Development of Appropriate Technology Road Condition Monitoring System

Case study: The city of Benghazi in Libya

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Division of Structural Engineering

By

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To Benghazi

Pride of the desert

Jewel of the Sea

Beacon of my voyage

Shore of my journey

Playground of my boyhood

Nobel hopes of my youth

Moonlit skies of my dreams

Dawn of my longings

Essence of my being

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ABSTRACT

This dissertation is concerned with the principles of pavement management systems and their applications in western and developing countries. The first part of the dissertation deals with the principles of pavement engineering and the role of the different layers in order to gain the required knowledge in highway pavement components, which will allow a cost-effective repair related to each specific defect.

The second part deals with the existing systems for monitoring pavement condition and evaluates their benefit in assessing highway condition. The study shows the main problems usually militate against using the sophisticated technology in monitoring highway condition and implementing maintenance management systems in some cities in developing countries.

In addition to the problems inherent in cities in developing countries, the city of Benghazi in Libya has special factors which have developed as a result of UN sanctions which were imposed in 1992. Therefore, the city of Benghazi has been selected as a case study for this particular research since it is a typical example of most cities in developing countries in terms of size, population and in terms of lack of maintenance resources and skilled labour (Benghazi might have been so well resourced that it would no longer fall into the category of developing city but for the sanction).

The objectives of the study are attained through conclusions which indicate that establishing a pavement maintenance strategy in the city of Benghazi based on any or some of the sophisticated technology in road condition monitoring is not appropriate. This conclusion is tested by manufacturing a unique prototype measuring machine and using it in pilot monitoring exercises in the cities of Newcastle and Sunderland. The results of these pilot exercises are analysed to evaluate the benefit which such appropriate technology equipment can bring to the issue of monitoring of pavement condition in cities in developing countries having problems similar to those that prevail in Benghazi.

The prototype equipment developed in this study is unique in that it is purely mechanical and uses no electronics in monitoring road condition. Moreover, all parts of the machine are fabricated from materials available in most cities in developing countries and therefore such machines could be easily maintained locally. The prototype described in this study is not only relevant to road monitoring but points the way towards the development of similar equipment in many engineering situations in developing countries. This research study points engineers in similar conditions in the direction that the Author thinks they should follow in applying their engineering abilities in developing countries.

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INTRODUCTION

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INTRODUCTION

1.1.Background

This thesis discuses the management of highway network maintenance in a situation where there are insufficient resources to do all that is needed. It is particularly focussed upon those highway networks where a significant level of maintenance is undertaken but that level is nonetheless insufficient to prevent progressive deterioration in serviceability.

Because the highway network of the city of Benghazi falls into this category, it is used as a case study in developing strategies and technique in the research discussed in this thesis. In addition to the difficulties inherent in a large city in a developing country, Benghazi has additional special factors which have come about as a result of sanction imposed in 1992. These sanctions mean that the effective employment of limited resources is particularly crucial. For these reasons, the outcomes of the research are particularly relevant and could be transferred to other authority working against similar background.

Most developing countries are suffering from difficulties in developing an adequate maintenance management system for their existing roads network. Even in some more developed countries (such as Libya) shortages of skilled and experienced staff or regular training to update the staff lead to difficulties in carrying out planning and management of the maintenance requirements of the highway network (Robinson 1986).

Large highway networks constructed during the last twenty-five years in developing countries have been subject to loads and use beyond levels for which they were designed. In many cases, maintenance has been inadequate and this absence of adequate maintenance has caused both minor and major deterioration to many roads which now need minor and sometimes major reconstruction rather than a maintenance operation (Robinson 1986).

A pavement management system is a set of tools or methods that assist in decision-making and in finding optimum strategies for providing and maintaining pavements in a serviceable condition over a given period of time (Hudson 1987).

A maintenance management system is not an option or good idea to implement. It is a crucial and important step towards preventing any premature or delayed maintenance activities from being carried out, thereby enabling the allocated maintenance budget to be spent efficiently. The aim of any maintenance management system is to keep the highway network serviceable to an acceptable level during the road's design life. Therefore, to implement a proper maintenance management system using high technology machinery to assess road conditions will need high capital allocated to the maintenance sector. This cannot be afforded by many developing countries. Therefore, the aim of this study.is the development of measurement system of low capital and maintenance cost.

1.2 Definition of Maintenance Terms

Maintenance activities can be classified in terms of road deterioration level as defined in TRL Report number 145 (Robinson 1988) to the following five maintenance levels:

- **Maintenance**

The objective of maintenance is to reduce the rate of deterioration and to lower the vehicle operating cost by providing reasonable riding quality and by keeping the road open on a continuous basis. Maintenance only improves surface characteristics, without adding much to the structural capacity of the road (Kerali 1986). For unpaved roads, regravelling can be considered as maintenance. Gravel, which is the surfacing material, may be worn away by traffic or blown away as dust and therefore, the subgrade will be exposed (ORN2 1987).

- **Rehabilitation**

When a road has deteriorated beyond the level at which the overlaying is a satisfactory engineering treatment, rehabilitation is required to extend road life to carry additional traffic load. Rehabilitation could be required also when the road was not built to the standards of quality required by the original design.

- **Reconstruction**

Reconstruction is activity carried out to provide additional life to the road when the road as a whole has failed. This kind of treatment is a high cost activity as it is means replacing most and sometimes all of the pavement layers.

- **Upgrading**

Upgrading may be required to provide additional capacity to the road either because of unforeseen change in the traffic load or because the road is nearing the end of its design life. A typical example of upgrading is the paving of gravel roads and the widening of roads.

- **Stage construction**

Like upgrading, stage construction aims to improve the standard of a road pavement, but at pre-determined and planned stages throughout the project life. Typical example of stage construction is the construction of a gravel road initially to be later paved when traffic volume reaches a certain level.

1.3 Objectives of the research

This thesis considers existing road condition monitoring systems in relation to the special factors applying in cities in developing countries, which are explained in paragraphs 3.4, 3.5 and 3.6. It is shown in Chapter 3 that many cities are experiencing unsatisfactory road and street performance, because of the unavailability of pavement maintenance systems which are orientated towards their specific and sometimes unique conditions.

The principal objectives of the thesis are to consider the special conditions relevant to cities in developing countries and to show how these conditions militate against the use of monitoring systems based upon sophisticated technology, then to draw conclusions regarding the type of monitoring systems which seem appropriate to the city of Benghazi in Libya (Benghazi is henceforth used as a case study for reasons which are explained in detail in Chapter 4).

These conclusions are tested by manufacturing prototype monitoring equipment, using it in a pilot monitoring exercise and thereby evaluating the benefit which such appropriate technology equipment can bring to the issue of monitoring pavement in cities in developing countries. The thesis includes a description of the development of the apparatus, comparing it with sophisticated and therefore less appropriate western machines.

The objectives of the study are attained through conclusions indicating the influence of the equipment developed in bringing potential tangible improvements to the condition of the roads in Benghazi and by inference to the roads in developing countries generally. This project points engineers in similar conditions in the direction that the Author thinks they should follow in applying their engineering abilities in developing countries.

1.4.Outline of the thesis

In Chapter 2, a general review of the principals of pavement engineering and the role of the different layers is presented, with more details about the most common bituminous material which are used in road construction. In addition to the general properties of the material used in the city of Benghazi road construction.

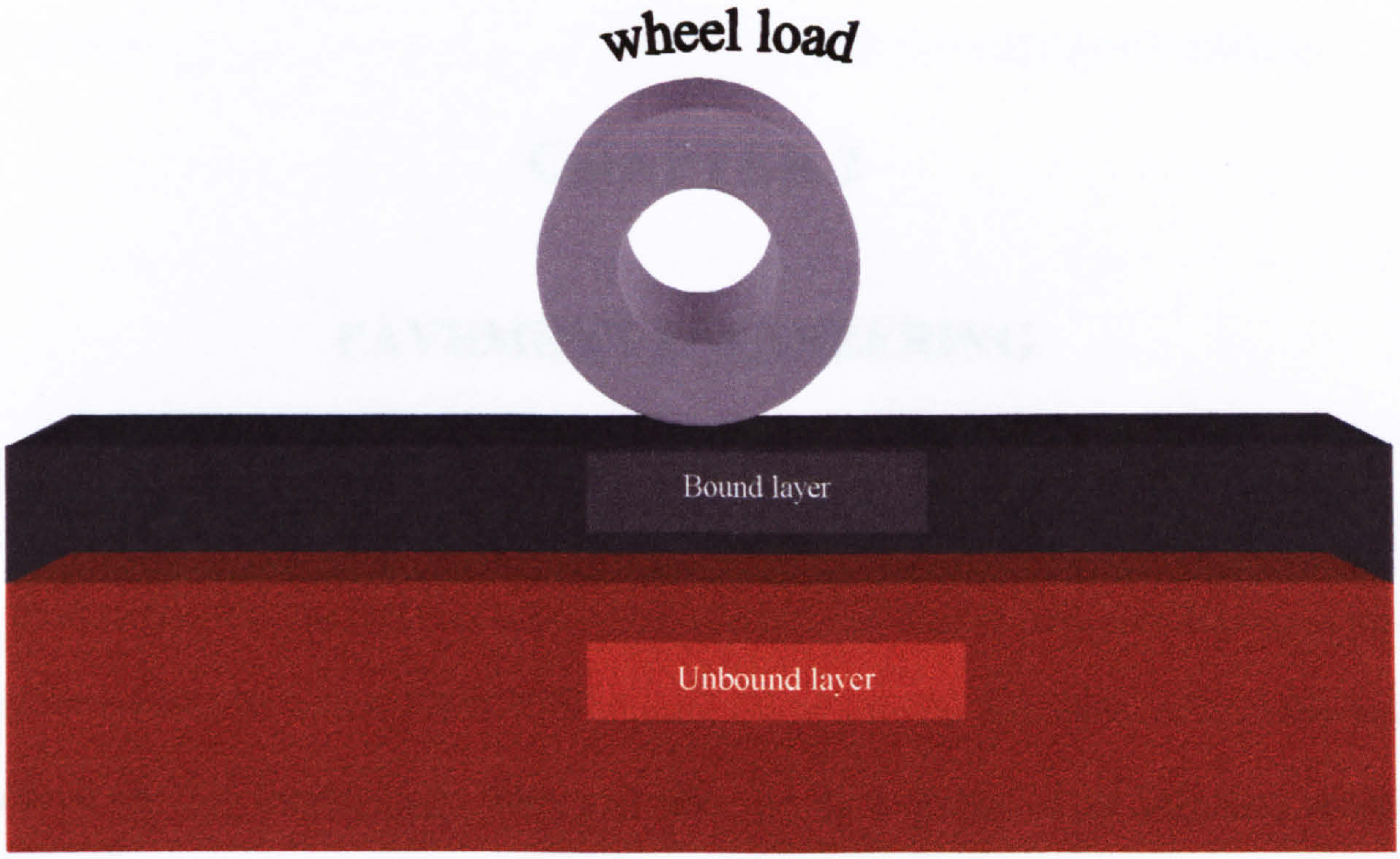
Chapter 3 considers the role and component of maintenance management systems. It presents the visual inspection-based systems to assess the required maintenance and remedies to be implemented throughout the highway network, together with an outline of the different high technology machinery used for road condition data collection. In addition to the main problems which obstructing the implementation of maintenance management systems in developing countries and the investment appraisal models which developed to be used in cities in some developing countries.

Chapter 4 presents the data collected relating to roads and transportation in the city of Benghazi from different aspects such as traffic volume and flow in the city, the number and influence of commercial vehicles in the network and the future increase and growth in population and number of vehicles in the city. It describes the general conditions in the city of Benghazi's roads network, using data collected during field trips to the city showing road condition and the concept of maintenance in the city.

Chapter 5 discusses the principal of using low-cost systems for collecting road condition data in the city of Benghazi, even with its high labour costs. It presents detailed drawings, photos and description of a low-cost system assembled in the Civil Engineering Department at the University of Newcastle Upon Tyne.

Chapter 6 analyses the data collected by the prototype monitoring equipment in different road sections at the city of Newcastle and Sunderland. In addition to a made up example applied on part of the city of Benghazi road network to show the influence of the equipment developed in implementing a proper maintenance strategies in the city.

Chapter 7 summarises the conclusion of the study and recommendations for further studies in the future regarding the development of low cost low technology equipment to assess other pavement defects such as cracking, skidding resistance and longitudinal profile.



CHAPTER 2

Pavement Engineering

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CHAPTER 2

PAVEMENT ENGINEERING

2.1 Introduction

This thesis starts with the fact that in the cities of many developing countries, highways pavement are unserviceable (Robinson 1988). It is important to review the mechanics of highway pavement behaviour, so that subsequently generated data can be assessed in an informed manner. By understanding the mechanisms of pavement performance, it is possible to link together data defining present pavement condition with a strategy for pavement remedial work. Knowledge of the function and properties of highway pavement components will allow a cost-effective repair related to each specific defect. This follows the principal that the first step in repair is learning how the broken object was intended to operate.

A pavement is the whole structure of the road from foundation to surface that implying its ability to absorb the stresses imposed by traffic and weather without cracking (Crony & Crony 1997). The purpose of a road pavement is to protect the underlaying subgrade from deformation under traffic loads and to provide a safe and comfortable riding surface (Hosking 1996). The structural layers of flexible pavements (Bituminous Pavement) are as shown in Figure 2.1.

A flexible pavement usually comprises three main layers, the surfacing, the structure and the foundation. The surfacing is generally divided to two main layers, the wearing course and the basecourse (known as Binder course in Libya). These two layers are installed separately one after the other. The surfacing is principally to provide adequate skid resistance and good riding quality with little structural significant (Brown 1996). The structure roadbase (known as base course in Libya) is the main structural element of the pavement. It is usually of dense bituminous material, or of two layers, upper and lower roadbase which, are frequently either lean concrete or dense bituminous macadam. In Libya, this layer is usually constructed of

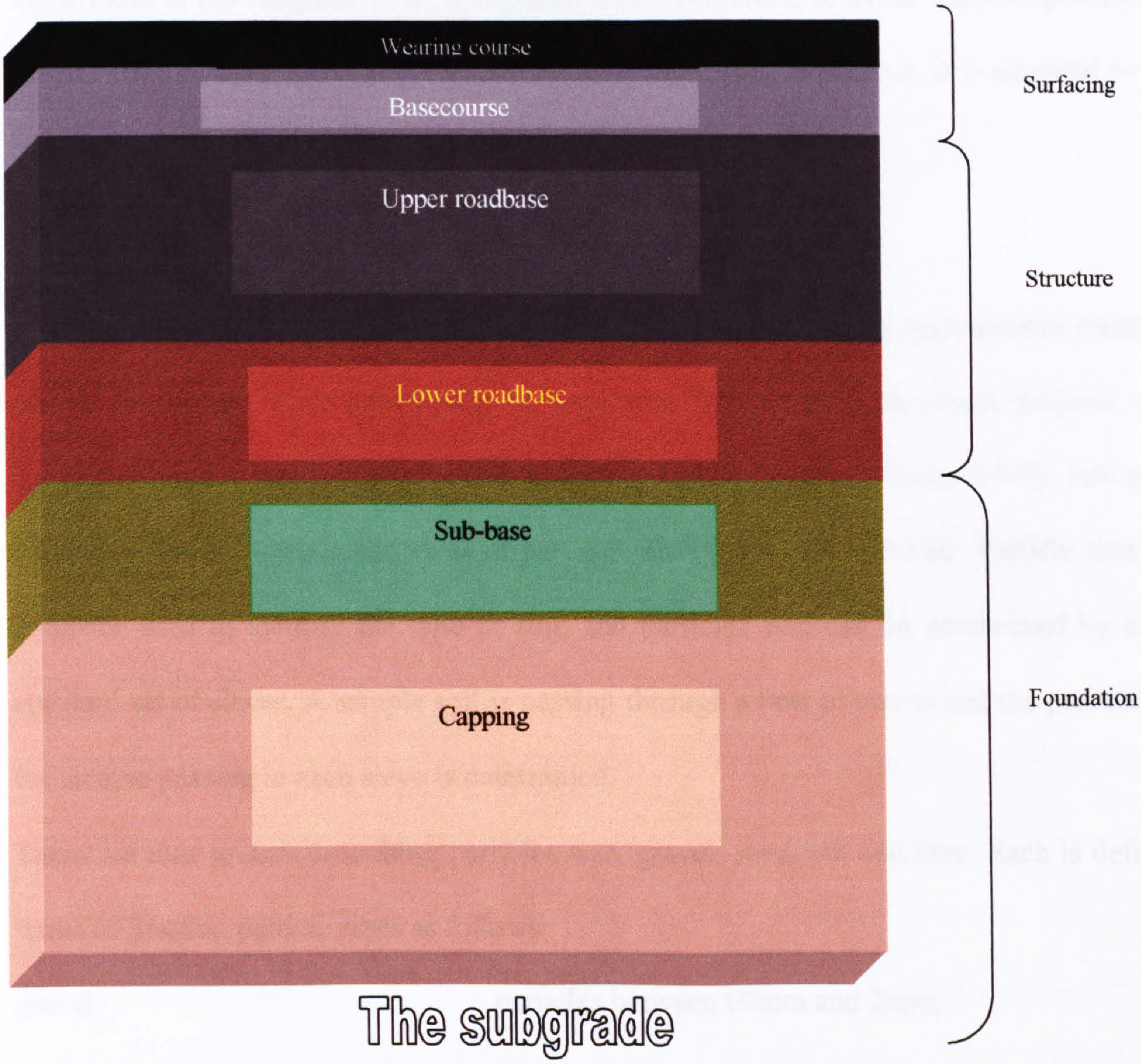

Figure 2.1. The structural layers of flexible pavement

unbound granular material. The foundation is a layer consisting of the underlying subgrade soil, capping material if required and sub-base. The sub-base is usually constructed of crushed rock material and used as a platform to carry the upper layers of construction.

In general, the main function of the different layers in the pavement construction is to limit the stresses in the subgrade to an acceptable level. Therefore, to avoid any unexpected major deterioration in the pavement foundation which, may prove expensive, it is essential to study the nature of the soil on which the pavement will be constructed.

2.2 Soil properties

A lack of detailed subgrade information may lead to early structural maintenance (before the end of the design life), particularly in large and heavy-traffic pavement projects, where general estimation to the soil condition is not applicable (Crony & Crony 1997). Soil usually comprises various shapes and sizes of particles plus water and some air. Particle size is the indicator used to identify the type of soil, and particles size can be determined by using a standard set of sieves. A sample soil is passing through a nest of sieves and the percentage of the sample passing in each sieve is determined.

There are four groups describing particles size, gravel, sand, silt and clay. Each is defined in terms of limiting particle sizes as follows:

gravel	particles between 60mm and 2mm,
sand	particles between 2mm and 0.06mm,
silt	particles between 0.06mm and 0.002mm,
clay	particles smaller than 0.002mm.

2.2.1 The state of the soil

The most important properties of soil related to pavement construction are strength properties, which are referred mainly to the state of the soil in terms of density and moisture content. Figure 2.2 shows the main three parts of a soil mass, which are air, water content and dry soil.

