 37, 37, 37

APPENDIX - D

VOLUME DATA

SITE CODE AN001

PERIOD	SECTION A PC	SECTION A LGV	SECTION A HGV
00-05	28	29	07
05-10	24	26	07
10-15	17	18	05
15-20	23	24	07
20-25	31	33	10
25-30	17	18	05
30-35	19	21	06
35-40	22	24	07
40-45	26	27	08
45-50	17	18	05
50-55	24	26	07
55-60	32	35	10

VOLUME DATA

SITE CODE AN001

PERIOD	SECTION B PC	SECTION B LGV	SECTION B HGV
00-05	22	23	07
05-10	17	18	05
10-15	13	14	04
15-20	20	21	06
20-25	18	19	06
25-30	18	20	06
30-35	19	20	06
35-40	19	21	07
40-45	21	23	05
45-50	15	16	06
50-55	18	19	06
55-60	17	18	05

VOLUME DATA

SITE CODE DL002

PERIOD	SECTION A PC	SECTION A LGV	SECTION A HGV
00-05	14	15	01
05-10	13	14	01
10-15	18	19	01
15-20	18	19	01
20-25	16	16	01
25-30	18	18	02
30-35	18	18	01
35-40	20	21	01
40-45	22	23	01
45-50	17	18	01
50-55	20	21	01
55-60	18	18	01

VOLUME DATA

SITE CODE DL002

PERIOD	SECTION B PC	SECTION B LGV	SECTION B HGV
00-05	14	15	01
05-10	13	14	01
10-15	18	19	01
15-20	23	24	01
20-25	16	16	01
25-30	23	23	02
30-35	18	18	01
35-40	25	25	01
40-45	22	23	01
45-50	18	19	01
50-55	22	23	01
55-60	18	18	01

VOLUME DATA

SITE CODE DL003

PERIOD	SECTION A PC	SECTION A LGV	SECTION A HGV
00-05	41	05	03
05-10	37	05	03
10-15	33	04	02
15-20	39	05	03
20-25	32	04	02
25-30	36	05	03
30-35	26	03	02
35-40	33	04	02
40-45	37	05	03
45-50	27	04	02
50-55	34	05	02
55-60	27	04	02

VOLUME DATA

SITE CODE DL003

PERIOD	SECTION B PC	SECTION B LGV	SECTION B HGV
00-05	35	05	03
05-10	33	04	03
10-15	36	05	02
15-20	32	04	03
20-25	28	04	02
25-30	32	05	03
30-35	27	03	02
35-40	27	04	02
40-45	26	03	03
45-50	37	04	02
50-55	27	05	02
55-60	32	04	02

VOLUME DATA

SITE CODE DL004

PERIOD	SECTION A PC	SECTION A LGV	SECTION A HGV
00-05	33	05	03
05-10	31	05	03
10-15	36	04	02
15-20	43	04	02
20-25	37	04	02
25-30	37	05	03
30-35	31	06	03
35-40	46	05	03
40-45	30	05	03
45-50	30	04	02
50-55	32	06	02
55-60	32	04	02

VOLUME DATA

SITE CODE DL004

PERIOD	SECTION B PC	SECTION B LGV	SECTION B HGV
00-05	25	03	02
05-10	22	03	02
10-15	28	04	02
15-20	35	05	03
20-25	29	04	02
25-30	29	04	02
30-35	22	03	02
35-40	37	05	03
40-45	22	03	02
45-50	30	04	02
50-55	32	04	02
55-60	32	04	02

VOLUME DATA

SITE CODE DL005

PERIOD	SECTION A PC	SECTION A LGV	SECTION A HGV
00-05	33	01	01
05-10	48	01	01
10-15	46	02	01
15-20	32	02	0
20-25	36	01	0
25-30	33	02	0
30-35	44	01	0
35-40	37	02	01
40-45	30	01	0
45-50	43	01	0
50-55	38	02	0
55-60	45	02	0

VOLUME DATA

SITE CODE DL005

PERIOD	SECTION B PC	SECTION B LGV	SECTION B HGV
00-05	31	01	01
05-10	40	01	01
10-15	42	02	01
15-20	31	02	0
20-25	38	01	0
25-30	33	02	0
30-35	37	01	0
35-40	50	02	01
40-45	33	01	0
45-50	32	01	0
50-55	38	02	0
55-60	38	02	0

VOLUME DATA

SITE CODE ED006

PERIOD	SECTION A PC	SECTION A LGV	SECTION A HGV
00-05	21	27	03
05-10	24	30	03
10-15	26	32	03
15-20	27	34	03
20-25	27	34	03
25-30	21	27	03
30-35	28	36	03
35-40	23	29	03
40-45	30	38	04
45-50	26	32	02
50-55	15	19	02
55-60	16	20	02

VOLUME DATA

SITE CODE ED006

PERIOD	SECTION B PC	SECTION B LGV	SECTION B HGV
00-05	20	27	03
05-10	17	25	03
10-15	26	22	02
15-20	24	33	03
20-25	18	23	03
25-30	24	30	03
30-35	19	24	03
35-40	24	30	03
40-45	23	29	02
45-50	21	27	02
50-55	16	20	02
55-60	17	21	02

VOLUME DATA

SITE CODE ED007

PERIOD	SECTION A PC	SECTION A LGV	SECTION A HGV
00-05	19	24	02
05-10	12	15	01
10-15	21	27	03
15-20	24	30	03
20-25	14	17	02
25-30	21	27	03
30-35	16	21	02
35-40	18	23	02
40-45	16	21	02
45-50	18	23	02
50-55	19	24	02
55-60	24	31	03

VOLUME DATA

SITE CODE ED007

PERIOD	SECTION B PC	SECTION B LGV	SECTION B HGV
00-05	16	20	02
05-10	11	13	01
10-15	13	17	02
15-20	16	21	02
20-25	13	16	02
25-30	20	25	02
30-35	10	12	01
35-40	16	21	02
40-45	12	15	01
45-50	21	26	02
50-55	16	21	02
55-60	15	19	02

VOLUME DATA

SITE CODE ED008

PERIOD	SECTION A PC	SECTION A LGV	SECTION A HGV
00-05	20	23	02
05-10	20	23	02
10-15	21	24	02
15-20	15	17	02
20-25	23	27	03
25-30	18	20	02
30-35	21	24	02
35-40	12	14	01
40-45	20	23	02
45-50	24	28	03
50-55	22	25	02
55-60	17	20	02

VOLUME DATA

SITE CODE ED008

PERIOD	SECTION B PC	SECTION B LGV	SECTION B HGV
00-05	16	18	02
05-10	15	18	02
10-15	12	14	01
15-20	15	17	02
20-25	09	11	01
25-30	16	19	02
30-35	19	22	02
35-40	08	10	01
40-45	17	19	02
45-50	17	20	02
50-55	13	15	01
55-60	15	18	02

VOLUME DATA

SITE CODE EK009

PERIOD	SECTION A PC	SECTION A LGV	SECTION A HGV
00-05	25	29	02
05-10	27	31	02
10-15	29	34	02
15-20	23	26	02
20-25	18	21	01
25-30	19	22	01
30-35	31	35	02
35-40	24	28	02
40-45	18	21	01
45-50	19	22	01
50-55	20	23	01
55-60	24	28	02

VOLUME DATA

SITE CODE EK009

PERIOD	SECTION B PC	SECTION B LGV	SECTION B HGV
00-05	23	26	02
05-10	22	25	01
10-15	22	25	01
15-20	24	28	02
20-25	17	20	01
25-30	14	16	01
30-35	27	31	02
35-40	25	29	02
40-45	14	16	01
45-50	19	22	01
50-55	19	22	01
55-60	22	25	01

VOLUME DATA

SITE CODE OG011

PERIOD	SECTION A PC	SECTION A LGV	SECTION A HGV
00-05	50	01	02
05-10	50	03	02
10-15	52	00	02
15-20	53	00	02
20-25	55	04	02
25-30	51	02	02
30-35	51	02	02
35-40	53	02	02
40-45	55	02	02
45-50	41	02	01
50-55	40	02	01
55-60	44	02	01

VOLUME DATA

SITE CODE OG011

PERIOD	SECTION B PC	SECTION B LGV	SECTION B HGV
00-05	43	01	02
05-10	47	03	02
10-15	37	00	02
15-20	45	00	02
20-25	48	04	02
25-30	56	02	02
30-35	42	02	02
35-40	47	02	02
40-45	37	02	02
45-50	33	02	01
50-55	37	02	01
55-60	29	02	01