- Air voids (air content)

The space in the soil mass occupied by air is called air voids and from Figure 2.2 the percentage ratio of the air volume to the total volume of soil is called the air content (a)

$$a = \frac{Va}{V} \times 100$$

- Water content

The water content (w) is the percentage ratio of the weight of water to the weight of dry solids.

$$w = \frac{Ww}{Ws} \times 100$$

- Dry density

The dry density (ρd) is the weight of dry material in unit volume of wet soil

$$\rho d = \frac{Ws}{V}$$

2.2.2 Compaction

Compaction of soil means excluding the air from its mass by compressing particles closer to each other, in order to increase dry density. Compaction has an important role in the quality of the underlying earthworks and the road structure in order to withstand heavy traffic. Compaction tests are carried out to provide an indication of the soil compactability in the field. One of these tests is known as the Proctor Test (British standard 1377: 1975, Test 12). In the proctor test, the soil is laid in a cylindrical mould of 101.6mm diameter and 116mm height in three equal layers. Each layer is compacted by a hammer of 51mm diameter and weight 2.5 Kg falling through a distance of 305mm 25 times. The dry density is calculated from the moisture content of the soil and the volume of the mould. Another heavier compaction test (British Standard 137: 1975, Test 13) is employed to produce greater densities. In this test, the sample is compacted in five layers using a hammer of 4.54-kg

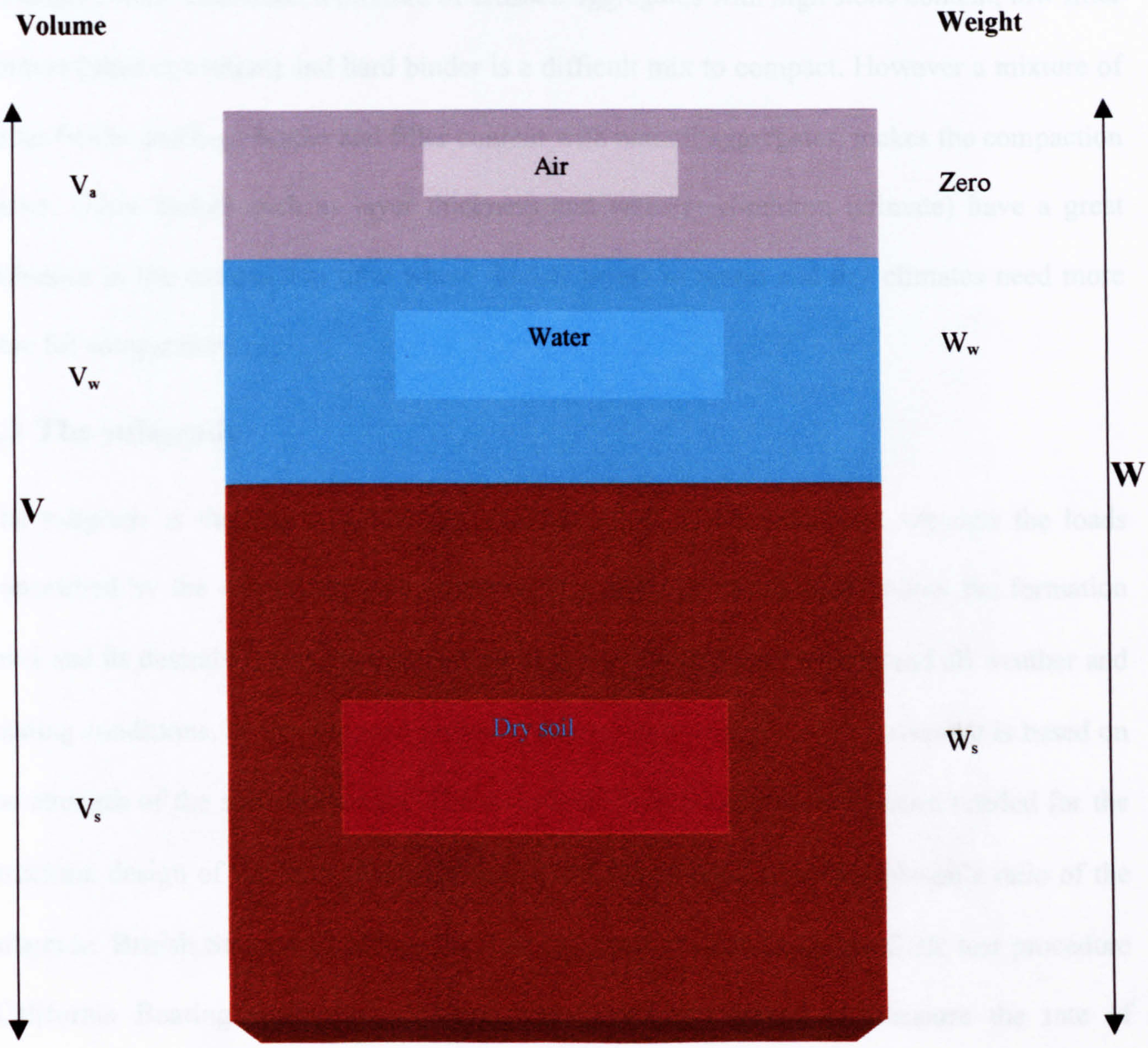

Figure 2.2 Parts of a soil mass

falling from a height of 457mm (Crony & Crony 1997). For asphalt layers, the degree of compaction depends on the design mix of the materials, which comprise 95% by weight of aggregates and the remaining 5% is made up of bituminous binder agent (Kirschner & Kloubert 1988). Therefore, a mixture of crushed aggregates with high stone content, low filler content (sand or cement) and hard binder is a difficult mix to compact. However a mixture of softer binder and high binder and filler content with natural aggregates, makes the compaction easier. Other factors such as layer thickness and weather condition (climate) have a great influence in the compaction time where thicker layers in warm and dry climates need more time for compaction.

2.3 The subgrade

The subgrade is the upper part of the soil, natural or constructed, that supports the loads transmitted by the overlaying road structure. It is the soil immediately below the formation level and its desirable properties are a high compressive strength to withstand all weather and loading conditions. In flexible road projects, the structural design of the pavement is based on the strength of the soil underneath. The most important foundation properties needed for the structural design of the road pavement are the elastic modulus and the Poisson's ratio of the subgrade. British Standard 1377: 1975, Test 16 describes details of the CBR test procedure (California Bearing Ratio test) (Figure 2.3), which is adapted to measure the rate of penetration in a soil sample. A soil sample is compacted into the mould at the same moisture content and dry density that it is estimated to achieve in the prepared subgrade. The soil sample is subjected to applied load to record the rate of penetration and the reading given shows the strength of the soil. The load required causing 2.5 and 5mm penetration is recorded and expressed as a percentage of the load required for the same penetration in a certain standard material. The test provides information largely related to soil strength in terms of stiffness and permanent deformation information (Dawson 1996).

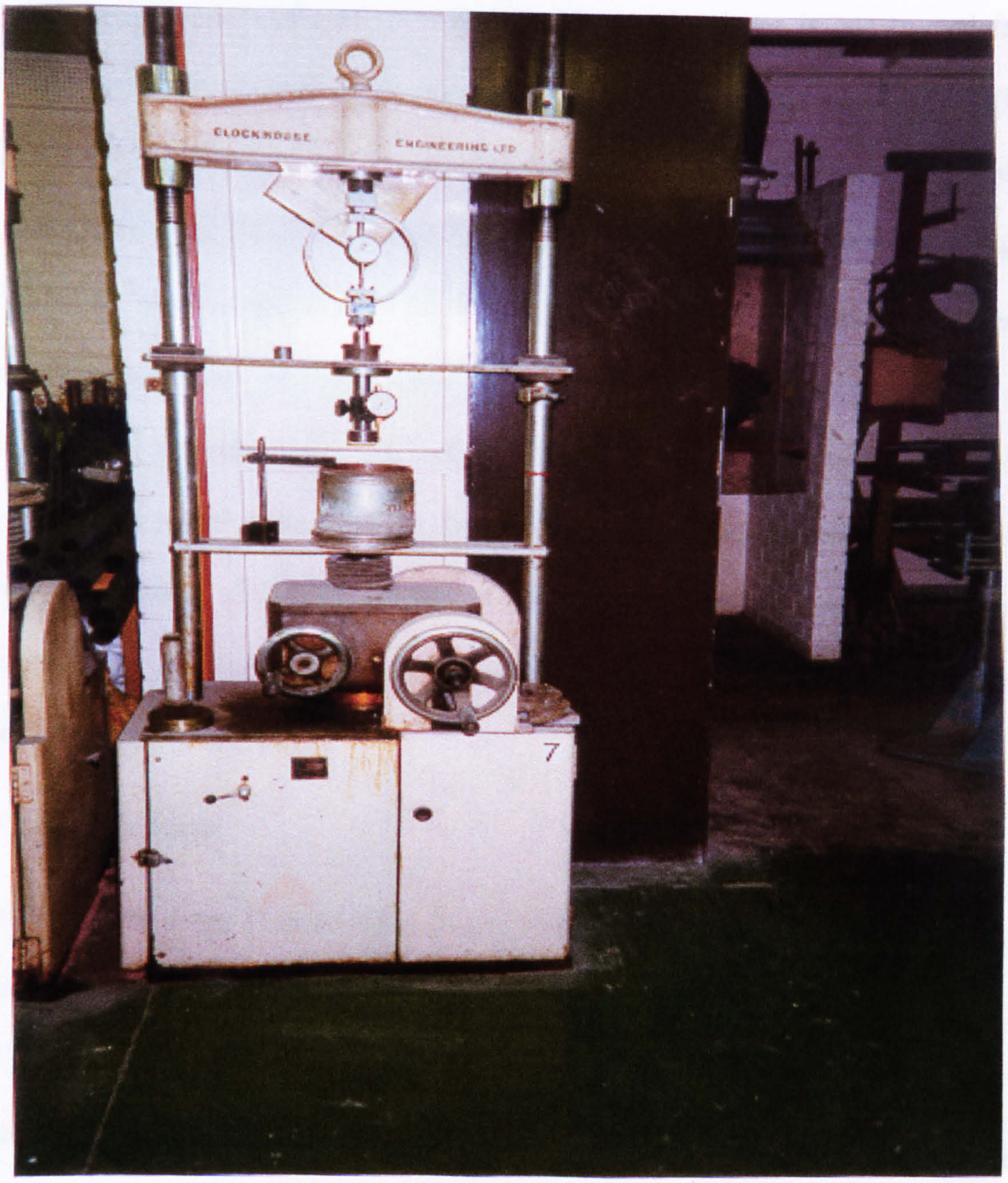

Figure 2.3 The CBR test apparatus

In the case of low values of CBR (<5 per cent) at the formation level, a capping layer between the subgrade and the sub-base is required. The capping layer is constructed from locally available low-cost material with minimum CBR of 15% after compaction (Knapton & Meletiou 1996). Table 2.1 shows the foundation thickness for different subgrade strengths. In case of lower CBR values (< 2 per cent), the capping material may be separated from the subgrade by a geotextile membrane to avoid losing its advantages as a capping due to contamination by the wet soil. Table 2.2 shows the advantage obtained from a geotexile membrane fabric between the soil and the selected material. Tests have been carried out by the TRRL on crushed stone layers (200mm) laid over a weak soil of CBR < 2 per cent (Croney & Croney 1997). The layers constructed with and without separation of material using a fabric of 10.5 KN/m strength and both forms of construction were subjected to repeated passes of load truck.

2.4 The sub-base

The sub-base is a one or more layer of material placed immediately above the subgrade. It is generally of granular material comprising crushed rock or slag. It is structurally significant and provides a working-platform to facilitate transport, laying, and compacting the upper pavement layers (Powell et.al.1984). In the case of flexible pavements, the sub-base is the layer that exist between the subgrade and the roadbase, The sub-base has two ways of construction, either unbound compacted granular material or similar material bound with cement. The sub-base layer has an advantage of accepting greater compressive stress than the subgrade, which reduces the deformation of the pavement under traffic loading.

2.4.1 The unbound sub-base

Type1 sub-base granular material comprises crushed rock aggregate, crushed slag or crushed concrete. The material should lie within the grading envelope of Table 2.3, and should be transported, laid and compacted without drying or segregation (Knapton & Meletiou 1996).

Table 2.1 Foundation thickness for various subgrade strengths (Knapton & Meletiou 1996)

CBR of Subgrade	Capping Thickness (mm)	Sub-base Thickness (mm)
1%	600	150
2%	350	150
3%	250	150
5%-7%	Not required	225
10%-30%	Not required	150

Table 2.2. The influence of geotextile layer on deformation

Number of passes of truck	Pavement deformation at the surface (mm)	
	without fabric	with fabric
50	28	20
100	37	25
200	47	29

Type 2 sub-base comprises crushed rock mixed with natural sand or gravel. The material should lie within the grading envelope of Table 2.4. The material should satisfy the minimum CBR requirement of 20%, and should be transported, laid and compacted without drying or segregation.

2.4.2 The bound sub-base

The addition of cement to the granular material is an approach to increase its strength but it is not recommended for the material with sufficient strength to act as an unbound (sand gravel soil). Table 2.5 shows the grading limit for cement bound material category 1 (CBM1). Special machines are used to distribute and mix the cement to compact the mixed product. Laboratory tests should be carried out to determine the water cement ratio that been used to obtain the required strength and cubes of 150mm are used to determine the cubes strength. CBM1 should be made from materials that have a grading finer than the limits of Table 2.5. CBM2 should be made from gravel-sand, washed granular material, crushed rock, slag or any combination of these. The material should lie within the grading limits of Table 2.6. Cement bound material is preferred if good quality sub-base materials are not available, particularly for construction in wet weather situations. However, the structural contribution of a cement-bound sub-base cannot be guaranteed to be greater than that of a Type1 granular sub-base (Powell 1984). Table 2.7 shows summary of foundation layers role in pavement construction. The general specifications of the material used for the sub-base layer in the city of Benghazi road construction should be granular, free draining and with Plasticity Index between 0-6% maximum with minimum CBR reading of 25%.

2.5 The roadbase

The roadbase is one or more layers of material placed above the sub-base that constitute the main structural elements of a flexible pavement, laid immediately below the bituminous surfacing of a flexible pavement. Its purpose is to spread the stresses induced by traffic loads

Table 2.3 Sub-base Type 1 range of grading

BS Sieve Size	Percentage by Mass Passing
75 mm	100
37.5 mm	85-100
10 mm	40-70
5 mm	25-45
600 micron	8-22
75 micron	0-10

Table 2.4. Grading limits for type 2 sub-base

BS sieve size	Percentage by Mass Passing
75 mm	100
37.5 mm	85-100
10 mm	45-100
5 mm	25-85
600 μm	8-45
75 μm	0-10

Table 2.5 Material for CBM1-range of grading

BS Sieve Size	Percentage by Mass Passing
50 mm	100
37.5 mm	95
20 mm	45
10 mm	35
5 mm	25
600 micron	8
300 micron	5
75 micron	0

Table 2.6 Material for CBM2-range of grading

BS Sieve Size	Percentage by Mass Passing
50 mm	100
37.5 mm	95-100
20 mm	45-100
10 mm	35-100
5 mm	25-100
2.36 mm	15-90
600 micron	8-65
300 micron	5-40
75 micron	0-10

Table 2.7 Summary of foundation role in typical flexible pavement section (Dawson 1996)

Role	Ability required	The required layer	Material properties needed
Construction traffic load spreading	To carry a few large load cycles	Subgrade, capping and sub-base	Good stiffness, permanent deformation resistance
Compaction platform	To present a firm base for construction of higher levels	Capping, sub-base and base	Good stiffness
Compaction control	To maintain level	Capping and sub-base	Permanent deformation resistance
Support of working load	To carry canalised small load cycles	Subgrade, capping and sub-base	Reasonable stiffness and permanent deformation resistance
Drainage layer	To carry water out of pavement	Capping and sub-base	High permeability, good falls
Frost protection	To withstand frost from heave and insulate	Capping and sub-base	High permeability, thickness

over the foundation and to withstand internal stresses without excessive cracking or deformation. The roadbase can reduce the vertical compressive stress induced by the traffic in both the sub-base and the subgrade, thus it limits the deformation that may occur in these layers. Roadbases fall into two main groups, unbound and bound roadbases.

2.5.1 Unbound roadbase

Unbound roadbases are those which depend on their internal friction to develop the necessary bearing capacity (i.e. crushed rock and natural gravel) (Millard 1993). The common type of roadbase material used in the city of Benghazi road construction is wet-mixed crushed stone. The material obtained from approved sources consists of clean, hard, durable, well shaped stone, free from soluble salts and sulphates, organic contamination, soft or weathered fragments, shell and clay. The material is crushed, screened and blended to form a well-graded mixture conforming to the grading limits in Table 2.8. The CBR should not be less than 80% for a sample soaked in water and compacted to the maximum density. The material is laid by approved mechanical pavers in layers not exceeding 150-mm depth to give the required thickness after compaction.

2.5.2 Bound roadbase

Bound roadbases are those in which a binder (cement, lime or bitumen) is used to enhance their ability to reduce the traffic stresses on the layers underneath (Millard 1993).

2.5.2.1 Lean concrete (cement bound)

This material is made from coarse and fine aggregates, which can be crushed rock or gravel. Table 2.9 (Croney & Croney 1997) shows the grading limits of lean concrete with maximum sizes of 40mm and 20mm. This layer is very stiff and its stiffness is governed by the type and amount of cement/water content and by the aggregate type and grading.

Table 2.8 Unbound roadbase material grading limits in Benghazi

Sieves	Grading A	Grading B	Grading C
50mm	100	100	100
37.5 mm	80-100	70-100	80-100
20.0 mm	60-85	50-80	55-80
10.0 mm	40-70	40-70	40-75
N_o. 4	25-50	30-60	30-55
N_o. 10	20-40	20-50	25-45
N_o. 30	10-25	------	-------
N_o. 40	------	10-25	-------
N_o. 100	3-12	------	-------
N_o. 200	0-8	5-10	5-20

Table 2.9 Grading limits for lean concrete

BS sieve size	Percentage passing	
	40mm	20mm
50 mm	100	—
37.5 mm	95-100	100
20 mm	45-80	95-100
5 mm	25-50	35-55
600 μm	8-30	10-35
150 μm	0-8	0-8

2.5.2.2 Bituminous roadbase materials

Bituminous roadbases can be either coated macadam (dense coated macadam or heavy-duty macadam) or asphalt (rolled asphalt) which must have coarse aggregate contents of 60% to 50%. Dense coated macadam for compacted layers of 90 to 150mm thickness is of 40mm maximum size aggregate, layers of 70 to 100mm thickness is of 28mm maximum size aggregate. Table 2.10 shows the grading of both 40mm and 28mm maximum size. The significant advantage of these types of bituminous roadbases is their high stiffness and strength and their impervious surfacing to protect the lower layers from water ingress.

2.6 The surfacing

The surface of the road pavement is the layer between the vehicles tyres and the roadbase layer and in bituminous pavements, it consists of two components, the basecourse (binder course) and the wearing course. It is principally to provide adequate skid resistance and riding quality, it has little structural significance. It may vary between a layer surface dressing (spray and chip) to a 40-50 mm thickness dense bituminous mixture that contributes to the pavement structural integrity (Brown 1996).

2.6.1 The basecourse (Binder course)

The purpose of the basecourse is to provide a good surface over which to construct the wearing course and to protect the lower layers from any water penetration. Different types of bituminous materials are used in the construction of the basecourse layer, depending on the nature of the subgrade, the weather and the traffic flow of the road.

2.6.2 The wearing course

The wearing course provides a good riding surface whose texture and roughness ensure an adequate skid resistance and at the same time prevent water penetration to the lower layers of the pavement structure.

Table 2.10 The grading for 40 mm and 28 mm maximum size

BS sieve size	Percentage passing	
	40mm	28mm
50 mm	100	------
37.5 mm	95-100	100
28 mm	70-94	90-100
20 mm	—	71-95
14 mm	56-76	58-82
6.3 mm	44-60	44-60
3.35 mm	32-46	32-46
300 μm	7-21	7-21
75 μm	2-9	2-9

2.7 Bituminous mixes

Bituminous mixes used in pavement construction comprise a composition of mineral aggregates, bitumen and air (Figure 2.4), and the mix properties are significantly dependent on the volumetric properties of these three components.

2.7.1 Mineral aggregates

The particle size of aggregates used for bituminous mixes ranges from 37.5mm down to fine dust (Cooper 1996). The grading of aggregate particle sizes is determined by carrying out a sieve analysis. Table 2.11 shows the sieve analysis that may be used to define the proportion of each size of the aggregate. The material passing the 0.075mm sieve, and collected in the pan is classified as filler. The maximum aggregate size depends upon the type of mix, the thickness of the layer and the application for which the mix is used. For example, the maximum size of aggregate for bituminous mixes is 37.5mm for roadbase material, which can be laid in depths of 100mm or more. However, for wearing course mixes the maximum aggregate size is 14mm or 10mm (Cooper 1996).

The potential resources for building materials in Libya are of two major types; limestone and sandstone. Limestone formations are widely spread in the north east of Libya (Benghazi). Therefore, crushed limestone constitutes the main road construction aggregates (Municipality of Benghazi 1993). Table 2.12 shows the grading limits of crushed limestone aggregate processed at local quarries around the city of Benghazi used in road construction.

2.7.1.1 Aggregate polishing test (Millard 1993)

A sample of 10mm aggregate size is subjected to polishing by a pneumatic-tyre wheel (Figure 2.5) for six hours, divided into two stages of three hours each. The abrasive fed material in each stage is different. The state of polish in the sample is measured in terms of the coefficient of friction that ranges from zero to 30 for stones liable to become highly polished, and from 55 to 60 for stones likely to remain rough.

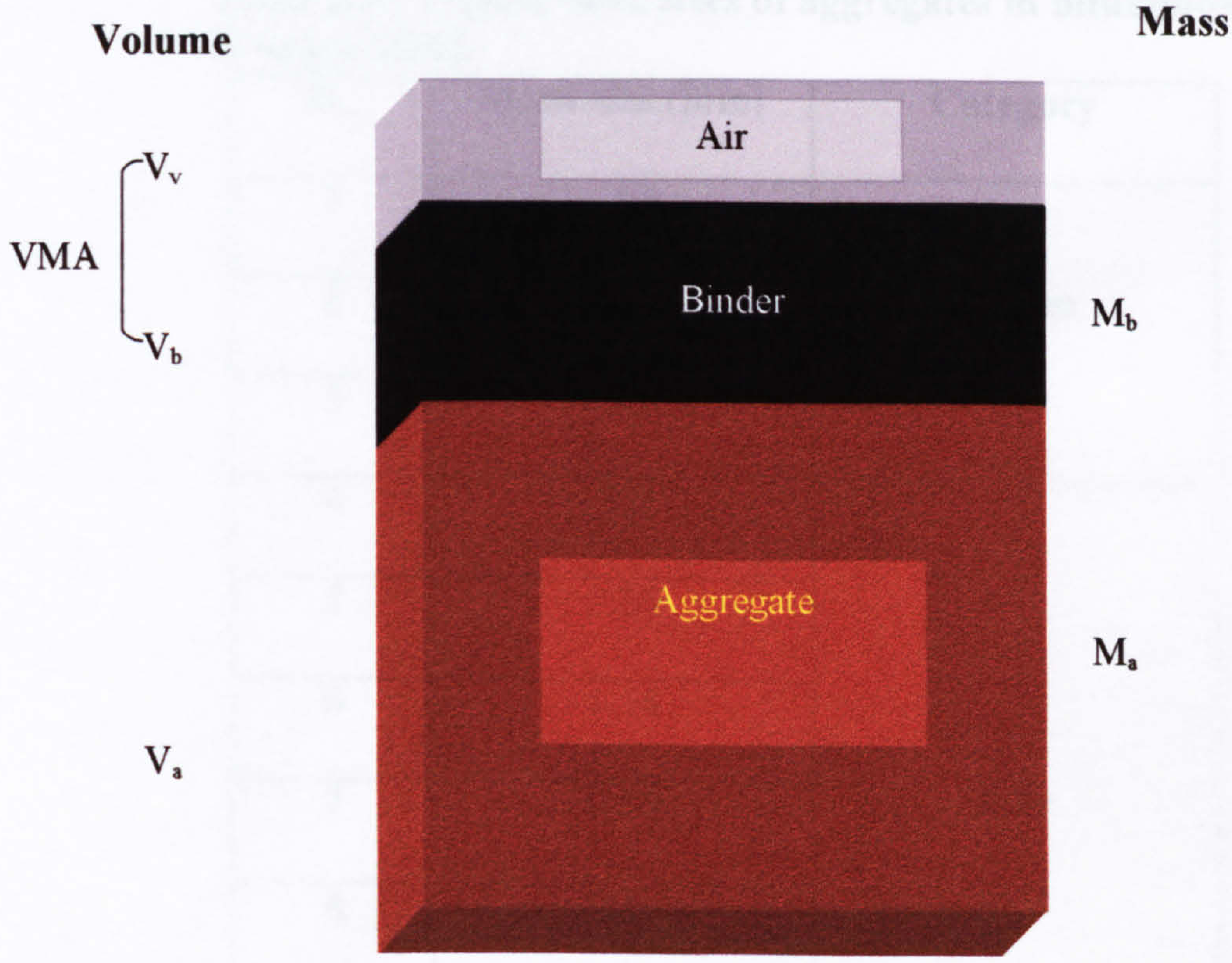

Figure 2.4 Composition of bituminous mixes

Note:

M_b is mass of binder in Kg.