VOLUME DATA

SITE CODE OG011

PERIOD	SECTION A PC	SECTION A LGV	SECTION A HGV
00-05	23	10	04
05-10	32	14	05
10-15	25	11	04
15-20	29	13	05
20-25	34	15	06
25-30	43	20	07
30-35	22	10	04
35-40	25	11	04
40-45	21	10	03
45-50	24	11	04
50-55	17	08	03
55-60	2	10	04

VOLUME DATA

SITE CODE OG011

PERIOD	SECTION B PC	SECTION B LGV	SECTION B HGV
00-05	19	08	03
05-10	19	08	03
10-15	18	08	03
15-20	25	11	04
20-25	25	11	04
25-30	28	13	05
30-35	18	08	03
35-40	19	09	03
40-45	19	09	03
45-50	24	11	04
50-55	24	11	04
55-60	418	08	03

VOLUME DATA

SITE CODE OG012

PERIOD	SECTION A PC	SECTION A LGV	SECTION A HGV
00-05	33	06	06
05-10	37	07	07
10-15	36	07	02
15-20	35	07	09
20-25	37	07	00
25-30	43	08	07
30-35	29	06	06
35-40	30	06	02
40-45	25	05	09
45-50	29	06	06
50-55	15	03	03
55-60	31	06	06

VOLUME DATA

SITE CODE OG012

PERIOD	SECTION B PC	SECTION B LGV	SECTION B HGV
00-05	28	05	05
05-10	25	05	05
10-15	22	04	04
15-20	29	06	06
20-25	27	05	05
25-30	26	05	05
30-35	28	05	05
35-40	22	04	04
40-45	20	04	04
45-50	30	06	06
50-55	21	04	04
55-60	32	06	06

VOLUME DATA

SITE CODE OS013

PERIOD	SECTION A PC	SECTION A LGV	SECTION A HGV
00-05	18	28	01
05-10	16	26	02
10-15	14	23	0
15-20	17	26	01
20-25	16	26	01
25-30	13	20	01
30-35	22	34	01
35-40	22	34	01
40-45	13	21	02
45-50	19	30	0
50-55	21	33	01
55-60	17	26	01

VOLUME DATA

SITE CODE OS013

PERIOD	SECTION B PC	SECTION B LGV	SECTION B HGV
00-05	17	26	01
05-10	15	24	02
10-15	12	19	0
15-20	16	25	01
20-25	15	23	01
25-30	13	21	01
30-35	14	23	01
35-40	14	22	01
40-45	15	23	02
45-50	13	20	0
50-55	13	20	01
55-60	15	24	01

VOLUME DATA

SITE CODE OS015

PERIOD	SECTION A PC	SECTION A LGV	SECTION A HGV
00-05	36	17	02
05-10	31	15	02
10-15	20	10	01
15-20	29	14	01
20-25	42	20	02
25-30	20	09	03
30-35	23	11	01
35-40	28	13	01
40-45	33	16	02
45-50	20	10	02
50-55	31	15	01
55-60	22	11	01

VOLUME DATA

SITE CODE OS015

PERIOD	SECTION B PC	SECTION B LGV	SECTION B HGV
00-05	29	14	02
05-10	27	13	02
10-15	20	09	01
15-20	27	13	02
20-25	32	15	02
25-30	25	12	02
30-35	23	11	01
35-40	25	12	02
40-45	25	12	02
45-50	27	13	02
50-55	23	11	01
55-60	24	11	01

VOLUME DATA

SITE CODE OY018

PERIOD	SECTION A PC	SECTION A LGV	SECTION A HGV
00-05	42	11	04
05-10	38	10	04
10-15	46	08	05
15-20	38	10	03
20-25	37	09	04
25-30	40	08	04
30-35	39	09	04
35-40	38	09	04
40-45	41	09	03
45-50	37	08	04
50-55	35	08	04
55-60	34	08	03

VOLUME DATA

SITE CODE OY018

PERIOD	SECTION B PC	SECTION B LGV	SECTION B HGV
00-05	35	11	04
05-10	38	10	04
10-15	43	08	05
15-20	30	10	03
20-25	33	09	04
25-30	36	08	04
30-35	37	08	04
35-40	35	08	04
40-45	38	09	03
45-50	33	07	04
50-55	37	08	04
55-60	32	07	03

VOLUME DATA

SITE CODE OY019

PERIOD	SECTION A PC	SECTION A LGV	SECTION A HGV
00-05	38	19	05
05-10	40	20	05
10-15	36	18	05
15-20	29	15	05
20-25	30	15	04
25-30	32	16	04
30-35	32	16	04
35-40	34	17	04
40-45	26	13	03
45-50	28	14	04
50-55	27	14	04
55-60	29	15	04

VOLUME DATA

SITE CODE OY019

PERIOD	SECTION B PC	SECTION B LGV	SECTION B HGV
00-05	29	15	04
05-10	34	17	04
10-15	34	17	05
15-20	37	19	05
20-25	35	18	06
25-30	31	16	04
30-35	41	21	04
35-40	43	22	05
40-45	39	20	04
45-50	40	20	04
50-55	40	20	04
55-60	34	17	03

Table 7.02a Flows and Densities for Road DL004 Section A

PC	*LGVs*	HGVs	LGVs *1.3	HGVs * 1.7	Flow/5 min	Flow/hr	Speed	Density
40	4	2	5.2	3.4	48.6	583.2	80	7.29
37	4	2	5.2	3.4	45.6	547.2	82	6.67
43	5	3	6.5	5.1	54.6	655.2	79	8.29
52	6	3	7.8	5.1	64.9	778.8	81	9.61
45	5	3	6.5	5.1	56.6	679.2	85	7.99
45	5	3	6.5	5.1	56.6	679.2	88	7.72
37	4	2	5.2	3.4	45.6	547.2	79	6.93
55	6	3	7.8	5.1	67.9	814.8	93	8.76
36	4	2	5.2	3.4	44.6	535.2	86	6.22
36	4	2	5.2	3.4	44.6	535.2	78	6.86
38	4	2	5.2	3.4	46.6	559.2	85	6.58
38	4	2	5.2	3.4	46.6	559.2	85	6.58
502	55	29				1650		29.46

Source: Survey

Table 7.02b Computed Flows and Densities for Road DL004 Section B

PC	*LGVs*	HGVs	LGVs*1	HGVs*1	Flow/5 min	Flow/Hr	Speed	Density
25	3	2	3	2	30	360	42	8.57
22	3	2	3	2	27	324	42	7.71
28	4	2	4	2	34	408	42	9.71
35	5	3	5	3	43	516	40	12.90
29	4	2	4	2	35	420	40	10.50
29	4	2	4	2	35	420	39	10.77
22	3	2	3	2	27	324	38	8.53
37	5	3	5	3	45	540	40	13.50
22	3	2	3	2	27	324	42	7.71
30	4	2	4	2	36	432	42	10.29
32	4	2	4	2	38	456	42	10.86
32	4	2	4	2	38	456	42	10.86
343	46	26				1007		40.56

Source: Survey **Note:** Traffic Composition (PC) 83% (LGV) 10% (HGV) 07%

Table 7.03a Computed Flows and Densities for Road DL005 Section A

PC	*LGVs*	HGVs	LGVs*1.3	HGVs * 1.7	Flow/5 min	Flow/ Hr	Speed	Density
33	1	1	1.3	1.7	36	432	82	5.27
48	2	1	2.6	1.7	52.3	627.6	82	7.65
46	2	0	2.6	0	48.6	583.2	90	6.48
32	1	1	1.3	1.7	35	420	90	4.67
36	2	0	2.6	0	38.6	463.2	89	5.20
33	1	1	1.3	1.7	36	432	89	4.85
44	2	0	2.6	0	46.6	559.2	85	6.58
37	2	0	2.6	0	39.6	475.2	90	5.28
30	1	1	1.3	1.7	33	396	89	4.45
43	2	0	2.6	0	45.6	547.2	85	6.44
38	2	0	2.6	0	40.6	487.2	83	5.87
45	2	0	2.6	0	47.6	571.2	83	6.88
465	20	5				1065		20.91