M_a is mass of aggregate in Kg.

V_v is volume of air voids in m^3.

V_b is volume of binder in m^3.

V_a is volume of aggregate in m^3.

Table 2.11 Typical sieve sizes of aggregates in bituminous mixes (Cooper 1996)

No.	Mesh size (mm)	Category
1	37.5	Coarse
2	20.0	
3	10.0	
4	5.0	Fine
5	2.36	
6	1.18	
7	0.60	
8	0.30	
9	0.15	
10	0.075	
11	Pan	Filler

Table 2.12 Grading limits of limestone aggregate in Benghazi bituminous mixes.

Grading sieve size	Base % passing	Base course % passing	Wearing course % passing
50 mm	100	----	-----
37.5 mm	95-100	100	-----
28 mm	70-94	80-100	100
20 mm	----	70-90	82-100
10 mm	50-70	55-75	70-90
6.3 mm	44-60	50-65	50-75
3.35 mm	32-46	40-56	40-55
1.18 mm	----	28-42	30-45
425 µm	----	15-27	17-27
300 µm	7-21	10-20	15-20
150 µm	----	7-15	10-18
75 µm	2-8	3-8	6-12

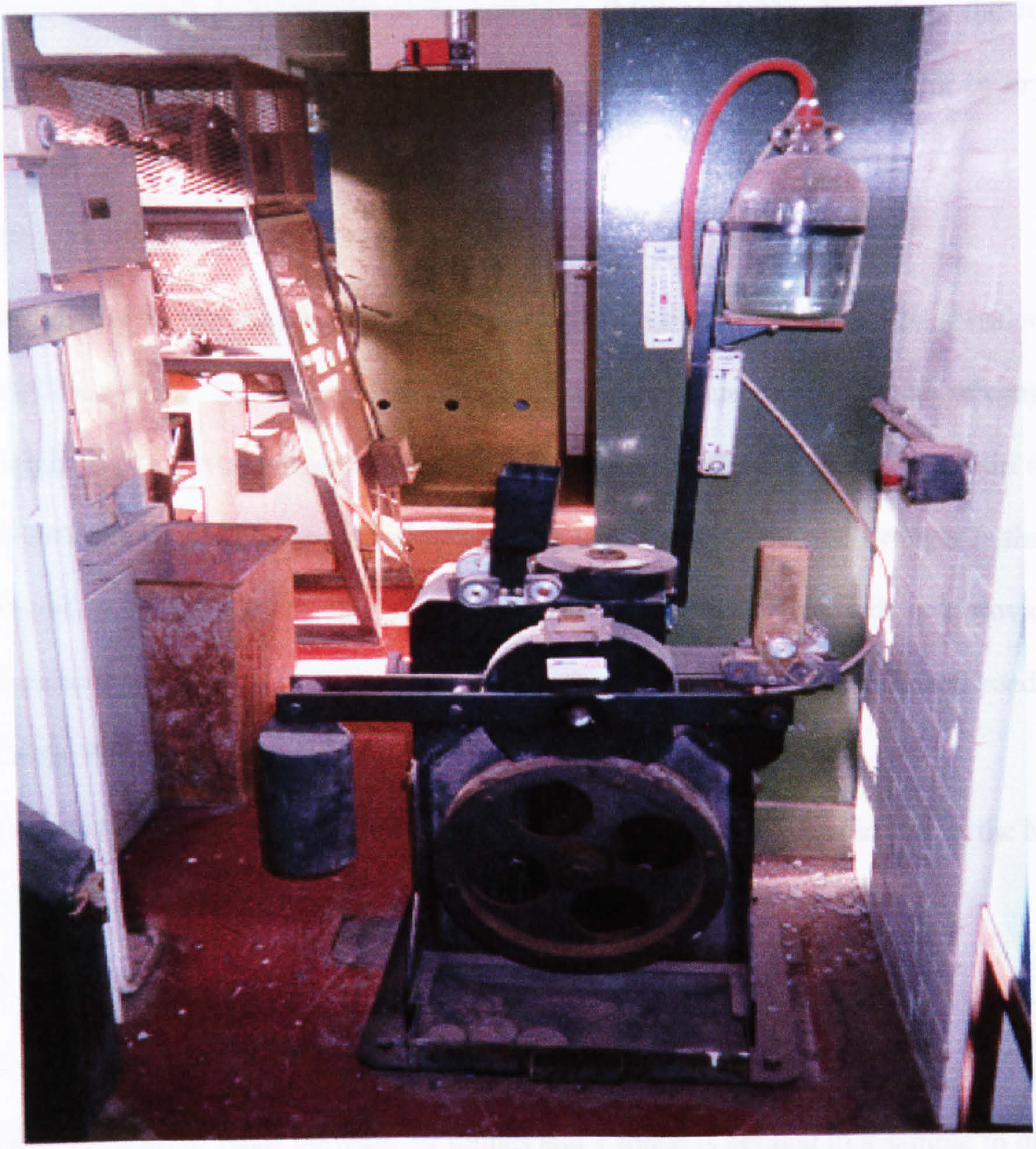

Figure 2.5 Aggregate polishing test

In most developing countries, the accident rates are significantly high because of slippery road surfacing (Millard 1993). In the city of Benghazi, road surfacing include crushed limestone which is highly prone to polishing (Millard 1993). Therefore, the road surface becomes slippery, either in wet condition because of a thin water-film or in dry condition when there is a thin layer of a sandstorm dust.

2.7.1.2 Abrasion test

Aggregates in the wearing surface need to have adequate resistance to abrasion under the traffic imposed. The abrasion resistance of the aggregate sample is the percentage loss in weight after subjecting the sample to abrasion by a flat circular metal surface in the presence of abrasion sand. The lower the losses in the aggregate weight, the stronger is the aggregate. Therefore, aggregates of abrasion value (AAV) more than 16% will not provide adequate resistance to abrasion in a wearing course except in case of light-trafficked roads (Crony & Crony 1997).

Table 2.13 shows a summary of test result on asphalt aggregate carried out at the Municipality of Benghazi Highway Laboratory.

2.7.1.3 -Ten per cent fines value

The ten per cent fines value test is used to determine the required load (in kn.) to produce 10% fines. A series of loads between 40 tonnes and 1 tonne is applied to a sample to determine the load which produces 10% of fines passing a 2.36mm sieve (Millard 1993). The test is undertaking using a metal plunger to apply a load to a sample of crushed rock contained in a test mould as showing in Figure 2.6. The results ranged from 10 kn. for material such as chalk to 400 kn. for stronger aggregate.

2.7.2 Bitumen

Petroleum bitumen is supplied in a number of different forms for different road purposes. Firstly, penetration-bitumen, which is the stiffer form of bitumen, having different grades

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DESCRIPTION	AGGR' SIZE (mm)	SPECIFIC GRAVITY			ABSOR' (%)	CRUSHING VALUE (%)	LOS ANGELES ABRASION (%)	FLAKINESS (%)	ELONGATION (%)	SOUNDNESS (%)	10 %FINE VALUE (%)	IMPACT VALUE (%)	REMARK
		BULK SPECIF'	BULK S.S.D	APP' SPECIFIC									
COARSE AGGREGAT	25 mm	2.574	[illegible].593	2.6[illegible]2	0.72					0.53			
	19 mm	2.[illegible]58	[illegible].584	2.627	1.10	28.9	31.2	-	-	0.39	143.[illegible]	8.[illegible]	
	10 mm	2.525	2.569	2.640	1.73					1.32			
FINE AGGREGAT	5 mm (SAND)	2.590	2.621	2.672	1.20					1.03			
SPECIFICATION	B.S	2.5 Min	2.5 Min	2.5 Min	3.0 MAX	30 MAX	30 MAX	35MAX	35 MAX	MAX 12	100 MIN	30 MAX	

Table 2.13 Summary of test results on asphalt aggregate in Benghazi

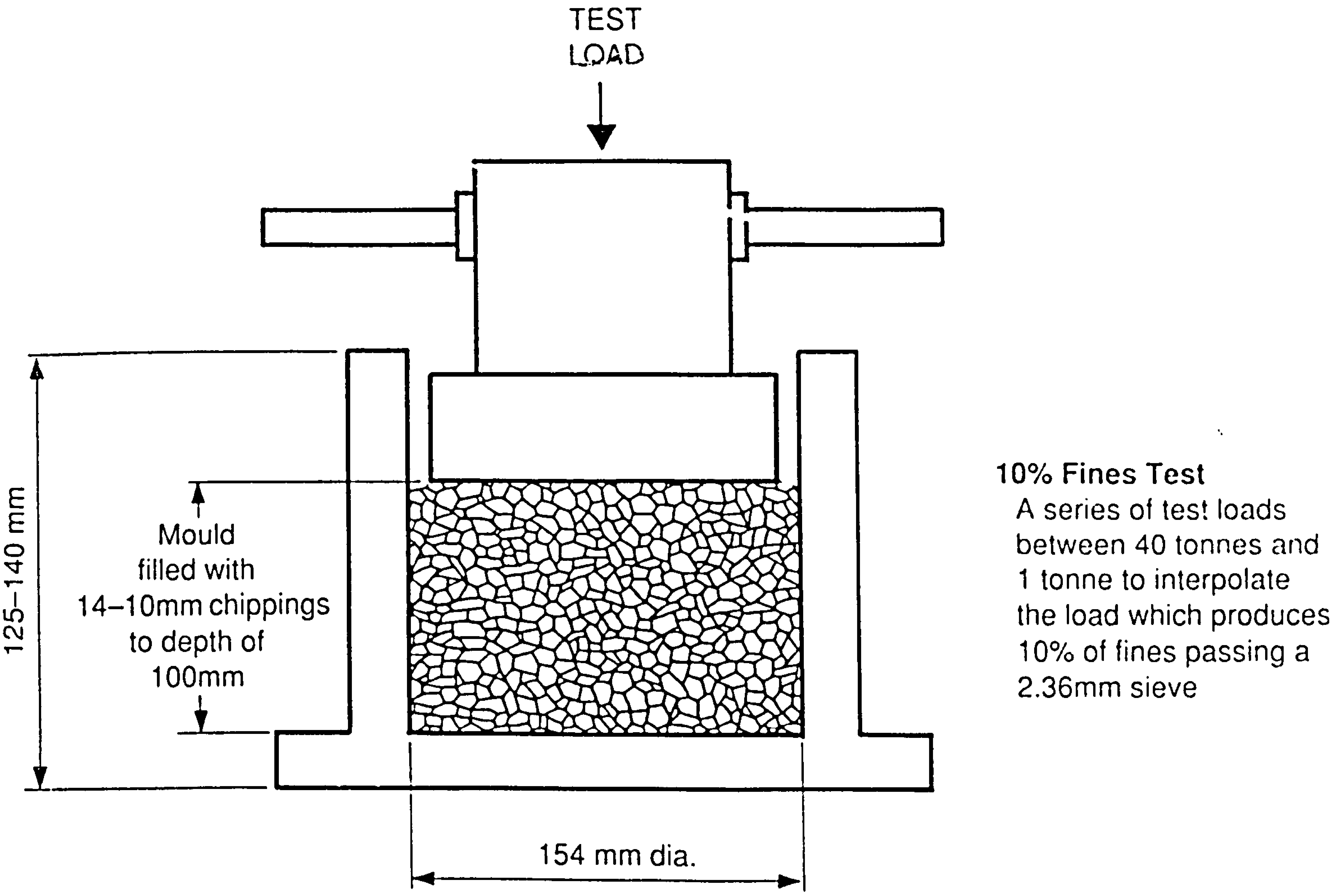


Figure 2.6 Apparatus for 10% fines test

depending on its penetration i.e. its resistance in shear deformation. The most common type of penetration-bitumen in Libya is that used in asphaltic concrete which is known as continuously graded mix (Cooper 1996). Secondly, cutback bitumen is used for lower temperature applications after blending the penetration bitumen with suitable oils to make it more fluid. Cutback bitumen is classified according to its viscosity grade. It is commonly used in surface dressing and is applied hot to the road surface before an application of chippings. Thirdly, bitumen emulsion is used cold or at lower temperatures than penetration bitumen (e.g. slurry seal, tack-coat, and surface dressing) after dispersing the bitumen in water in the presence of emulsifying agent. This type of bitumen is available in Benghazi in two forms, as MCO-2 tack coat to bind the binder course (basecourse) with the basecourse layer (roadbase), and as RC2 to bind the wearing course with the binder course (basecourse).

2.7.2.1 Penetration test

The test is carried out using a standard needle set touching the surface of a bitumen sample placed in a water bath at 25° C. The needle is released for exactly 5 seconds with 100 grams load. The penetration is recorded as the depth in tenths of a millimetre that the needle penetrates into the bitumen sample. Figure 2.7 shows the modern penetrometer used even in developing countries.

2.7.2.2 Softening point

In this test, two discs of bitumen samples contained in a standard model are placed in a water bath. Two steel balls are mounted over the centre of each bitumen disc. The water bath temperature is increased gradually by 5° C per minute and the temperature at which the steel balls fall through the bitumen discs so as to touch the plate below is the softening point of this sample. Figure 2.8 shows the apparatus used in the softening point test.

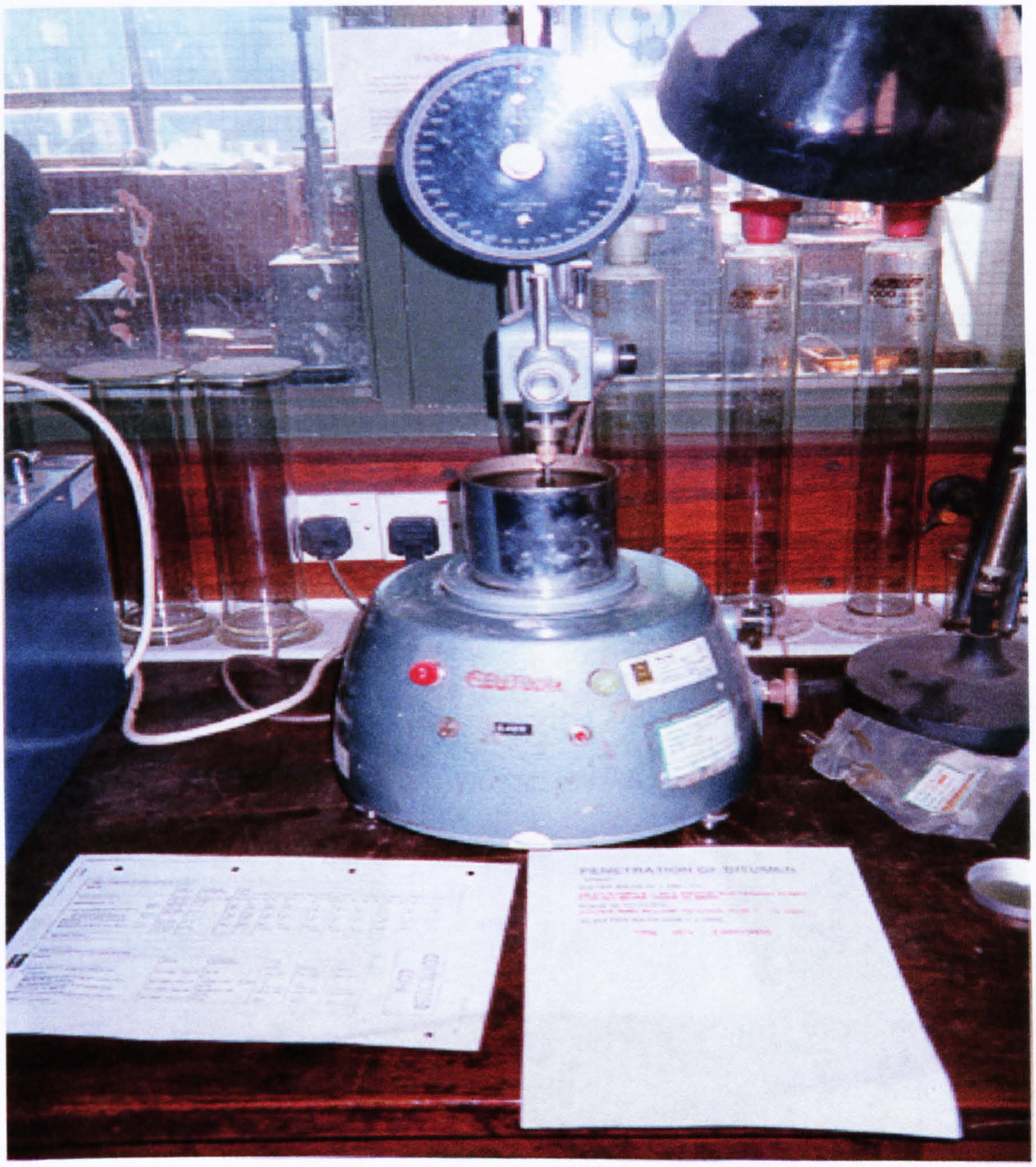


Figure 2.7 Penetration test for bitumen binder

Figure 2.8 Softening point test apparatus

2.8 Types of Bituminous Mixes in Pavements Construction

The choice of type of bituminous mixture for use on a particular road depends on certain factors. Firstly, local materials availability for making the mixture (size and type of aggregates, bitumen penetration grade). Secondly, the application for which the bituminous mixture is designed (Millard 1993). For example, high stiffness and deformation resistant mixtures are desirable for roads carrying heavy traffic. Thirdly the nature of the layer, either wearing course, basecourse or roadbase and the function of the layer, either for load bearing (roadbase), protecting other construction layers from the effects of weather (rain) or for skidding resistance as wearing course. In general, bituminous mixtures should embody the following characteristics, adequate stiffness to spread the imposed load, stability to resist deformation, durability to resist weather effect, workability for satisfactory laying and compaction and fatigue resistance to resist cracking under repeated loads. The different categories of bituminous mixes are as following.

2.8.1 Asphaltic concrete

This bituminous mixture comprises all sizes of aggregates from the maximum down to filler. The bitumen used for asphaltic concrete is normally in the range 60-100-penetration grade, with relatively high binder contents. This type has high strength and stability, with void content ranges between 3% to 5%. Asphaltic concrete mixture is widely used in Libya, with a penetration grade of 60-70 pen. Table 2.14 shows the municipality specification for asphaltic concrete mix.

2.8.2 Mastic asphalt

Mastic asphalt is not likely to be readily available in many developing countries because of its high cost and the specialist skills and equipment needed in manufacturing and laying (Millard 1993). Its high cost may be justified by its superior performance in carrying very heavy loads. This mixture has a high stiffness and strength with high resistance to deformation. It is

BENGHAZI - ASPHALT PLANT

CERTIFICATE OF QUALITY - ASPHALT

Sertificate No.: 272

Shore Tank: 105 Date Sampled: 01.08.1994

Vessel:

METHOD	TEST	RESULT
D - 70	Specific Gravity (a) 25 °C	1.0312
D - 2171	Absolute Viscosity at 60 °C Poise	2112 P
D - 2170	Kinematic Viscosity at 135 °C Cst	~
D - 5	Penetration at 25 °C, 100g. 5 Sec.	79
D - 92	Flash Point (Cleveland Open Cup) °C	260 °C
D - 2042	Solubility In Trichloroethylene % Wt	99.73
	DENSITY AT 15 °C KG/LT	1.0365
D - 1754	Thin Film Oven Test:-	
D - 6	(a) Loss On Heating at 163 °C, 5 Hrs % Wt	0.436
D - 2170	(b) Absolute Viscosity at 60 °C Poise	5312 P
D - 113	(c) Ductilityat 25 °C 5 cm / min cm	7100

30.10.94

1/8/23

Date: 01.08 CHEMIST

Table 2.14 Certificate of quality for asphaltic concrete mix in Benghazi durable and voidless with high filler and binder content and hard penetration grade bitumen (15-25 pen). In addition to its high cost, it has a smooth surface as wearing course, unless precoated chippings are rolled into the hot surface by surface dressing. Mastic asphalt mixes used in the city of Benghazi are most likely in bridge decks, building roofing or reservoirs.