Source: Survey

Table 7.03b Computed Flows and Densities for Road DL005 Section B

PC	*LGVs*	HGVs	LGVs*1	HGVs*1	Flow/5 min	Flow/ Hr	Speed	Density
31	1	1	1	1	33	396	39	10.15
40	2	1	2	1	43	516	40	12.90
42	2	0	2	0	44	528	40	13.20
31	1	1	1	1	33	396	40	9.90
38	2	0	2	0	40	480	41	11.71
33	1	1	1	1	35	420	40	10.50
37	2	0	2	0	39	468	38	12.32
50	2	0	2	0	52	624	38	16.42
33	1	1	1	1	35	420	39	10.77
32	1	0	1	0	33	396	39	10.15
38	2	0	2	0	40	480	39	12.31
38	2	0	2	0	40	480	39	12.31
443	19	5				856		31.92

Source: Survey **Note:** Traffic Composition (PC) 95% (LGV) 04% (HGV) 01%

Table 7.04a Computed Flows and Densities for Road ED006 Section A

PC	*LGVs*	HGVs	LGVs* 1.3	HGVs* 1.7	Flow/5 min	Flow/Hr	Speed	Density
21	27	3	35.1	5.1	61.2	734.4	89	8.25
24	30	3	39	5.1	68.1	817.2	80	10.22
26	32	3	41.6	5.1	72.7	872.4	85	10.26
27	34	3	44.2	5.1	76.3	915.6	80	11.45
27	34	3	44.2	5.1	76.3	915.6	80	11.45
21	27	3	35.1	5.1	61.2	734.4	85	8.64
28	36	3	46.8	5.1	79.9	958.8	85	11.28
23	29	3	37.7	5.1	65.8	789.6	86	9.18
30	38	4	49.4	6.8	86.2	1034.4	83	12.46
26	32	3	41.6	5.1	72.7	872.4	86	10.14
15	19	2	24.7	3.4	43.1	517.2	86	6.01
16	20	2	26	3.4	45.4	544.8	85	6.41
284	358	35				1504		28.09

Source: Survey

Table 7.04b Computed Flows and Densities for Road ED006 Section B

PC	*LGVs*	HGVs	LGVs*1	HGVs* 1	Flow/5 min	Flow/Hr	Speed	Density
20	25	2	25	2	47	564	39	14.46
17	22	2	22	2	41	492	37	13.30
26	33	3	33	3	62	744	39	19.08
24	30	3	30	3	57	684	37	18.49
18	23	2	23	2	43	516	39	13.23
24	30	3	30	3	57	684	39	17.54
19	24	2	24	2	45	540	40	13.50
24	30	3	30	3	57	684	40	17.10
23	29	3	29	3	55	660	40	16.50
21	27	3	27	3	51	612	39	15.69
15	20	2	20	2	37	444	39	11.38
17	21	2	21	2	40	480	40	12.00
248	314	30				1121		42.79

Source: Survey **Note:** Traffic Composition (PC) 45% (LGV) 50% (HGV) 05%

Table 7.05a Computed Flows and Densities for Road ED007 Section A

PC	*LGVs*	HGVs	LGVs* 1.3	HGVs* 1.7	Flow/5 min	Flow/ Hr	Speed	Density
19	24	2	31.2	3.4	53.6	643.2	80	8.04
12	15	1	19.5	1.7	33.2	398.4	79	5.04
21	27	3	35.1	5.1	61.2	734.4	86	8.54
24	30	3	39	5.1	68.1	817.2	79	10.34
14	17	2	22.1	3.4	39.5	474	83	5.71
21	27	3	35.1	5.1	61.2	734.4	80	9.18
16	21	2	27.3	3.4	46.7	560.4	84	6.67
18	23	2	29.9	3.4	51.3	615.6	86	7.16
16	21	2	27.3	3.4	46.7	560.4	80	7.01
18	23	2	29.9	3.4	51.3	615.6	78	7.89
19	24	2	31.2	3.4	53.6	643.2	79	8.14
24	31	3	40.3	5.1	69.4	832.8	80	10.41
222	283	27				1387		27.10

Source: Survey

Table 7.05b Computed Flows and Densities for Road ED007 Section B

PC	*LGVs*	HGVs	LGVs*1	HGVs * 1	Flow/5 min	Flow/ Hr	Speed	Density
16	20	2	20	2	38	456	36	12.67
11	13	1	13	1	25	300	38	7.89
13	17	2	17	2	32	384	43	8.93
16	21	2	21	2	39	468	45	10.40
13	16	2	16	2	31	372	44	8.45
20	25	2	25	2	47	564	40	14.10
10	12	1	12	1	23	276	44	6.27
16	21	2	21	2	39	468	44	10.64
12	15	1	15	1	28	336	43	7.81
21	26	2	26	2	49	588	40	14.70
16	21	2	21	2	39	468	40	11.70
15	19	2	19	2	36	432	39	11.08
179	226	21				1034	23.27	44.43

Source: Survey **Note:** Traffic Composition (PC) 42% (LGV) 53% (HGV) 05%

Table 7.06a Computed Flows and Densities for Road ED008 Section A

PC	*LGVs*	HGVs	LGVs* 1.3	HGVs* 1.7	Flow/5 min	Flow/ Hr	Speed	Density
20	23	2	29.9	3.4	53.3	639.6	90	7.11
20	23	2	29.9	3.4	53.3	639.6	89	7.19
21	24	2	31.2	3.4	55.6	667.2	88	7.58
15	17	2	22.1	3.4	40.5	486.0	87	5.59
23	27	3	35.1	5.1	63.2	758.4	85	8.92
18	20	2	26	3.4	47.4	568.8	85	6.69
21	24	2	31.2	3.4	55.6	667.2	80	8.34
12	14	1	18.2	1.7	31.9	382.8	85	4.50
20	23	2	29.9	3.4	53.3	639.6	85	7.52
24	28	3	36.4	5.1	65.5	786.0	85	9.25
22	25	2	32.5	3.4	57.9	694.8	83	8.37
17	20	2	26	3.4	46.4	556.8	80	6.96
233	268	25				1523		29.74

Source: Survey

Table 7.06b Computed Flows and Densities for Road ED008 Section B

PC	*LGVs*	HGVs	LGVs*1	HGVs * 1	Flow/5 min	Flow/ Hr	Speed	Density
16	18	2	18	2	36	432	36	12.00
15	18	2	18	2	35	420	39	10.77
12	14	1	14	1	27	324	40	8.10
15	17	2	17	2	34	408	40	10.20
9	11	1	11	1	21	252	43	5.86
16	19	2	19	2	37	444	43	10.33
19	22	2	22	2	43	516	40	12.90
8	10	1	10	1	19	228	43	5.30
17	19	2	19	2	38	456	43	10.60
17	20	2	20	2	39	468	39	12.00
13	15	1	15	1	29	348	40	8.70
15	18	2	18	2	35	420	39	10.77
172	201	20				895		38.36

Source: Survey **Note:** Traffic Composition (PC) 44% (LGV) 51% (HGV) 05%

Table 7.07a Computed Flows and Densities for Road EK009 Section A

PC	*LGVs*	HGVs	LGVs* 1.3	HGVs* 1.7	Flow/5 min	Flow/ Hr	Speed	Density
25	29	2	37.7	3.4	66.1	793.2	89	8.91
27	31	2	40.3	3.4	70.7	848.4	89	9.53
29	34	2	44.2	3.4	76.6	919.2	85	10.81
23	26	2	33.8	3.4	60.2	722.4	85	8.50
18	21	1	27.3	1.7	47	564	85	6.64
19	22	1	28.6	1.7	49.3	591.6	95	6.23
31	35	2	45.5	3.4	79.9	958.8	87	11.02
24	28	2	36.4	3.4	63.8	765.6	89	8.60
18	21	1	27.3	1.7	47	564	90	6.27
19	22	1	28.6	1.7	49.3	591.6	90	6.57
20	23	1	29.9	1.7	51.6	619.2	95	6.52
24	28	2	36.4	3.4	63.8	765.6	96	7.98
277	320	19				1577		29.13