2.8.3 Rolled asphalt

Rolled asphalt is a mixture of single size coarse aggregate, a graded fine aggregate and filler finer than 75 μm that fills the voids between the coarser particles during the compaction process. The nominal size and grading of the coarse aggregates depend on the use intended. The main feature of rolled asphalt surfacing material is the dense and impermeable matrix of fine aggregates and bitumen. However, it can be impervious to surface water if laid in adequate depths so basecourse and the underlying layers of the road will be protected from any deterioration owing to the entry of surface water. Like mastic asphalt, rolled asphalt is of high cost and smooth surface unless precoated chippings are used to increase the texture depth. It is not commonly used in Libya for surfacing, as the technique of rolling precoated chippings to maintain adequate texture depth for users safety is not yet adopted.

2.8.4 Coated macadam

The essential feature of coated macadam mixtures is the size and grading of aggregates, the mixtures range from open-grade through close-grade to dense coated macadam. Different categories of coated macadam are used as road base, basecourse and wearing course. The main ingredients of coated macadam are the aggregates of different types and grading, filler (natural dust, ground limestone and Portland cement) and binder of different penetration grade. These types of bituminous mixes gain their strength and stability from the internal friction and mechanical interlock between the aggregate particles. Therefore, the resistance to permanent deformation is high.

In the city of Benghazi, it is recognised that most pavement problems are initiated by water (Chapter 4), either surface precipitation or utilities water (storm, foul), in conjunction with lack of road maintenance. Therefore, it should be recommended that, dense and impermeable mixtures (mastic, hot rolled asphalt) be used for roadbases and basecoures. Moreover, mixtures of high texture depth are used for wearing course to reduce spray and standing of surface water and therefore increase skidding resistance. Table 2.15 shows a comparison between the different bituminous mixtures and their main composition.

2.9 Modes of failure in flexible pavement

Pavement structures deteriorate gradually with time to a terminal level that may be considered as failure. For example, the failure level criterion in the UK is taken to be a 20-mm rut depth in the nearside wheel track or extensive cracking (Brown 1996). Modes of failure in flexible pavements of bound roadbases are illustrated in Figure 2.9. They are (A) Horizontal strain at the bottom of the bound layer causing the upward propagation of vertical cracks through this layer (fatigue cracking). (B) Vertical strain at the top of the subgrade, causing consequent deformation in the bound, unbound layers which in severe cases may extend to the surface (permanent deformation) (Watson 1994).

2.9.1 Fatigue cracking

Fatigue cracking is one of the primary distress modes in flexible pavements. However, "fatigue in bituminous pavements is the phenomenon of cracking. It consists of two main phases; crack initiation and crack propagation and is caused by tensile strains generated in the pavement by not only traffic loading but also temperature variations and construction practice" (Read 1996).

Temperature variations in pavements will cause expansion and contraction in the pavement structure, and differential movement between pavement layers. Thereby, this will generate tensile strains in the pavement causing a reduction in the fatigue life of the structure.

Table 2.15 Comparison of composition and properties of different bituminous mixes (BACMI 1992)

Type of mix	Fine graded macadam	Dense macadam/ Asphaltic concrete	Pervious macadam	Mastic asphalt	Rolled asphalt
Composition					
Coarse aggregate content	—	Medium	High	Low	Low
Fine aggregate content	High	High	Low	High	High
Filler content	Medium	Medium	Low	High	High
Binder content	Medium	Medium	Low	High	High
Binder grade	Soft	Medium/Hard	Hard	Very hard	Hard
Properties					
Void content	Medium	Low	High	Nil	Low
Structural contribution	Low	High	Low	High	High
Deformation resistance	Low	High	Medium	Medium/High	High
Weather resistance	Low	Medium	Low	Very high	Very high
Texture depth	Poor	Poor	Good	Good(chipped)	Good(chipped)
Spray & Noise reduction	Poor	Poor	Very good	Poor	Poor
Workability	High	Low	Medium	Low	Medium
Cost	Low	Medium/High	High	Very high	Medium/High

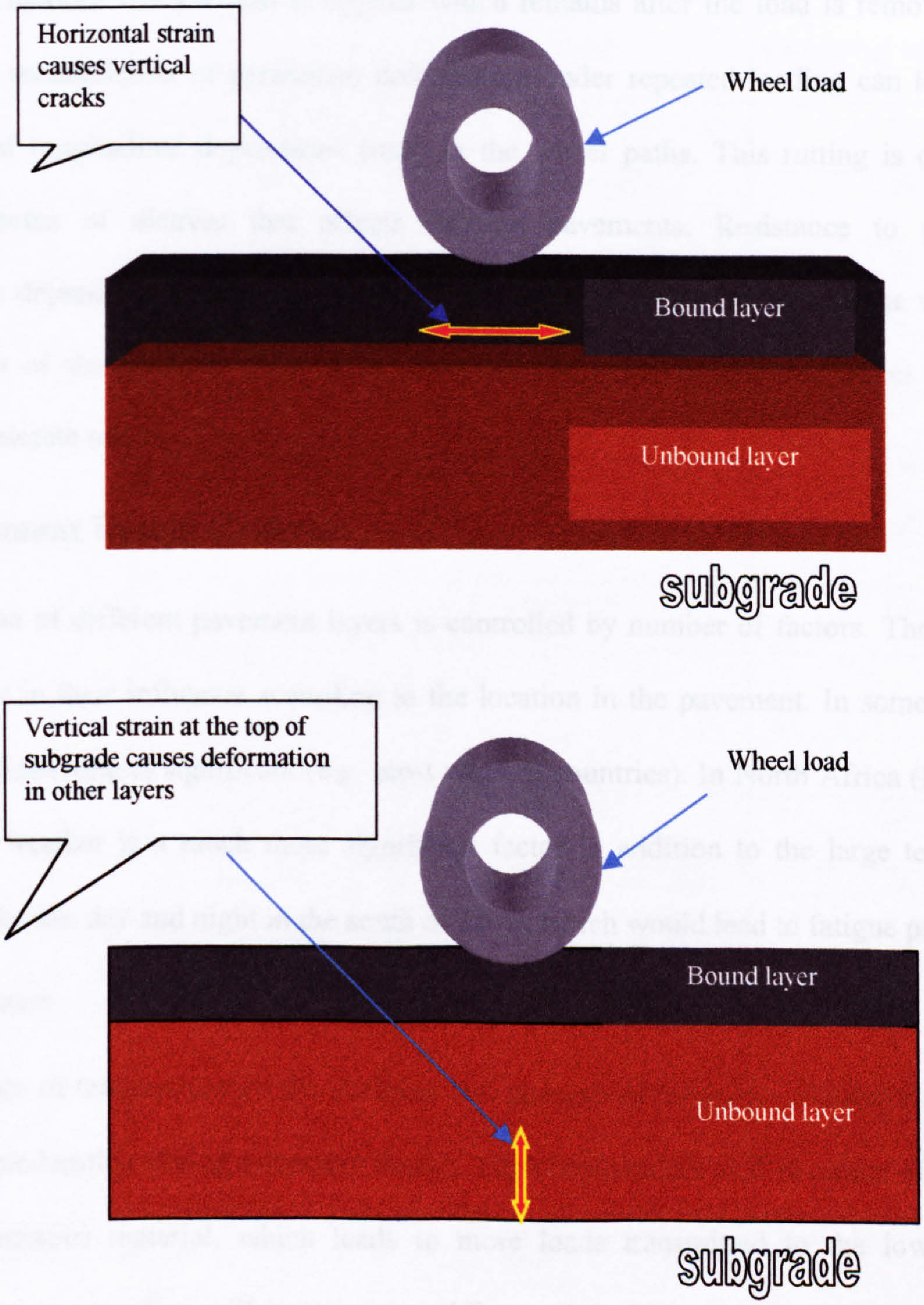


Figure 2.9 Modes of failure in flexible pavement

2.9.2 Permanent deformation

Permanent deformation in pavements occurs as a result of vertical strain induced in a bituminous mixture when a load is applied which remains after the load is removed (Gibb 1996). The accumulation of permanent deformation under repeated loading can lead to the formation of longitudinal depressions (ruts) in the wheel paths. This rutting is one of the principal forms of distress that affects flexible pavements. Resistance to permanent deformation depends to a great extend upon the properties of the binder and the volumetric composition of the mixture. Table 2.16 illustrates the main factors that affect rutting of asphaltic concrete mixes.

2.10 Pavement Design Criteria

The selection of different pavement layers is controlled by number of factors. These factors are different in their influence according to the location in the pavement. In some countries freezing and thawing is significant (e.g. most western countries). In North Africa (Libya) hot and humid weather is a much more significant factor in addition to the large temperature variation between day and night in the south of Libya which would lead to fatigue problems.

2.10.1 Climate

The influence of temperature on the stiffness and strength of bituminous material should be taken in consideration during pavement design. High temperature will decrease the stiffness of the bituminous material, which leads to more loads transmitted to the lower layers. However, low temperature will increase the stiffness of the bituminous material and make it brittle which, may results a splitting between the aggregate and the binder (Crony & Crony 1997).

A study of the climatic conditions in Libya (Elazzabi 1975) has emphasised that in a country like Libya where approximately 90% of its land is desert, the climate is characterised by sandstorms high temperatures and shortage of water (rainfall). The coast which, is about 1800

Table 2.16 Factors affecting rutting of asphalt concrete mix (Gibb 1996)

	Factors	Change in factor	Effect of change in factor on rutting resistance
Aggregate	Surface texture	Smooth to rough	Increase
	Gradation	Gap to continuous	Increase
	Shape	Round to angular	Increase
	Size	Increase in maximum size	Increase
Binder	Stiffness	Increase	Increase
Mixture	Binder content	Increase	Decrease
	Air void content	Increase	Decrease
	VAM	Increase	Decrease
	Method of compaction	*	*
Test/field condition	Temperature	Increase	Decrease
	State of stress/strain	Increase in tyre contact pressure	Decrease
	Load repetitions	Increase	Decrease
	Water	Dry to wet	Decrease if mix is water sensitive

* The method of compaction may influence the structure of the system and therefore the propensity for rutting

Km long (from Tunis to Egypt) is under the influence of both the Mediterranean basin from the north and the desert from the south. Summer is hot and dry and winter is cool and wet in some places, particularly in the north (Benghazi). Rainfall throughout the country is erratic, although it is not plentiful it comes in the form of heavy downpours. This amount and form of runoff can reach damaging levels and causes serious road deterioration. However, the road surface may be washed away if an adequate drainage system is not included in the road design or if the road has not been maintained before the first onset of the rainy season. The most common winds at Benghazi blow from the Northeast and from the North during summer and from the Northwest, West and Southwest during winter. The wind velocity exceeds 60 Km/hr during winter and spring and reaches its minimum during summer. During autumn, the city of Benghazi experiences dust storms blowing from the south (desert), causing two principal highway problems. Firstly, formations of sand or dust film on the road surface, which reduces the skidding resistance and therefore causes, hazard to road users. Secondly, poor visibility because of thick clouds of dust in the air, which restricts the visibility to not more than 150 to 200 metre.

2.10.2 The bearing capacity of the subgrade

The mechanical properties of all pavement materials and soils are to some extent adversely affected by water (Brown 1996). It is important that the subgrade and the granular layers should be well drained, as their bearing capacity depends on their moisture content condition. Subgrade of high moisture content will require a strong foundation of granular material with intermediate mechanical performance between the subgrade soil and the roadbase (sub-base). In some cases, a capping layer of lower quality of granular material will be essential over the subgrade in order to act as a working platform and to provide resistance to compaction effort.

2.10.3 Traffic loading

The number and volume of traffic expected to pass over the pavement construction has a great influence on pavement design. The different road categories (trunk roads, principal roads.... etc.) in the network are classified according to their volume of traffic and the importance of the road in the network. The most important design criteria are listed in TRRL laboratory report (Powell 1984) which can be summarised as following;

- subgrade should be able to withstand loads imposed by traffic without excessive deformation. However, this can be achieved by determining the vertical compressive stress or strain at the formation level,
- Roadbase materials (bituminous or cement-bound) must not crack under the influence of traffic. This is controlled by the horizontal tensile stress or strain at the bottom of the roadbase,
- Sub-base and capping layers must be capable of adequately spreading the loads imposed, in order to provide a satisfactory foundation and working platform.

2.11 Pavement defects

Roads carrying regular traffic flow will deteriorates by time. This deterioration may extend to a more serious stage if it is not maintained at the right time with the proper remedy. The common defects and their remedy that usually occur in flexible pavement are varying according to the function of the defective part of the road. Firstly, structural maintenance is undertaken to protect the structural integrity of the existing road by carrying a regular assessment of road conditions in terms of deflection and surface condition. Secondly, safety maintenance is undertaken to provide the adequate skid-resistance and riding quality to the road users, and to keep the traffic signs legible and visible to minimise road hazard. Finally, environmental maintenance is undertaken to preserve the amenity aspect of the roads by carrying out proper maintenance and cleaning of the drainage systems. This will ensure adequate flow of water from the road surface to avoid any serious structural or foundation deterioration owing to water penetration.

The most common defects that usually occur on any flexible pavement are as follow:

2.11.1 Loss of skidding resistance

The loss of skidding resistance on the pavement surface occur when there is a difference between the required and the actual values of friction force coefficient (para.3.4.2.) at a particular location. However, appropriate treatment is recommended when this defect is recorded in 30% or more of the sub-section length (Weller 1980). Pavement skid resistance is a very important factor in terms of road user safety (Kalombaris 1990). The value of the friction between the road surface and the vehicle tyre depends on the vehicle speed, the road surface condition (wet or dry) and the type of aggregates used and its polishing value. The level of skidding resistance depends on the following factors.

2.11.1.1 Aggregate's polished-stone value

In order to maintain an adequate skidding resistance for the road surface, it is essential to use aggregates with high polishing resistance to provide good micro-texture surface. Table 2.17 gives the required values of SFC at speed of 50 km/h for different sites. To achieve the required value of SFC for each site, it is necessary to use suitable aggregates which have the required value of polishing and abrasion. Table 2.18 shows the required Polished Stone Value (PSV) and Abrasion Aggregate Value (AAV) in relation to the traffic volume on the road surface

2.11.1.2 Depth of road surface texture

The surface texture depth (macro-texture) depends on the type of surfacing material used. Table 2.19 shows the different types of surfacing material and the required texture depth for each type, in the case of high-speed skid resistance, macro-texture has a significant role to minimise the risk of skidding. Deep macro-texture allows water to flow through its natural

Table 2.17 Minimum values of skidding resistance at speed of 50km/h (Salt 1977)

Site	Definition	SFC(at 50 km/h)									
		Risk rating									
		1	2	3	4	5	6	7	8	9	10
Very difficult	Approaches to traffic signals or pedestrian crossing						0.55	0.6	0.65	0.7	0.75
Difficult	Approaches to major junctions, roundabouts, bends with radius less than 150 m on roads with speed limit > 40 mph				0.45	0.5	0.55	0.6	0.65		
Average	Straight sections of motorways, trunk and principle roads	0.3	0.35	0.4	0.45	0.5	0.55				
Easy	Straight with light traffic	0.3	0.35	0.4	0.45						

Table 2.18 Values of PSV and AAV to achieve the required SFC (Salt 1977)

Required SFC at 50 Km/h		PSV					
		Traffic (in commercial vehicles per lane per day)					
		250	1000	1750	2500	3250	4000
0.30		30	35	40	45	50	55
0.35		35	40	45	50	55	60
0.40		40	45	50	55	60	65
0.45		45	50	55	60	65	70
0.50		50	55	60	65	70	75
0.55		55	60	65	70	75	-
0.60		60	65	70	75		
0.65		65	70	75			
0.70		70	75				
0.75		75					
AAV	Chipped surfacing	14	not > 12		not > 10		
	Macadam	not > 16		not > 14		not > 12	

Table 2.19 Texture-depth of bituminous surfacing (BACMI 1992)

Surfacing material	Texture depth (mm)
Dense bitumen macadam wearing course	0.6-1.2
Rolled asphalt wearing course(lightly chipped)	0.7-1.2
Rolled asphalt wearing course(heavily chipped)	1.2-2.0
Open textured macadam wearing course	1.5-2.5
Pervious macadam wearing course	2.0-3.5
Surface dressing	2.0-3.5

channels on the surface to prevent the presence of water film between the tyres and the road surface.

The texture depth of a road surface can be measured by using a simple test on site called the Sand-patch test (Figure 2.10). A specific volume of sand is slowly spreaded in a circular shape to fill the surface voids at the tested point in the road. The measured diameter of the sand gives an indication of the texture depth, whereby the smaller the sand-patch diameter the deeper the surface texture.

2.11.1.3 The traffic volume

The volume of the traffic running on a road surface has an affect on the level of skidding significantly during the first year of the road life. Heavy and high-speed traffic causes a rapid wear to the road surface texture.

2.11.1.4 Tyres tread pattern

In the case of wet conditions, the tyre tread pattern provides drainage channels with the road surface to allow surface water to flow beneath the tyre. However, in dry condition, smooth tyres showed better resistance to skidding force than a pattern tyres (Rhodes 1996). In the case of high speed, the need for tyre tread pattern in conjunction with adequate macro-texture is crucial to reduce the risk of skidding (Rhodes 1996).

2.11.2 Rutting in the wheel paths

Rutting is the permanent deformation of the pavement owing to the regular passing of commercial vehicles and buses over a pavement (Wingate & Peters 1975). Wheel track rutting can be an indicator of surface, structure or foundation failure based on the depth and width of the rut. Narrow ruts of 0.75 metre or less, will normally be associated with surface failure and wider ruts of one metre or more are associated with structural failure. Foundation

Figure 2.10 Sand-patch test

failure might be associated with ruts which are more than 1.5 metres wide (Kennedy 1996 **)[1].

The depth of the rutting is not always an indication of pavement structural failure, especially if not associated by cracking (Weller 1980). Therefore, ruts associated with surface failure are termed wheel track rutting (hazard and nuisance) and ruts associated with structural failure are termed wheel track rutting (structural). Table 2.20 shows the different classification of road surface condition according to the depth of rutting and the size of the cracks at the wheel path.

2.11.3 Deflection

The assessment of the structural condition of road pavement in the UK was in the early 1950s (Ju-kun pan 1994), using a deflection beam. Currently, the measurement technique of road deflection in UK is carried out using automated deflectographs (Hosking 1996). Therefore, following this concept and developing an assessment of road defects techniques in developing countries can be justified. Pavement deflection is the magnitude of the transient deformation which occurs under traffic load and it may be important to carry out deflection surveys regularly for two reasons;

- to predict the ability of the tested road to carry the future traffic load,
- to predict the ideal time for strengthening and the required thickness of overlay for the road pavement (Smith & Jones 1980).

Because asphalt is a thermo-plastic material, bituminous pavements are hard in cold condition and soft in hot condition. Because of this phenomenon, its stiffness is influenced by the change in temperature and therefore, the measured deflection is affected as well. However, the best time to carry out a deflection survey is during the spring and autumn seasons. The pavement temperatures at that time are between 10 and 30^0 C, and the yearly variation in

---

[1] ** Personal communication through E-mail

Table 2.20 Classification of Road Surface Condition in Terms of Rutting
(Weller 1980)

Classification	Code	Visible Evidence
Sound	1	No cracking. Rutting less than 5 mm
	2	No cracking. Rutting from 5 mm to 9 mm
Critical	3	No cracking. Rutting from 10 mm to 19 mm
	4	Cracking limited to single crack or extending over less than half of the width of the wheel path. Rutting 19 mm or less
Failed	5	Multiple cracking covering the greater part of the width of the wheel path. Rutting 19 mm or less.
	6	No cracking. Rutting 20 mm or more
	7	Cracking same as code 4. Rutting 20 mm or more
	8	Cracking same as code 5. Rutting 20 mm or more

subgrade moisture contents and hence subgrade stiffness, is generally small (Kennedy 1978). The pavement temperature is recommended to be measured either at the pavement surface or at standard depths of 40 mm and 75 mm based on the bituminous layers thickness.

2.11.4. Cracking

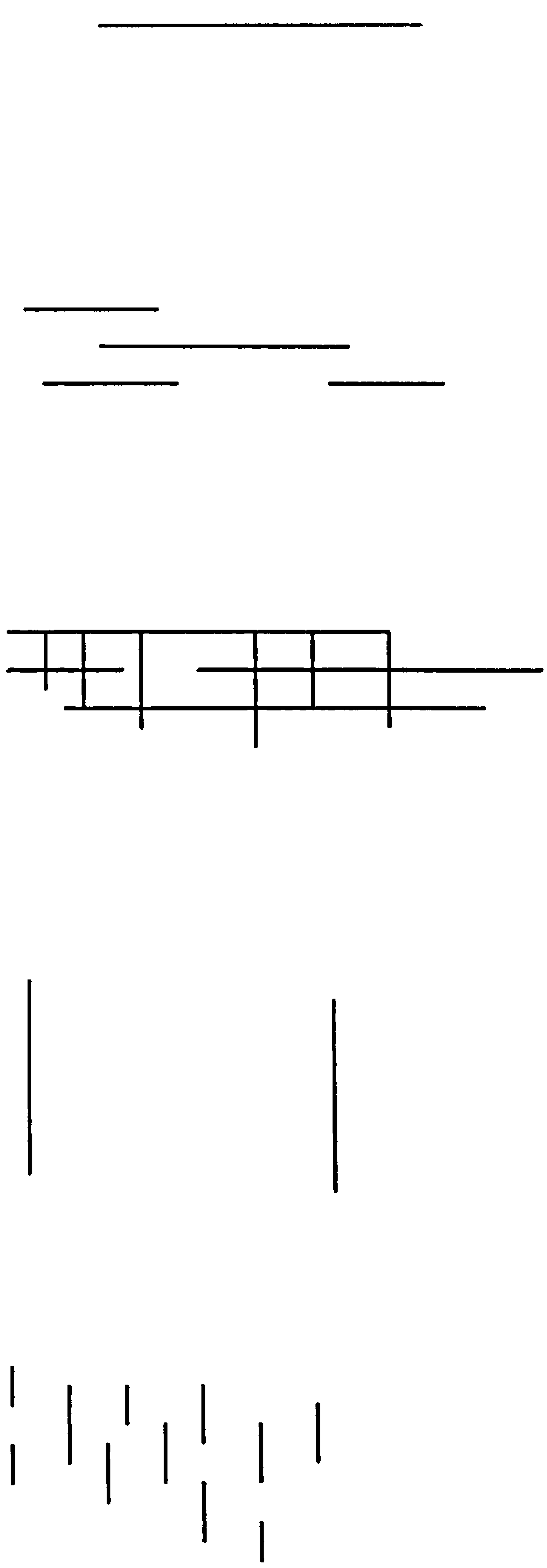
The visual appearance of cracks on pavement surface is one of the evident indications of pavement distress (Thom 1996). The different cracks pattern and types imply different modes of distress (Figure 2.11).

- **single longitudinal crack** is a classic fatigue cracking of a relatively thick pavement structure,
- **Multiple longitudinal cracks** are indication to either thinner pavement structure or a surface effect,
- **Crazing crack** is an advanced stage of pavement deterioration and its block size is related to the thickness of the cracked layers,
- **Regular transverse cracking** is often related to thermal cracks in a cement bound base,
- **Multiple transverse cracking** is most probably shallow cracks initiated during rolling.

2.12 Discussion

This Chapter has reviewed the principals of pavement engineering, the role of the different layers and the most common bituminous material, which are used in road construction, in order to understand the mechanisms of pavement performance and to assess subsequently generated data in an informed manner. In addition, the properties of the material used in the city of Benghazi road construction are described. Knowing the soil properties on which the pavement layers will be constructed and the composition and behaviour of the bituminous mixes will have a significant role in setting a cost effective repair to each pavement defect.

The different systems employed to assess a road condition and the suitable remedy to each defect in the road networks are discussed in details in Chapter 3, in order to emphasise the importance of establishing a proper maintenance management system from aspects, economically, socially and environmental.



Single longitudinal cracks

Multiple longitudinal cracks

Crazing cracks

Regular transverse cracking

Multiple transverse cracking

Figure 2.11.Different cracks patterns appear on pavement surface

CHAPTER 3

ROAD MAINTENANCE MANAGEMENT

Contents:

CHAPTER 3

ROAD-MAINTENANCE MANAGEMENT

3.1 Introduction

One of the objectives of this thesis is to consider the existing systems for monitoring pavement conditions and to evaluate the benefits of using sophisticated technology in assessing highway conditions. Moreover, to discuss the possibility of establishing a maintenance management system in the city of Benghazi, using a monitoring system appropriate to the city maintenance strategy, which at present militates against using western monitoring systems for road condition assessment.

The aim of highway maintenance management is to keep roads in good or acceptable condition through their design life for the least expenditure. Regular roads maintenance is crucial to achieve this aim and to prevent rapid premature deterioration of roads. A pavement management system (PMS) is a set of tools or methods that assists decision makers in finding optimum strategies for providing and maintaining pavements in serviceable condition over a given period of time (Hudson 1987). Pavement Management System (PMS) has to satisfy the need for effective management and control of road networks maintenance using need-based budgeting (Brain 1985).

A PMS can increase the efficiency of decision-making, provide easy access to road condition data, assess maintenance needs against defined standards, and determine the factors that may contribute to pavement deterioration (climate, traffic, mix design of bituminous material).

PMS is an established documented procedure which, links and arranges all of the activities involved in Pavement Management in a systematic and co-ordinated manner.

3.2- Procedures to establish PMS

There are four principal sequential steps required to establish an adequate Pavement Maintenance Management System for a road networks (Overseas Road Note 1 1987).

3.2.1-Network Referencing

Each length of road in the network must be defined by a unique reference code, either by using numbers or by a combination of numbers and letters. In each road, lengths with similar characteristic (traffic volume, category, and design) are divided into sections which must be referenced with a unique node code at the junctions.

3.2.2- Set-up of Minimum Inventory

A team of trained inspectors must survey the whole road network to collect and set-up a minimum inventory for each road. The inventory may consist of the number of lanes in the road, the width, the drainage system and whether the road is double or single carriageway. The inventory must comprise the essential data required only to avoid any delay or extra cost during the processing of the maintenance system activities.

3.2.3-Network Historical Data

Historical information about each road in the network is required to link this information with other factors which affect the carrying out of suitable maintenance activities, such as axle load, environmental considerations and material available. Historical information may comprise the following: -

- construction record,
- maintenance history,

- traffic flow and loading.

3.2.4-Assessment of road condition

The road condition data can be collected by using either visual survey systems (para. 3.4.1) or machine-based systems (para. 3.4.2), depending on the budget allocated to the maintenance sector, the skill of the inspection team and the type of defect to be inspected.

3.3-Components of Maintenance Management System

ORN1 (Overseas Road Note 1 1987) and ORN2 (Overseas Road Note 2 1987) together comprise a practical guide to the management of maintenance operations. They are useful documents for improving efficiency and making more productive use of maintenance resources (ORN1 1987). ORN1 and ORN2 are published by the Overseas Unit of the Transportation and Road Research Laboratory (TRRL), in order to improve road maintenance practices in developing countries. ORN1 outlines the maintenance operations required to keep roads in good condition; the note does not cover any form of road improvement work, pavement strengthening or reconstruction activity (ORN1 1987). ORN1 gives advice leading to good maintenance practice in a restricted area, but for any large highway network, the savings in the maintenance budget achieved by following the ORN1 techniques are not substantial (Kerali 1986).

To carry on with an efficient maintenance system, a sequence of tasks must be assigned to the maintenance team (the maintenance engineers, inspectors....) throughout the period of the maintenance system implementation. Overseas Road Note 1 (ORN 1 1987) has described these tasks in detail to assist and boost the maintenance team with the instructions required to carry out a proper maintenance system.

3.3.1-Inventory

The inventory is a set of information about the basic engineering and traffic characteristics of the road network to give an indication of the level of traffic and the main features of each section of road. The inventory should be kept as simple as possible and should include only the necessary information about the road network so as to avoid gathering unnecessary information and thus slow the operation of databases in the case of computer-based systems. This type of information may includes the following:

- type of surface and construction,
- cross-section width,
- traffic volume (number of vehicles per day),
- location of junctions,
- road furniture (guard rails, road signs...),
- rainfall in the city,
- other structures in the road (pipe culverts, bridges...).

Overseas Road Note 1 has presented the information which, can be recorded in an inventory using three useful approaches (Overseas Road Note 1 1987).

- A diagrammatic map in which a general road plan of the area is shown in terms of construction type, width of lanes, traffic levels and category of road surface (Figure 3.1)
- A strip map used as a quick means of reference during the inspection. The strip map records only the significant information about a section of road (Figure 3.2)
- A card index, which is a system used to record details about specific items such as road signs and highway structures

KEY

Category	Annual average Daily Traffic	Surface Type	Width m.
2	1000+	Bituminous	7.0
3	500–1000	Bituminous	7.0
4	200–500	Bituminous	5.0–7.0
5	>200	Gravel.	7.0
6	<200	Bituminous	5.0
7	50–200	Gravel	5.0
8	up to 50	Earth	3.5

Major Bridge (Reference No.)

Sub–Standard Alignment

Principal Towns

Scale 0 10 20 30 40 50 km

INVENTORY

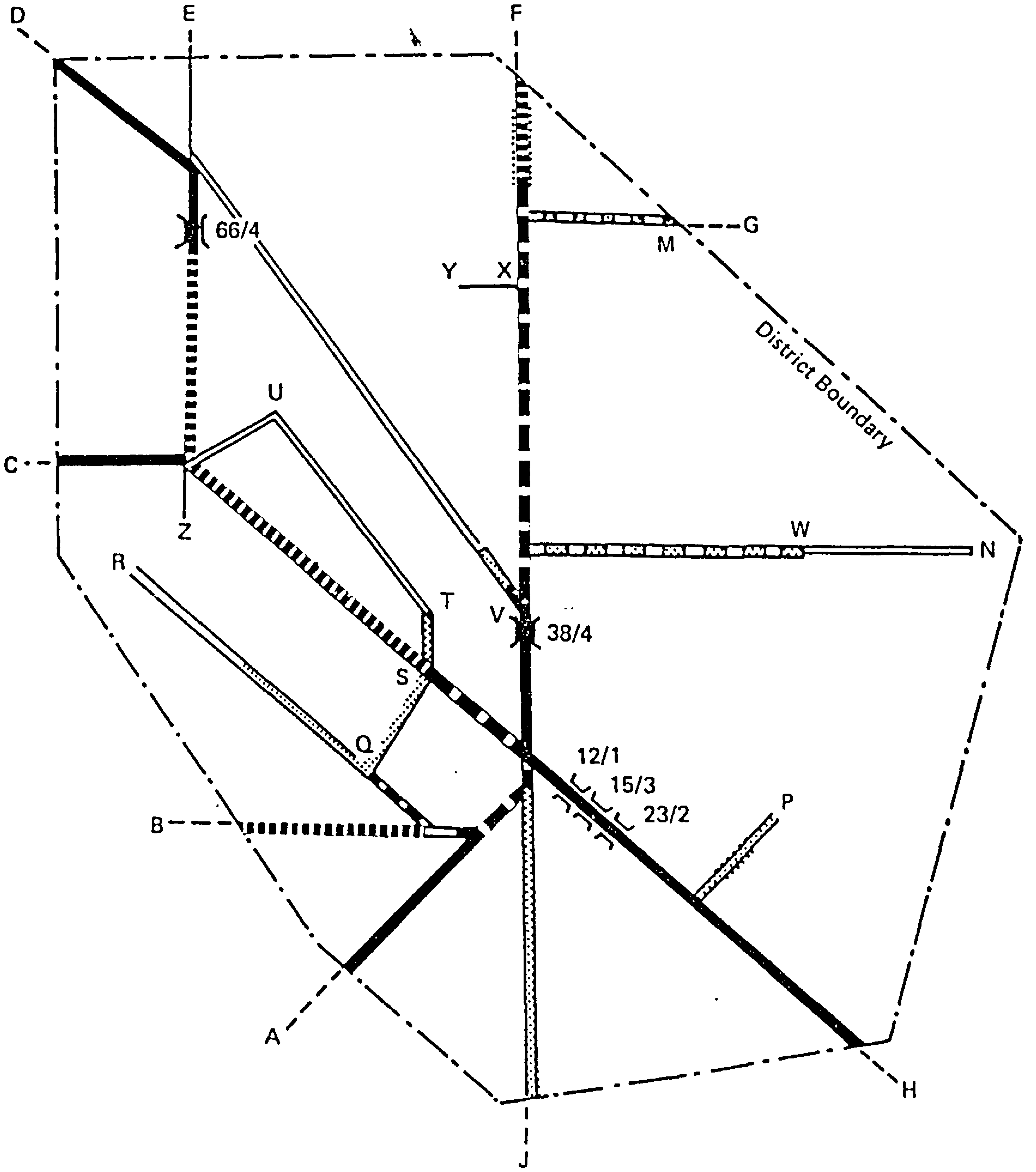


Figure 3.1 Diagrammatic map

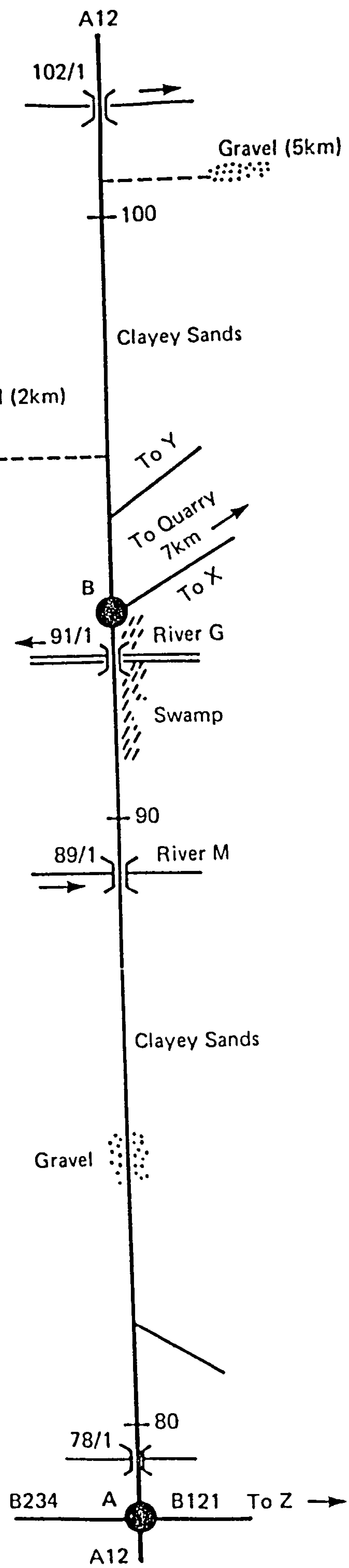


Figure 3.2 Strip map

3.3.2-Inspection

The maintenance team must carry out an inspection survey throughout a road section in order to measure the level of deterioration which, has occurred and so define the required maintenance. Overseas Road Note 1 (ORN1 1987) has emphasised the importance of a site visit by the Maintenance Engineer to determine the level of work and to assess the site requirement. Overseas Road Note 1 (ORN 1 1987) has presented two standard inspection forms (Figures 3.3 and 3.4) to be used during the site inspection; one for paved roads and the other for unpaved roads. The inspection form should be easy to understand and complete and the results filled in accurately throughout the inspection.

3.3.3-Maintenance needs

The Maintenance Engineer must decide the maintenance needs and the required form of maintenance activity (para.3.3.5). Overseas Road Note 1 presents in tables, the intervention levels for the different defects in both paved and unpaved roads in addition to the action and the maintenance activity required for each defect. The intervention level is the stage at which there are indications that a road section needs action to prevent any further deterioration. Therefore, the pavement maintenance policy is defined as a series of intervention levels (Brain 1985). These levels are variable and depend on road category in the network and the type of defect that has occurred in this category.

3.3.4-Estimation of Resources (Costing)

After identifying the maintenance needs in terms of intervention levels, it is important to determine the resource requirement in terms of labour, equipment and materials required to carry out the required work. Overseas Road Note 1 emphasises the importance of identifying the method used to carry out the work (manually or using machinery) to estimate the amount

UNPAVED ROAD INSPECTION REPORT

ROAD NO.	SUB-SECTION NO.	DATE	START km	INSPECTOR	SURFACE TYPE

		Distance	0	25	50	75	0	25	50	75	0	25	50	75	0	ACTION REQUIRED
LEFT	Side drain /turnout	Silt														
		Scour														
	Shoulder	Deform.														
		Scour														
		Vegetation														
Gravel thickness																
RIGHT	Shoulder	Vegetation														
		Scour														
		Deform.														
	Side drain /turnout	Scour														
		Silt														
Notes/comments																
MONITORING	Camber															
	Longtd. Deform.															
	Rutting															
	Corrugations															
	Pot-holes															
Notes/comments																

Figure 3.3 Inspection form for unpaved roads

PAVED ROAD INSPECTION REPORT	DATE			INSPECTOR			
ROAD NO.		SUB–SECTION NO.		START km		PAVEMENT TYPE	

Distance			0	25	50	75	0	25	50	75	0	25	50	75	0	ACTION REQUIRED
LEFT	Side drain /turnout	Silt														
		Scour														
	Shoulder	Deform														
		Scour														
		Vegetation														
	Edge step															
	Edge damage															
CARRIAGEWAY	Rutting															
	Cracking	Wheeltrack														
		Other														
	Stripping/fretting															
	Pot-holes															
	Fatting-up/bleeding															
	Lane marking															
RIGHT	Edge damage															
	Edge step															
	Shoulder	Vegetation														
		Scour														
		Deform.														
	Side drain /turnout	Scour														
		Silt														
Notes/comments																

Figure 3.4 Inspection form for paved roads

of labour and equipment required. The required materials are estimated from inspection results as quantities and measurements. Overseas Road Note 1 presents tables which include the different activities on a site and the required men, equipment and materials for each activity in order to allocate the available budget efficiently.

3.3.5-Priorities

In the case of inability to fulfil the full program of work owing to a shortfall in budget allocations, Overseas Road Note 1 suggests a method of setting priorities. This method depends on the importance of a particular maintenance activity to the traffic performance of the road, and the importance of the particular road in the network. Therefore, top priority for maintenance must be given to both the strategically important roads in the network and the roads that carry the heaviest traffic in terms of frequency and weight. Table 3.1 shows road maintenance classification based on the category of importance as presented in Overseas Road Note 1, where strategic roads have top priority whatever the traffic flow because of the important links that those roads have with other roads in the network. Therefore, regular maintenance activities must be carried out throughout the network to keep the roads open to traffic most of the time.

Overseas Road Note 1 classifies the different maintenance activities to be carried out regularly throughout the network as follow.

- Urgent: for unforeseen or emergency repairs which demand top priority.
- Routine: to be carried out whatever the road condition.
- Recurrent: to be carried out at intervals during the year.
- Periodic: required only at intervals of several years.

- Special: covering the high cost maintenance such as overlaying and reconstruction. This activity to be treated as capital projects which, may not be covered by the regular maintenance budget.

Table 3.2 sets out the different maintenance activities by category of priority based on the importance of the road and the traffic level, in which 1 denotes high priority to urgent maintenance on strategic roads and 48 denotes low priority for special works on unpaved roads.

Table 3.2 is suggested by Overseas Road Note 1 to ensure that every road in the network receives the minimum maintenance required to keep the road in service. The list of priorities in Table 3.2 can be re-ordered to suit the local conditions for any highway network. There are many local conditions which may influence maintenance requirements such as soil type, topography and climate. Therefore, an accurate inventory for each single road in the network would play a significant role in producing the ideal list of priorities for different road categories. It is important to compare the actual costs of the proposed maintenance work and resource with available funds. This would assist the maintenance engineer in deciding which task can be included in the current financial year and which can be postponed to next year.

3.3.6-Scheduling and Execution

Overseas Road Note 1 recommends the scheduling of the work details to identify to the maintenance team how much work is to be done each day and the required resources. Overseas Road Note 1 has presented a simple worksheet form for work scheduling in order to arrange different work elements such as target production, resources, period of time and activity location.

Table 3.1 Roads classified by category of importance

TRAFFIC CATEGORY	ANNUAL AVERAGE DAILY TRAFFIC AADT	SURFACE TYPE
1	Strategic roads	Paved
2	> 1000	Paved
3	500-1000	Paved
4	200-500	Paved
5	> 200	Unpaved
6	< 200	Paved
7	50-200	Unpaved
8	< 50	Unpaved

Table 3.2 Maintenance priorities based on road traffic category

Category of Maintenance activity	Priority							
	Traffic category							
	1	2	3	4	5	6	7	8
Urgent	1	7	8	9	10	11	12	13
Routine maintenance	2	14	15	16	17	18	19	20
Recurrent work	3	21	24	27	30	33	36	39
Periodic work	4	22	25	28	31	34	37	40
Other routine work	5	23	26	29	32	35	38	41
Special work	6	42	43	44	45	46	47	48

3.3.7-Monitoring

Monitoring is important from two aspects. Firstly, to ensure the quality and effectiveness of the work carried out and secondly to provide the essential data that is required to make adjustments to future maintenance operations. The monitoring task consists of both field inspection and desk review. Therefore, Overseas Road Note 1 has focussed on the role of the maintenance engineer site inspection to gain the following advantages.

- To check the quality of the work and the labour's skill.
- To make a personal assessment of the condition of the roads.
- To discuss problems on site directly with the staff concerned

Overseas Road Note 1 recommends a desk review for all the maintenance documentation (reports, requirement forms, work schedules) to assess the degree of success in the programmed work and to plan for future work. The office work will give an indication of the accuracy of resources allocation.

ORN1 comprises very useful recommendations for improving maintenance methods and it could be an initial step towards establishing a maintenance strategy in a city like Benghazi. The road authority in the municipality of Benghazi (and Libya in general) is responsible for a large and high standard highway network, without establishing any formal maintenance strategy to maintain it (see Chapter 4). Therefore, following the recommendations cited in ORN1 and ORN2 and encouraging the engineers and technicians to adopt their techniques may lead to establishing the first proper maintenance strategy in the city. However, the need for comprehensive and powerful maintenance management systems for cities in developing countries and particularly the city of Benghazi is apparent. Other systems for maintenance management and road investment appraisal are described elsewhere in this chapter (Para. 3.4)

3.4 Road Condition Assessment Systems

A road network's condition can be surveyed and assessed by using either visual inspection systems or machine-based systems. On occasions, both systems may be used together. The decision to choose a suitable system for a road network depend on the size of the road network, size and type of inspection and survey required and the budget allocated to this task.