Source: Survey

Table 7.07b Computed Flows and Densities for Road EK009 Section B

PC	*LGVs*	HGVs	LGVs*1	HGVs * 1	Flow/5 min	Flow/ Hr	Speed	Density
23	26	2	26	2	51	612	35	17.49
22	25	1	25	1	48	576	34	16.94
22	25	1	25	1	48	576	35	16.46
4	28	2	28	2	34	408	36	11.33
17	20	1	20	1	38	456	39	11.69
14	16	1	16	1	31	372	38	9.79
27	31	2	31	2	60	720	35	20.57
25	29	2	29	2	56	672	36	18.67
14	16	1	16	1	31	372	36	10.33
19	22	1	22	1	42	504	40	12.60
19	22	1	22	1	42	504	40	12.60
22	25	1	25	1	48	576	40	14.40
228	285	16				827		32.35

Source: Survey **Note:** Traffic Composition (PC) 45% (LGV) 52% (HGV) 03%

Table 7.08a Computed Flows and Densities for Road OG011 Section A

PC	**LGVs**	HGVs	LGVs* 1.3	HGVs* 1.7	Flow/5 min	Flow/ Hr	Speed	Density
50	2	2	3	4	57	684	95	7.20
50	2	2	3	4	57	684	93	7.35
52	2	2	3	4	59	708	95	7.45
53	2	2	3	4	60	720	99	7.27
55	2	2	3	4	62	744	95	7.83
51	2	2	3	4	58	696	93	7.48
51	2	2	3	4	58	696	93	7.48
53	2	2	3	4	60	720	95	7.58
55	2	2	3	4	62	744	97	7.67
41	2	1	3	2	46	552	93	5.94
40	3	0	4.5	0	44.5	534	90	5.93
44	3	0	4.5	0	48.5	582	90	6.47
595	26	19				1449		23.68

Source: Survey

Table 7.08a Computed Flows and Densities for Road OG011 Section B

PC	***LGVs***	HGVs	LGVs*1	HGVs * 1	Flow/5 min	Flow/ Hr	Speed	Density
43	2	1	2	1	46	552	45	12.27
47	2	2	2	2	51	612	45	13.60
37	2	1	2	1	40	480	44	10.91
45	2	1	2	1	48	576	48	12.00
48	2	2	2	2	52	624	44	14.18
56	2	2	2	2	60	720	44	16.36
42	2	1	2	1	45	540	45	12.00
47	2	2	2	2	51	612	45	13.60
37	2	1	2	1	40	480	48	10.00
33	1	1	1	1	35	420	47	8.94
37	2	1	2	1	40	480	46	10.43
29	1	1	1	1	31	372	46	8.09
501	22	16				966		39.44

Source: Survey **Note:** Traffic Composition (PC) 62% (LGV) 28% (HGV) 10%

Table 7.09a Computed Flows and Densities for Road OG012 Section A

PC	*LGVs*	HGVs	LGVs* 1.3	HGVs* 1.7	Flow/5 min	Flow/ Hr	Speed	Density
33	6	6	7.8	10.2	51	612	86	7.12
37	6	7	7.8	11.9	56.7	680.4	86	7.91
36	6	7	7.8	11.9	55.7	668.4	86	7.77
35	6	7	7.8	11.9	54.7	656.4	89	7.38
37	6	7	7.8	11.9	56.7	680.4	85	8.00
43	5	8	6.5	13.6	63.1	757.2	85	8.91
29	8	6	10.4	10.2	49.6	595.2	89	6.69
30	8	6	10.4	10.2	50.6	607.2	85	7.14
25	8	5	10.4	8.5	43.9	526.8	89	5.92
29	6	6	7.8	10.2	47	564	85	6.64
15	3	3	3.9	5.1	24	288	85	3.39
31	6	6	7.8	10.2	49	588	85	6.92
380	74	74				1500		29.00

Source: Survey

Table 7.09a Computed Flows and Densities for Road OG012 Section B

PC	*LGVs*	HGVs	LGVs* 1	HGVs * 1	Flow/5 min	Flow/ Hr	Speed	Density
27	6	6	6	6	39	468	38	12.32
22	6	7	6	7	35	420	38	11.05
18	6	7	6	7	31	372	38	9.79
27	6	7	6	7	40	480	38	12.63
24	6	7	6	7	37	444	39	11.38
20	5	8	5	8	33	396	35	11.31
27	8	6	8	6	41	492	38	12.95
19	8	6	8	6	33	396	38	10.42
18	8	5	8	5	31	372	39	9.54
29	6	6	6	6	41	492	37	13.30
23	3	3	3	3	29	348	38	9.16
33	6	6	6	6	45	540	37	14.59
287	74	74				1179		51.16