3.4.1-Visual Inspection Systems

There are many assessment systems based on visual evidence from the inspection team. The best known and most widely used systems in the UK are CHART (Computerised Highway Assessment of Rating and Treatments), and MARCH, (Maintenance Assessment, Rating and Costing for Highways). The Burrow Snaith maintenance management system (BSM) is used in developing countries.

3.4.1.1 CHART System

The Report of the Committee on Highway Maintenance (The Marshall Report 1970) included recommendations on standards of maintenance for use by highway authorities. These recommendations show how to inspect road's conditions by applying ratings to those standards to assist in the determination of priorities for remedial treatment (Wingate and Peters 1975). CHART is a visual survey system to assess the road condition. This system was designed and developed by TRRL (Transport and Road Research Laboratory) to assess and record the visual condition of a road by site inspectors using a mainframe or minicomputer to produce management information. CHART is a management system used to assist the highway maintenance engineer in assessing the structural maintenance needs of highways, using factual data of the highway network condition obtained by systematic inspection (Wingate and Peters 1975). The main conditions assessed through the CHART system are as follows:

1. wheel track rutting,

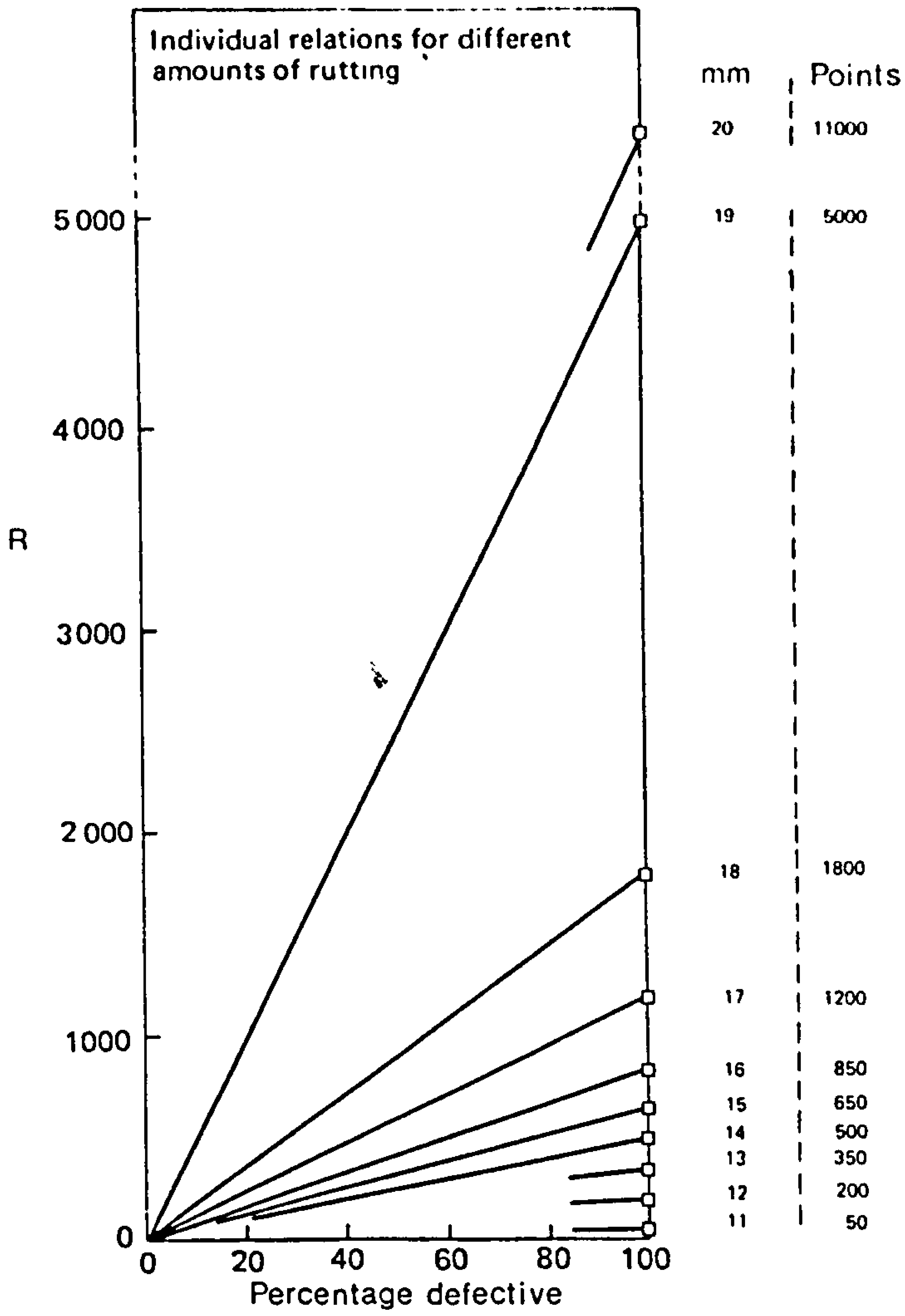
2. wheel track cracking,
3. whole carriageway major deterioration,
4. whole carriageway minor deterioration,
5. loss of skidding resistance,
6. surface irregularity (loss of riding quality),
7. adverse camber,
8. edge defects,
9. inadequate drainage of the surface,
10. existing patching,
11. footway deterioration,
12. inadequate kerb upstand,
13. kerb deterioration,
14. need for kerbs.

In the CHART system, the above 14 standard defects, which are collected through the inspection survey, are processed and rectified as follows to meet the suitable remedy according to defined standards.

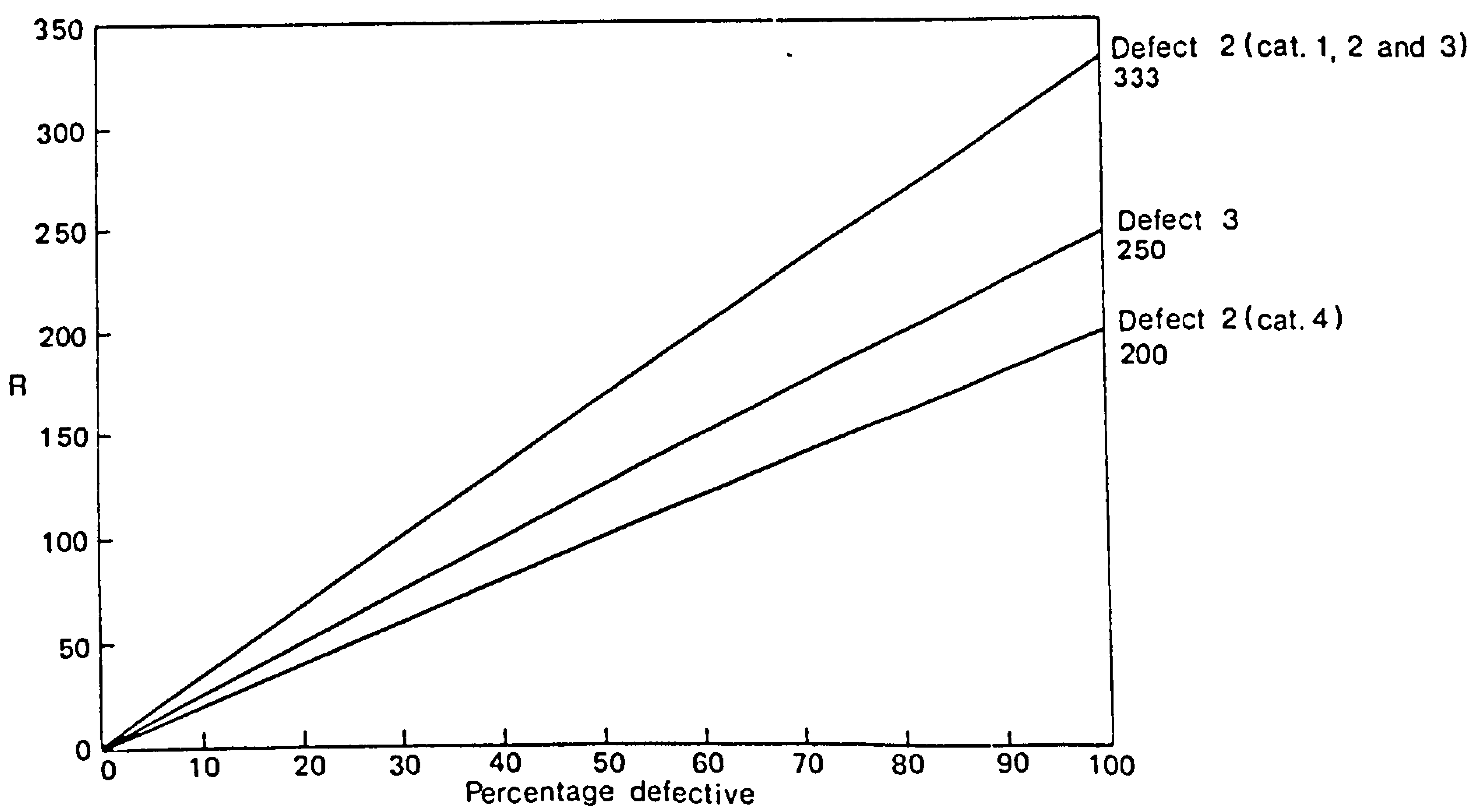
- Reconstruction for all defects 1 to 10.
- Resurfacing for defects 1 to 7 and defect 10.
- Surface dressing for defects 2 to 5 and defect 10.
- Edge repair for defect 8.
- Drainage treatment for defect 9.

For each of the above defect, there are rating values that vary according to the severity, extent and importance of the defect. These rating values are based on linear relations between the percentage defective and a rating value, which is a numerical value given to the remedial treatment for that defect. This relation is given by graphs for different defects (i.e. rutting, roughness). Figure 3.5 is a typical graph from the CHART system, which shows the linear relationship between the rating value and amount of defect for rutting and cracking. So, if a micro-section has in one side 25% of its length with 16mm ruts contributing 300 points to the basic rating, 40% of its length with 18mm ruts contributing 800 points and 35% of length with 19mm ruts contributing 1800 points. The total basic rating value for rutting in this micro-section would be 2900 points and the higher of the two ratings from both sides is the rating value of the sub-section. The defect rating values in each sub-section are then compared with critical defect ratings to determine the treatment ratings and the treatments required for each sub-section. In the CHART system, the road network is divided into sections and sub-sections where the sub-sections have lengths of 100 metres as standard. The section is the length on which data are inputted to the CHART system. Sections must be carefully selected as follows:

- each section must have a unique identity through the data input,
- each section must start and finish at junctions,
- section must not cross section
- each section must be of one of the above categories and road classification,
- each section must contain one named street,
- each section should be of uniform carriageway construction,
- each section must be without large changes in traffic flow,
- each carriageway of a dual carriageway road must be considered separately,
- each carriageway of a dual carriageway road must be considered separately,
- roundabouts and very large junctions areas must be separate sections
- slip roads must be separate sections,
- sections must not exceed 9.9 kilometre in length for motorways,



DEFECTIVENESS RATING RELATION – DEFECT 1
Wheel track rutting



DEFECTIVENESS RATING RELATION – DEFECTS 2 AND 3
Wheel track cracking and whole carriageway major deterioration

Figure 3.5 Defectiveness rating relation

- short sections must be avoided. They must not be shorter than 24m and not longer than 3 km for trunk and main roads.

The main criterion for categorising roads in the CHART system is the importance of the road in the area of the study. The main roads categories in the CHART system are as follows.

- Motorway and very important trunk roads.
- Other trunk roads and important principal roads.
- Other principal roads and important non-principal roads.

3.4.1.2 MARCH System.

Since the publication of the "Report of the Committee on Highway Maintenance", (Marshall Report 1970), the need for a system assessing the maintenance needs for highways based on recommendations and standards cited in the Marshall Report has become essential. The Marshall Committee has established uniform standards for types of remedial treatments, and for road serviceability and maintenance (Kerali 1986).

The MARCH system was developed by the MARCH Policy Group. Like the CHART system, the MARCH system is based on a visual inspection to collect the road condition data. The processing of data in the MARCH system is faster and simpler than that in the CHART system, and adequate for the initial screening and priority assessment, but it is less precise in its survey data (Snaith et al 1982)

The MARCH system has been developed for assessing budgeting costs, through a priority list of the different defects and their treatment. The implementation of the MARCH system starts with an inventory of the road network furniture, such as junctions and roundabouts. These permanent features of the road network will be used as fixed markers for the maintenance lengths "stretches". These stretches are about three kilometres long; each stretch has a unique identification (numbers or letters), and is marked at both ends by one of the identifiable features of the road (junctions). The stretch is divided into about ten equal maintenance lengths, each with its own identifier (Snaith et al 1982). The information collected is combined together in a master file, which contain the critical deterioration limits recommended in the Marshall Report together with codes for different traffic loads and tuning factors used to set the priorities for maintenance.

The rating of defects in the MARCH system is calculated using equation 3.1 below, in order to determine the priority of a maintenance length. This priority is based on selecting the defects which exceed the critical level recommended in the Marshall Report in each maintenance length so as to assign the proper treatment for each defect. Finally, the priority rating of each defect in each maintenance length is calculated, so the highest priority is then given to the defect with the highest rating

$$Rating = \frac{(p \times f1) + (DL \times f2 \times k)}{DPF \times TFF} \qquad \text{Equation 3.1}$$

Where

p = percent of the defective length or area

$f1$ = percent factor

DL = length of deterioration

$f2$ = length factor

k = scale factor

DPF = priority factor of defect

TFF = traffic or footway factor

The percent and length factors (*f1,f2*) are used for tuning the equation. As it could be used to suit the local conditions, the scale factor k is equal to:

$$k = \frac{100}{average.length.of.elements}$$

The Defect Priority Factor (*DPF*) is used to reflect the importance between the different defects measured in a maintenance length. Thus, a square metre of major deterioration in a carriageway is more important than a square metre of footway deterioration. The Traffic or Footway Factor (*TFF*) relates to the traffic loading on the maintenance length, and the importance of the road. However, the roads carrying high traffic loads are given a low value of TFF which result in a higher priority.

A priority list of all maintenance lengths requiring remedial treatments is prepared to cost the actual treatment. Following this, the total cost of remedial treatment required by maintenance lengths of higher priority is produced. In the MARCH system, the defects for each road length in the section are collected together before processing to determine the criticality for treatment. Consequently, the location of a particular defect cannot be identified as in the CHART system. The only information available is that there is a particular defect somewhere in a particular road length.

The MARCH system has the advantage of incorporating cost and basic inventory modules, where a list of the recommended remedial treatments in priority order is prepared with individual cost to each treatment, and so provides a cumulative cost for all maintenance lengths requiring treatment. The MARCH system is based mainly on three main stages:

- collection of data throughout the road networks,
- formation of the master file,

- determination of treatment, costs and priorities.

3.4.1.3. The BSM System

The Burrow Snaith Maintenance Management System (BSM) is a second generation management system developed for use primarily in developing countries, as a result of experience with Overseas Road Note 1, MARCH and CHART (Snaith et al 1985). The implementation of the BSM system is based on similar procedures followed in the MARCH system for road condition data collection. However, the BSM system has the ability to adopt the local conditions of the intended areas of application. The BSM system has been developed to overcome the problem of establishing proper maintenance management in developing countries, as neither of the previous systems (CHART, MARCH) were applicable for developing countries because they were both developed to comply with the recommendations given in the Marshall Report (Kerali 1985).

The BSM system has been tested in many developing countries, such as, Botswana, China, Malaysia and Thailand, through funding from either the World Bank or the Overseas Development Administration (Snaith et al 1985). The BSM System is based on a relatively simple manual method, similar to that in the MARCH system. The national highway network is divided into regions and districts, then to sections of 3 km in length demarcated by fixed road features (i.e. junctions). Each section is then divided into sub-sections of 250m in length. The road characteristics (i.e. carriageway widths, shoulders) and conditions (i.e. rutting, major/minor carriageway deterioration) are recorded by a Field Survey Team (FST). The fixed road characteristics are combined into an Area Master File (AMF), and the sub-section's conditions are annually updated by the FST.

The implementation of the BSM system in China and Thailand was covered in a three- phase program:

- Pre-implementation
- Implementation
- Review

During the pre-implementation phase, a specialist adviser visited the recipient country to decide with the local maintenance authority the required variation to bring the system BSM into line with established practices in that country (Snaith, Kerali and May 1986). Then the system was tailored in the UK to the needs of the recipient country and tested for about three months.

In the second phase, all BSM system operation equipment was installed and commissioned. This needed a two-month period to be completed. Then the headquarters staff and technicians were introduced to the system and trained in its operation to become familiar and able to commence using the system. At this stage the BSM system was introduced to a trial on a road section, in order to test the technicians and to re-tune the system to suit the local condition.

Following this stage, the local trained teams continued collecting the condition data of the trial area (500-km), and using the system to record all surveying information. This stage took about six months. After this, the two-man team of experts in the system undertook a review of the work done, assessing progress and making any final adjustments necessary to the system.

As a result of this training and implementation, the local teams would have sufficient experience with the system to operate it without undue dependence on expatriate staff (Snaith et al 1985)

The priority rating method adopted in the BSM system is similar to the rating method used in the MARCH system. However, this method is modified to suit the conditions, which exist in the developing countries (Kerali 1985). It takes into account the importance of the road, type of pavement, the degree of distress and the riding quality. As this system is developed to suit the local conditions of the recipient country, the maintenance standards input to the Area Master File (AMF) reflect the availability of materials and the maintenance practice in the area of application

CHART and MARCH are maintenance management systems, which are mainly applicable to UK conditions only (Kerali 1986). They are both based on recommendations given in the Marshall Report, which defines a common standard for road maintenance in UK, and recommends a system for determining priorities for maintenance projects. Unlike the MARCH system, the CHART system is a very detailed and complex system requiring skilled labour at the stage of data collection, with accurate results in identifying defective lengths.

The processing of data in the MARCH system is faster and simpler than that in the CHART system, but less precise in relation to its survey data (Snaith et al 1982). In the MARCH system the location of a particular defect cannot be identified as in the CHART system. The only information available is that there is a particular defect somewhere in a particular road length. The CHART system is fairly slow, with a daily survey capacity of 2 to 6 km (Kennedy 1996), depending on the skill of the inspection team, the weather conditions, the road condition, the amount of data required and the traffic flow on the particular road during the inspection.

The BSM system was developed by Highway Management Services Ltd (Robinson and Sniath 1985). It is a microcomputer system combining data from the field inspection team describing the road condition. It then outputs a treatment priority order, together with its cost, in order to prepare an annual report to the road authority setting out the maintenance needs and the budget required to cover those needs. This system could be a good tool for establishing a proper maintenance-management system in the city of Benghazi if the following conditions could be met. Firstly, the road authority in the city could find the resources to cover the implementation process, as Libya is not eligible for any funded aid either from the World Bank or from donor agencies. Secondly, the road authority in the city would have to encourage its highway engineers and technicians to adopt computer technology and have regular intensive courses locally and overseas.

3.4.2-Machine-based survey systems

Surface condition assessment can be carried out nowadays using high technology systems, which can operate at normal traffic speed without disruption to traffic. The use of machine-based systems for collecting road condition has the significant advantage of minimising the disruption to traffic, increase inspection capacity, maximising the operators safety during the survey and providing reliable data in which the maintenance system is based.

The system currently employed in the UK (Kennedy 1996) uses the following equipment.

- High-Speed Road Monitor(HRM)
- Sideways-Force Coefficient Routine Investigation Machine(SCRIM)
- Deflectograph
- Falling Weight Deflectometer (FWD)
- The Bump Integrator(BI)
- Transverse profilometer
- High-speed profilometre

3.4.2.1 High-Speed Road Monitor (HRM)

The HRM has been designed and developed by TRL (Transport Research Laboratory). A trailer, which carries the equipment, is towed by a surveying vehicle, which contains computer facilities to process the data collected during the survey. HRM is used to provide a broad assessment of road condition in a single pass (skidding, texture depth, rut depth, riding quality) and then special equipment for each defect may be used for more details.

HRM consist of five laser sensors, four are mounted on a rigid beam at the nearside of the trailer and the fifth sensor is mounted on a transverse beam at the centre of the trailer. In addition to two distance-sensors are fitted to the trailer wheels.

The new version of the HRM is a trailer less or self-contained vehicle developed by WDM Ltd called Multifunction Road Monitor (MRM) (Figure 3.6). MRM is a vehicle-based system, which can provide the objective routine assessment of road condition with low-labour cost, safely and quickly with speeds up to 100 kph. MRM can merge with traffic without any disruption to the other road users owing to its ability to collect data at variable speed, and the sensors in MRM have been mounted on the vehicle chassis to provide a more compact and manoeuvrable machine (Hosking 1996).

3.4.2.2) Sideways-force Coefficient Routine Investigation Machine (SCRIM)

SCRIM was designed by TRL and manufactured under license by WDM Ltd to measure skidding resistance, which has a significant role in main road accidents owing to low macro and micro texture of the surface. The vehicle (SCRIM) normally operates at 50 Km/h during testing (Kennedy 1996). A fifth wheel is fitted on the vehicle at an inclination of 20 degree with the direction of travel and can be lifted clear of the road when not in use. During the testing,

Figure 3.6 Multifunction road monitor

the wheel is lowered and subjected to a vertical load of 200 Kg. A thin film of water poured in advance of the test from a tank mounted beside the fifth wheel (Figure 3.7).

The Side Force Coefficient (SFC), which is the ratio of the force developed at right angles to the plane of the wheel to the load imposed on the wheel (vertical reaction between the wheel and road surface), is calculated for section lengths of 10 metres and stored in a tape cassette with the pre-programmed section identifiers.

The SCRIM can cover about 200 lane kilometres daily in different road categories and about 80,000 lane kilometre are surveyed throughout the UK annually (Kennedy 1996). The skid resistance level required in the road network varies according to the location and definition of the section. Sections approaching traffic signals, pedestrian crossings or roundabouts require higher values of skid resistance level (0.45 to 0.55) than other sections like single or dual carriageway (0.35 to 0.40) (Salt 1977).

3.4.2.3) Deflectograph

The Deflectograph is designed to evaluate the structural condition of flexible pavement by measuring the maximum transient deflection of the road surface. A pivoted beam is positioned on the road surface while a standard load on the rear twin wheels axle passes over the tip of the beam assembly and the deflection is determined from the movement of the pivoted beam. Unlike the deflection beam method, the beam in the Deflectograph is placed beneath the vehicle chassis and between the vehicle axles to lift it automatically for the next point of measurement. During travelling between sites, the beam is lifted clear of the road and the vehicle can travel at normal road speed. The vehicle speed during operation is 2.5 kph to allow the electro-mechanical clutch fitted at the front of the vehicle to pull the beam forward at twice the vehicle speed and to release it again for the next measurement cycle.

Figure 3.7 The SCRIM

The British version of the Deflectograph is called the Pavement Deflection Data Logging Machine (PDDLM) (Kennedy 1996) (Figure 3.8). It is one of the machines used in the UK structural maintenance design system for flexible pavement. Deflection measurements obtained by PDDLM are displayed in the system's recorder at the vehicle control unit. The system can monitor 12 to 20 lane kilometres per day to provide about 3,000 to 5,000 measurements in each wheel path. The assessment of structural conditions of roads in terms of deflection is important in the allocation of funds needed to cover major maintenance work. Therefore, using equipment such as the PDDLM in road maintenance systems is essential to predict the remaining life of the road and required overlay thickness.

3.4.2.4) Falling Weight Deflectometer

The Falling Weight Deflectometer (FWD) (Figure 3.9) is another method of measuring the deflection of pavement. It is a trailer-mounted system but the trailer is stationary during the measurement cycle. The Falling Weight Deflectometer (FWD) measurement cycle starts when a mass is dropped onto a set of damped springs mounted on a rigid circular plate of 300 mm diameter, resting firmly on the pavement surface to ensure a reasonably uniform contact pressure. The impulse load acting on the pavement simulates the vertical pulse obtained by a vehicle wheel load. Thus, the falling weight may be chosen to match the standard wheel load used in the pavement design method (FEHRL 1996). The deflection measurements are recorded by a set of deflection sensors (geophones) placed at radial distances between 0 at the load centre and 2500 mm at the outer sensors position (FEHRL 1996). The minimum number of deflection sensors used in the Falling Weight Deflectometer necessary to describe the deflection bowl shape of the different pavement layers is six (FEHRL 1996). The maximum load and deflections are measured to give an indication of the structural strength of the pavement. The suitable temperature range for measuring deflection on pavement using the

Figure 3.8 The British Deflectograph

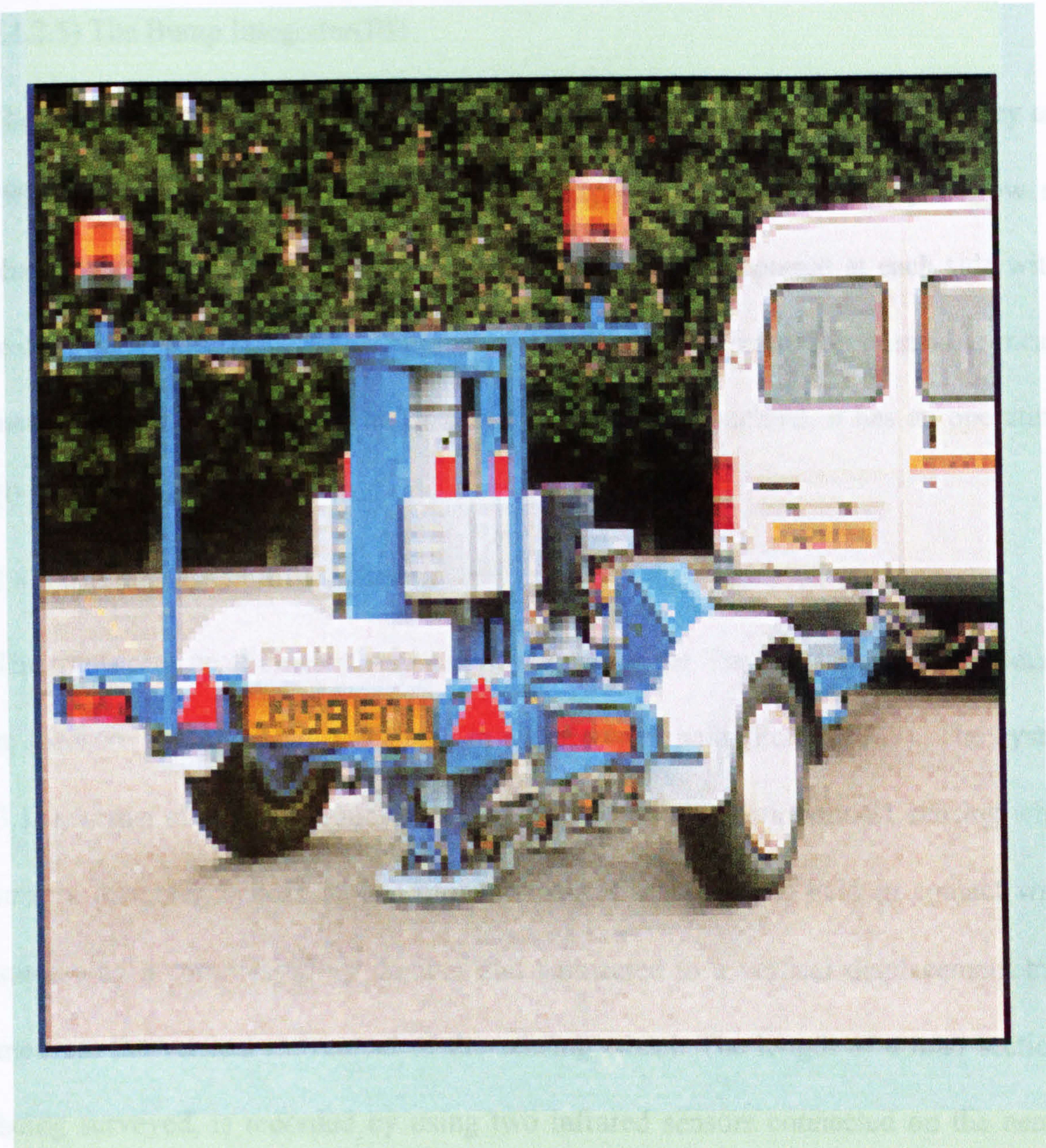


Figure 3.9 The falling weight deflectometer

Falling Weight Deflectometer (FWD) is between 0 and 30°C, and should be measured at a depth of ≥ 40 mm.

3.4.2.5) The Bump Integrator(BI)

The Bump Integrator has been in use in Europe for more than 40 years (Croney and Croney 1997) to measure the road surface irregularity. It consists of a heavy hollow rectangular chassis with a single wheel at the middle (Figure 3.10) supported at each side with a single-leaf spring. The downward movement of the wheel relative to the chassis is measured by a mechanical integrator unit. The BI is not a high-speed machine, it has an operating speed of 20 miles per hour.

3.4.2.6) Transverse profilometer

The transverse profilometer has been developed at the Transport Research Laboratory, TRL, to measure the rut depth and shape in a one-wheel path (Potter 1989). The system (Figure 3.11) consist of a trailer mounting a 2 m long beam which supports 21 sensing wheels of 200 mm in diameter, spaced at 100 mm intervals. Each wheel is held in contact with the road surface by a compressed air damper and connected to a vertical displacement transducer to measure the vertical movement of the sensing wheel. The length of a road section, which is being surveyed, is recorded by using two infrared sensors connected on the nearside of the trailer, which registers the longitudinal position of roadside reflectors.

The system is computer controlled and requires one person to drive and operate. Average values of rut depth and shape can be calculated every 10 m length at speeds of up to 10 km/h. A summary of information about the measurements can be provided for immediate analysis and full detailed information can be recorded for more detailed analysis on a mainframe computer

Figure 3.10 The bump integrator (BI)

The machine in operation

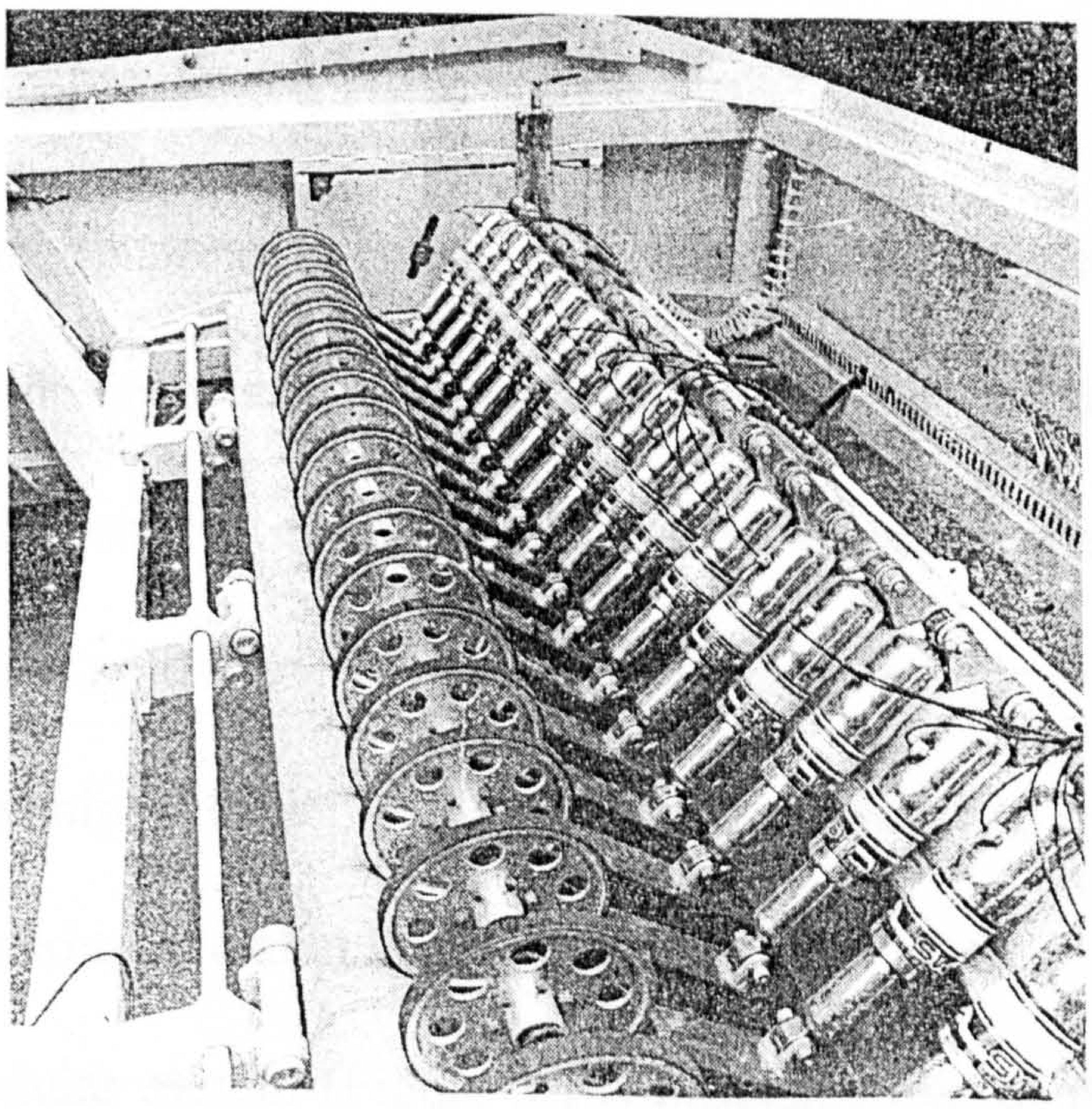

Calibration of the sensor wheels

Figure 3.11 The transverse profilometer

3.4.2.7) High-speed profilometer

This machine is used to measure the rut depth of the pavement (Jordan and still 1982). It is a trailer with two wheels on which a 4.5 metre long beam is supported. This beam carries four laser sensors (Figure 3.12); each one measures the vertical distance between the beam and the road surface. The sensors have the ability to make up to 3300 measurements per second. The vehicle, which tows the trailer, carries the power supply and the computer system. The rut measurements are taken by riding the trailer's wheels on a road to measure the height of the axle from the road surface using the laser sensors. The rut depth is obtained by calibrating the measured values over the deformed surface with values measured over a plane surface by following the same procedures (figure 3.13)

3.5 low-cost system for Road Data Collection

Professor M Snaith and his group at Birmingham University have used a simple and low-cost modular data collection system (Tillotson, Snaith and Tachtsi 1996). This system was originally designed for use in developing countries where limited resources (funds and technology) are obstructing the use of more sophisticated equipment. This work was carried out through a partnership between the Transport Research Laboratory, the University of Birmingham and Cambridge Parallel Processing Ltd.

The Birmingham modular system (Figure 3.14) measures two of the main defects that any pavement management system must include. These defects are the surface roughness and rutting. Also an attempt to measure cracks using an image processing technique is undertaken. Crack measurement cannot be considered as low cost when compared with the measurement of roughness and rutting. The modules in the Birmingham system are inexpensive and can be bought separately. Additionally, they can be fitted to any survey vehicle to provide the data required by the Pavement Management System (PMS).

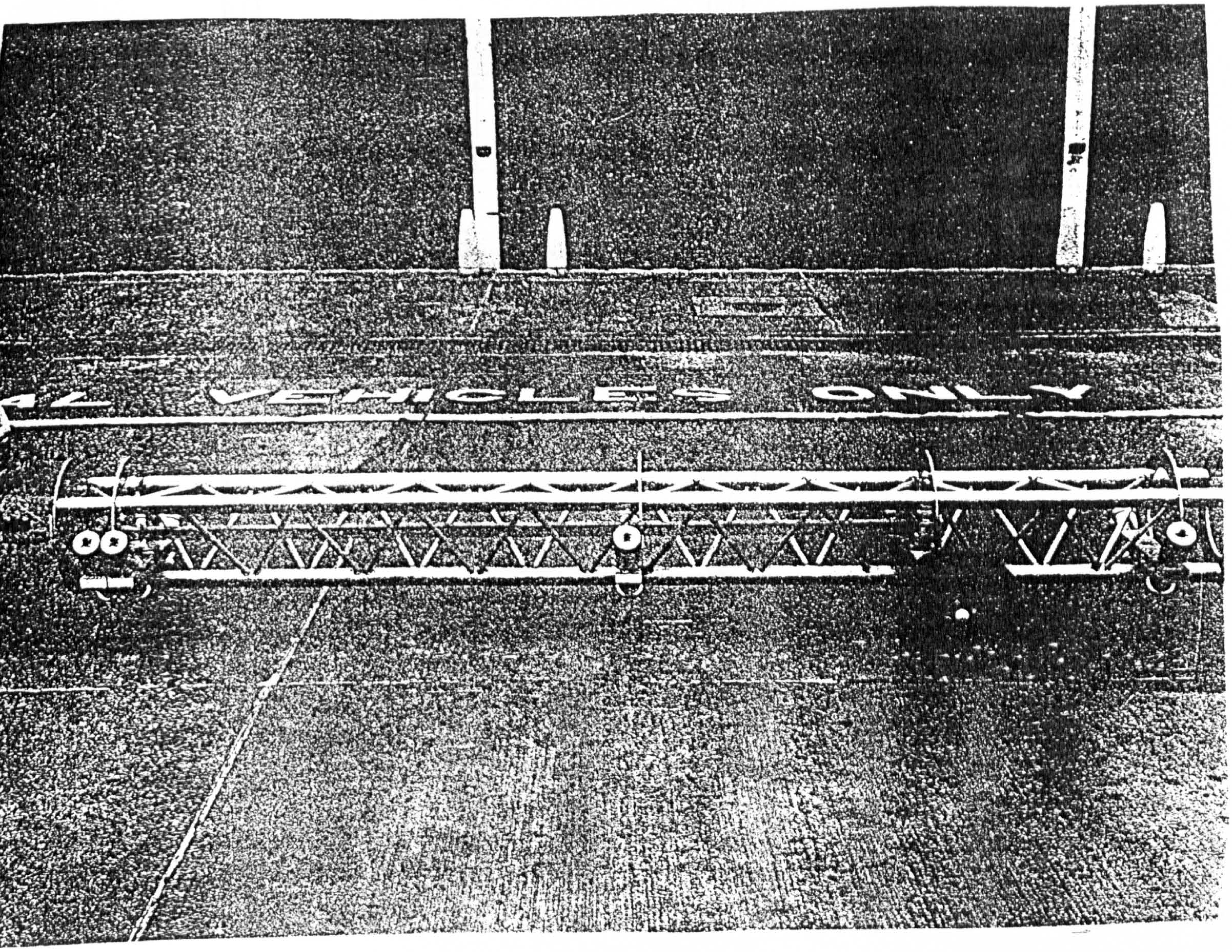
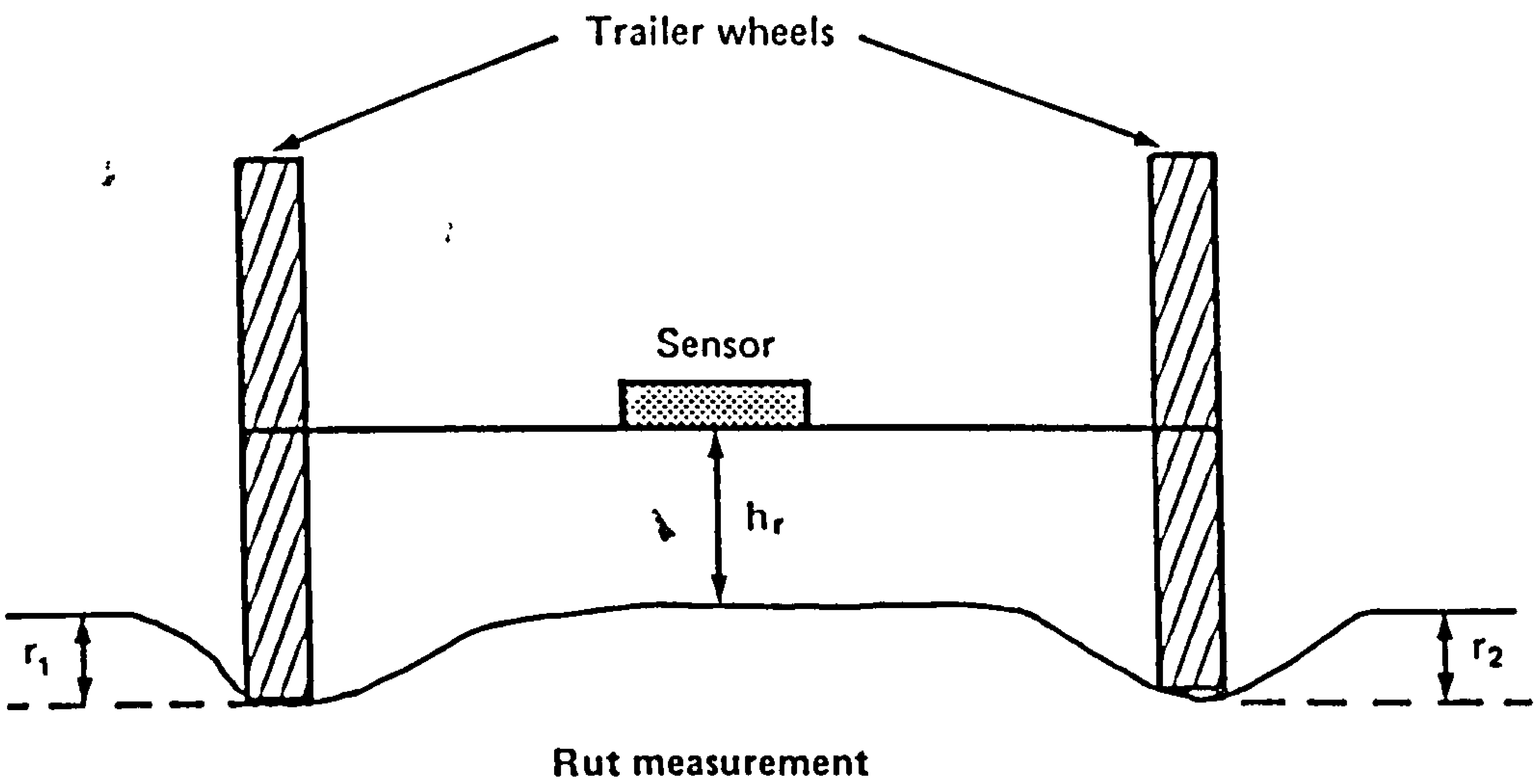
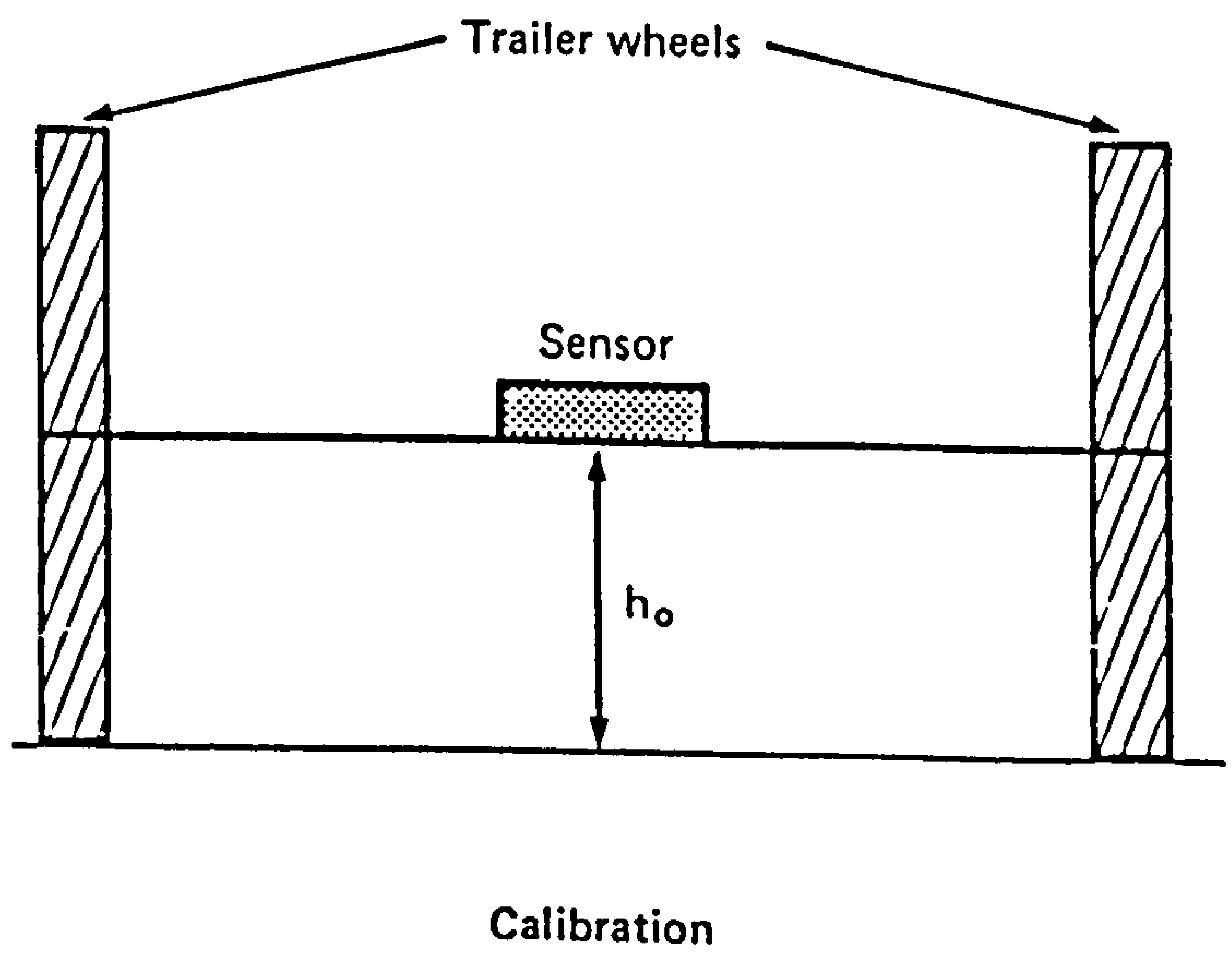