Source: Survey

Table 7.10a Computed Flows and Densities for Road OY018 Section A

PC	*LGVs*	HGVs	LGVs* 1.3	HGVs* 1.7	Flow/5 min	Flow/ Hr	Speed	Density
42	10	4	13	6.8	61.8	741.6	95	7.81
38	9	4	11.7	6.8	56.5	678	95	7.14
46	10	5	13	8.5	67.5	810	93	8.71
38	9	4	11.7	6.8	56.5	678	95	7.14
37	8	4	10.4	6.8	54.2	650.4	100	6.50
40	9	4	11.7	6.8	58.5	702	99	7.09
39	9	4	11.7	6.8	57.5	690	95	7.26
38	9	4	11.7	6.8	56.5	678	95	7.14
41	9	4	11.7	6.8	59.5	714	95	7.52
37	8	4	10.4	6.8	54.2	650.4	93	6.99
35	8	4	10.4	6.8	52.2	626.4	92	6.81
34	8	4	10.4	6.8	51.2	614.4	93	6.61
465	106	49				1595		27.90

Source: Survey

Table 7.10b Computed Flows and Densities for Road OY018 Section B

PC	*LGVs*	HGVs	LGVs*1	HGVs *	Flow/5 min	Flow/ Hr	Speed	Density
35	8	4	8	4	47	564	41	13.76
38	9	4	9	4	51	612	45	13.60
43	10	5	10	5	58	696	44	15.82
30	7	3	7	3	40	480	44	10.91
33	7	4	7	4	44	528	47	11.23
36	8	4	8	4	48	576	46	12.52
37	8	4	8	4	49	588	46	12.78
35	8	4	8	4	47	564	46	12.26
38	9	4	9	4	51	612	46	13.30
33	7	4	7	4	44	528	45	11.73
37	8	4	8	4	49	588	44	13.36
32	7	3	7	3	42	504	42	12.00
427	96	47				1431		54.19

Source: Survey

Table 7.11a Computed Flows and Densities for Road OY019 Section A

PC	*LGVs*	HGVs	LGVs* 1.3	HGVs* 1.7	Flow/5 min	Flow/ Hr	Speed	Density
38	19	5	24.7	8.5	71.2	854.4	89	9.6
40	20	5	22.1	8.5	70.6	847.4	85	9.97
36	18	5	24.7	8.5	69.2	830.4	89	9.33
37	18	5	23.4	8.5	68.9	826.8	90	9.19
35	16	5	20.8	8.5	64.3	771.6	90	8.57
31	21	4	27.3	6.8	65.1	781.2	89	8.78
41	22	5	28.6	8.5	78.1	937.2	86	10.90
43	20	6	26	10.2	79.2	950.4	89	10.68
39	20	5	26	8.5	73.5	882	89	9.91
40	20	5	26	8.5	74.5	894	89	10.04
40	20	5	26	8.5	74.5	894	93	9.61
34	17	4	22.1	6.8	62.9	754.8	96	7.86
454	231	59				1701		31.08

Source: Survey

Table 7.11b Computed Flows and Densities for Road OY019 Section B

PC	*LGVs*	HGVs	LGVs* 1	HGVs * 1	Flow/5 min	Flow/ Hr	Speed	Density
29	15	4	15	4	48	576	36	16.00
34	17	4	17	4	55	660	36	21.67
34	19	4	19	4	57	684	38	18.63
29	15	4	15	4	48	576	38	15.16
30	15	4	15	4	49	588	37	15.89
32	16	4	16	4	52	624	36	17.33
32	16	4	16	4	52	624	38	16.42
34	17	4	17	4	55	660	38	17.37
26	13	3	13	3	42	504	38	13.26
28	14	4	14	4	46	552	38	14.53
27	14	4	14	4	45	540	37	14.59
29	15	4	15	4	48	576	37	15.57
364	186	47				1080		43.02

Source: Survey **Note:** Traffic Composition (PC) 61% (LGV) 31% (HGV) 08%