Figure 3.12 High-speed profilometer





$$h_o - h_r = \frac{r_1 + r_2}{2} = \text{rut depth averaged over both wheel paths}$$

Figure 3.13 Rut-depth measurement

Figure 3.14 Birmingham data-collection vehicle

A portable microcomputer with a database stores the data collected by the instruments. The onboard database (ODB) is divided into three sections:

i) the inventory data of the road sections to be surveyed,

ii) the collected condition data,

iii) the other general information about the survey (date,time,speed.....etc.).

Roughness is measured using a Vehicle Mounted Bump Integrator (VMBI), which is less expensive than the standard Bump Integrator. The VMBI registers the vertical movements (Roughness) between the rear axle and the vehicle chassis.

The Birmingham Group has used an improved version of Ultrasonic Rutmeter where the time which elapses between sending the pulses and receiving them again after a reflection from the road surface gives a spot height. The road profile can be provided for every nine spot heights. The materials used in manufacturing this module are inexpensive and some of them can be manufactured locally.

The measurement of cracks using a digitised image cannot be considered as a low-cost module relative to the other modules. The digitisation equipment takes a television picture from videotape; this picture is subjected to several stages of analysis, starting with sieving the noise and then thinning and linking the crack fragments to reach the final image. The digitised image represents an area of road which is approximately 0.5m x 0.5m. The real-time crack measuring system needs less than 40 milliseconds to process each image and by using the British Television Standard, a complete frame needs only 40 milliseconds to be produced. This module (apart from its expense) shows considerable promise for future work.

Establishing a pavement maintenance strategy in the city of Benghazi based on any or some of the reviewed systems in monitoring road condition, together with the prevailing conditions and problems cited in Chapter 4, is not the aim of this research. As none of these systems could be used regularly and efficiently at this time in the city of Benghazi. Even the Birmingham low-cost system and Transverse Profilometre are not appropriate to the city of Benghazi. In spite of their low-cost, these systems still comprise high technology equipment to measure road condition, and need skilled people to operate them. In some developing countries, where the management of the roads is carried out by World Bank initiatives and road aids agencies, it will be more appropriate to use the high technology systems in highway network monitoring, as these projects are funded by experts and professionals through World Bank assistance. The approximate costs of these high technology systems (Hosking 1996) in 1995 values are as follow:

high-speed road monitor	£400,000
deflectograph	£250,000
falling weight deflectometer	£100,000

The problem of providing and developing equipment that may achieve similar data to that which more sophisticated equipment produces is a crucial requirement of some developing countries, where funding and resources are always the main difficulty, in addition to lack of experience in using lasers and computer-based systems. Low-cost and simple to operate equipment to measure road defects may solve at least a part of this problem and assist in establishing a proper "PMS" in these countries.

3.6 Roads Maintenance in Developing Countries

In most developing countries, the rate of road building has increased since 1960 (Robinson 1988). Large networks have received loads and use beyond values that they were designed to withstand without adequate maintenance. This absence or lack of adequate maintenance has led to minor and major deterioration to these networks.

The main problems usually obstructing the implementation of maintenance management systems in developing countries are:

- lack of skilled and qualified people at all levels,
- inadequate assignment of responsibilities and duties,
- incorrect assessment in budgeting and priorities,
- absence of regular training programs,
- absence of modern data filing systems,
- conflict in allocation of funds between maintenance and construction, where politicians often seek prestige by constructing new projects, something which is not available in maintenance work. In many cases in the city of Benghazi in Libya, the road authority signed contracts for new road construction while the utility system underneath needed comprehensive maintenance at high cost. Therefore a maintenance management system is not just an option or good idea to implement, it is crucially important, because its absence will lead to the need for a higher budget to cover the required maintenance to keep the network serviceable.

The cost of road maintenance will increase with time because even with proper maintenance, roads deteriorate depending on the climate, traffic volume, subgrade strength and the axle loads of commercial vehicles. However, regular maintenance will keep the network in a state of good riding quality until the end of its design life (> 20 years) by controlling road defects through the carrying out of maintenance activities on time. In 1990, The UK spent £2.6 billion on pavement maintenance of which £1.2 billion was spent on resurfacing and patching (Collop 1994). Table 3.3 shows the maintenance and rehabilitation cost of an adequate maintenance management system (Robinson 1988).

From Table 3.3 it can be concluded that failure to carry out a proper routine and recurrent maintenance programme leads to a premature need for periodic maintenance whose cost is 15 times the cost of routine maintenance. The same is true for late periodic maintenance where the cost of an overlay is about 7 times the cost of periodic maintenance. Therefore, failure to create a proper maintenance management system will cost much more than just missing one stage of the maintenance activity (Robinson 1988).

The implementation of a proper maintenance strategy with its different activities is crucial for the optimum allocation of resources. However, there is no reason to not establish at least the minimum level of maintenance, especially in view of the technological development of this subject and the development of various simple models for road condition assessment at low cost.

3.6.1 The economic effect of proper maintenance strategy

The benefits that could be gained by establishing and following an organised maintenance strategy go much further than preserving roads from deterioration. The economic-returns from preserving the whole highway network from rapid deterioration may justify the maintenance expenditure

3.6.1.1 Control of Maintenance Expenditure

Implementation of a proper maintenance system with the required activities (para.3.3.5) needs an adequate budget to cover the task. The budget allocated to the maintenance activities must not be diverted and spent on other highway construction projects. The following example (Robinson 1988) can show the effects of using the maintenance budget on other tasks. Table 3.4 shows the cost of different maintenance activities for both paved and unpaved roads (Faiz and Harral 1987), to maintain a road network comprising 1000 km of paved roads and 1000 km of unpaved roads. According to Table 3.4, the annual maintenance expenditure will be; $6.0 million for paved roads and $2.5 million for unpaved roads.

The whole network required an annual budget of $8.5 million. If part of this budget is used, for example, for new road construction to extend the network by 1% per year, the result will be a lack of maintenance in part of the network as shown in Table 3.5. After 10 years of the same policy, the result will be an increase of 200 km in both paved and unpaved roads throughout the network. Moreover, a loss of about 417 km of paved roads and 480 km of unpaved roads will ensue, which would require full reconstruction to be brought to service again. The total cost according to Table 3.4 is as follows:

reconstruction for paved roads	417 km x $175,000	= $72,975,000
reconstruction for unpaved roads	480 km x $45,000	= $21,600,000
	total cost	= $94,575,000.

One also needs to take into consideration the additional costs owing to maintenance requirement for the new roads which would cost $600,000 per year for paved roads and $250,000 per year for unpaved roads. A road condition report in the city of Manchester in the UK (Oliver 1997) has shown that there was a significant underfunding in bids claimed by the city council in order to maintain the city's roads. From 1994 to 1998, underfunding of claimed bids was as follows. In 1994-95, the city was allocated £1.63 million after biding for £2.44 million; in 1995-96, the city received £1.66 million from a bid of 3.05 million. In 1996-97, the city was awarded £0.77 million from a bid of £2.72 million; and in 1997-98, only £0.84 million was allocated from a bid of £2.04 million. Underfunding of maintenance expenditure during this period was £5.35 million (£10.25 million claimed and £4.9 million allocated). Moreover, the result was that 47% of the city's principal roads reached the end of their economic life and a bid of £27.7 million is needed now to bring the road up to an acceptable

Table 3.3 Maintenance and Rehabilitation Costs (US $ per km)

Road type	Activity	Cost range in US $
Earth	Routine and recurrent maintenance	100-1,000
Gravel and paved	Routine and recurrent maintenance	200-1,000
Gravel and paved	Periodic maintenance	8,000-10,000
Gravel and paved	Routine, recurrent and periodic maintenance (annual average)	1,500-3,000
Paved	Strengthening overlay	50,000-75,000
Paved	Rehabilitation	120,000-200,000

June 1980, source: World Bank (Robinson 1986)

Table 3.4 maintenance costs for paved and unpaved roads in US dollars per kilometre

Activities	Paved	Unpaved
Routine and recurrent maintenance	500	1,000
Periodic reseal(after five years)	12,000	
Overlay(after ten years)	42,000	
Regravelling(after five years)		8,000
Reconstruction	175,000	45,000
Annual maintenance cost	6,000	2,500
New construction	250,000	120,000

(Source Faiz and Harral 1987)

Table 3.5 New allocation of the maintenance budget

The amendments	paved roads	Unpaved roads
Annual increase in road length	10 km	10 km
Annual construction cost	$2.5 million	$1.2 million
Balance of budget remaining for maintenance	$3.5 million	$1.3 million
Length of road that can be maintained each year with this sum	583 km	520 km

level of repair. At this level of deterioration and at this high cost of maintenance, the city council stated " the rate of deterioration has out-stripped our ability to repair the city's principal roads and we are faced with an ever increasing backlog of structurally failed highway" (Oliver 1997). A spokeswoman for the council said " if the government does not give a big enough grant for 1998-1999, we will have to start closing roads"

3.6.1 2 Axle Loading

The role of controlling the axle load limits throughout the network is significant for road deterioration where underestimating axle loads during design may lead to rapid deterioration of the road. It has been reported that axle loads of 16 tonnes cause 20 times as much damage to a road as an axle load of 8 tonnes (Robinson 1988). Therefore, the enforcement of the axle load limits throughout the network using the axle loads survey is crucial for road maintenance planning, as underestimates of actual loading on a road may shorten its design life (Robinson 1988).

The importance of efficient use of the maintenance budget and the enforcement of legal axle load is not recognised in some developing countries (e.g. Libya) as a consequence of a lack of road management and responsibility. The next Chapter presents the transportation situation and the road conditions in the city of Benghazi

3.6.1.3 Vehicle operating cost

Neglecting regular maintenance will lead to road deterioration, and as a result a paved road will crack, develop pothole and lose its riding quality. These defects will increase vehicle operating cost, which means additional fuel consumption, tyres, spare parts and import of new vehicles, all of which need foreign exchange in most developing countries. Transport Research Laboratory, TRL, carried an investigation (Robinson 1988) on 100 km length of road in a developing country. The road carried out a daily traffic of 750 vehicle for about four years from the date of opening. During that period, the road received no maintenance and consequently deformation, cracks and potholes started to appear. An estimation of the vehicle operating cost (VOC) showed an increase of about $1.5 million per year. This cost may increase to about $5.0 millions per year if the road maintenance is neglected any further.

3.7 Investment appraisal models for road maintenance management

The aim of designing any road investment appraisal model is to determine the appropriate level of investment and economic returns of the project (Kerali 1986). The size of the investment is governed by construction and maintenance costs and the economic returns gained in the form of savings in road users costs. The model should estimate the costs of road construction, road maintenance and road user for specified analysis period.

The first fully integrated road investment appraisal model for developing countries was made by the World Bank in 1968 (Kerali 1986). In 1973, the TRRL (then RRL) Transport Road Research Laboratory in collaboration with the World Bank commenced a major field study in Kenya (Hodges, Rolt and Jones 1975). The results of this study were used to develop a prototype Road Transport Investment Model (RTIM) (Robinson et.al. 1975) to evaluate the costs of road construction, annual road maintenance and vehicle operation (Kerali 1986).

In 1981, the World Bank in collaboration with the Massachusetts Institute of Technology developed a new extended version of the previous models. This model was known as the Highway Design and Maintenance Standards Model (HDM) (Watanatada et. al. 1987). In the meantime, the TRRL had developed their investment model (RTIM) after five years of using it in some developing countries (Kerali 1986) by rewriting the program to include a calculation of Vehicle Operation Cost (VOC) in study carried out in the Caribbean (Morosiuk and Abaynayaka 1982). This new version is known by RTIM2.

3.7.1 The World Bank's HDM3 model

The Highway Design and Maintenance Standard Model (HDM) is a multi-function tool for studying the economic viability of alternative road improvement and maintenance strategies (Haas, Hudson and Zaniewski 1994). The model implements empirical relationships to estimate the performance of the road and vehicle operating costs. These relationships were based upon studies carried out in Kenya, Brazil, India and the Caribbean (Kerali 1986).

Figure 3.15 illustrates the interaction of costs of road construction, maintenance and user in the HDM model. The three interacting sets of costs are added together over time and discounted to present values in order to make comparative cost estimate and economic evaluation of various policy options (Haas, Hudson and Zaniewsk 1994). The costs are determined by predicting physical quantities of resource consumption, which are then multiplied by unit prices. The total costs of large numbers of alternative project designs and policies are estimated year by year for up to thirty years, then discounting the future costs at different interest rates in order to search for the alternative with the lowest discounted total cost (Watanatada et.al. 1987).

In order to make a qualitative comparison between the different policy options, the model must be given detailed specifications of the various alternative sets of construction programs, design standards and maintenance policies in addition to the unit costs, traffic volume and environmental conditions.

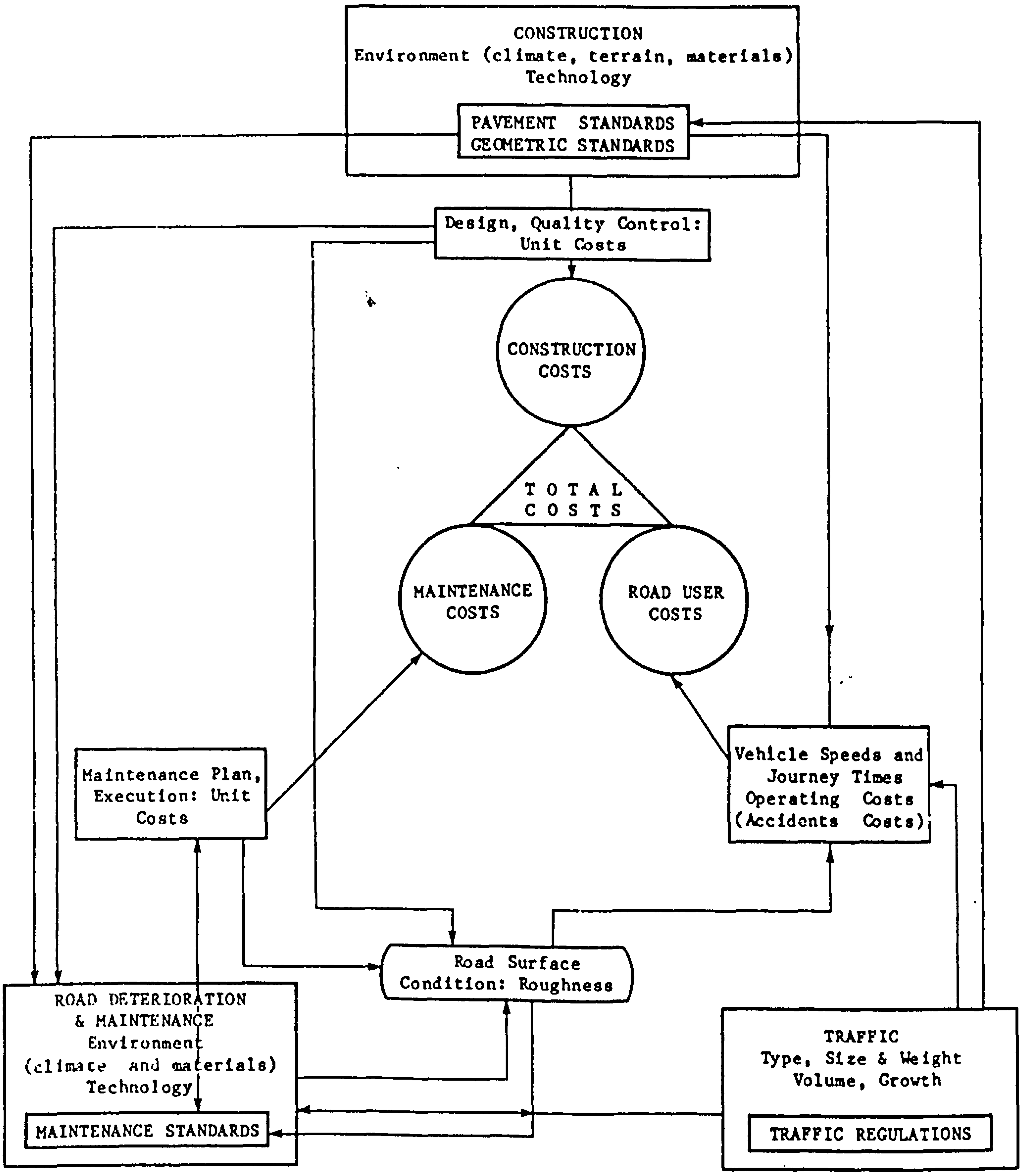


Figure 3.15 The HDM Model : Interaction of costs of road construction, maintenance and use

It is planned that a new version of the model (HDM-4) will be released during 1999. The new HDM-4 provides additional improvements from the previous version of the model (International study of HDM 1999). The core function of the HDM-4, will include:

- A comprehensive range of road deterioration and works effect (RDWE) models
- A comprehensive range of road user effect (RUE) models, covering motorised and non-motorised traffic effects and cost for wide rang of vehicle types, time cost and congestion effects
- A set of models addressing safety, environment and energy (SEE) issues (e.g. accident cost, emission effects)
- An improved user interface in the Windows 95/98/NT environments
- Data management functions that facilitate the creation, adjustment and sharing of the various data objectives required to perform a study.

3.7.2. The RTIM model

The Road Transport Investment Model is widely used to carry out cost benefit analysis on road construction, upgrading and maintenance projects in developing countries, it is designed to aid investment decisions within the roads sector in developing countries. The model calculates the construction cost of a road and predicts the road condition in order to estimate the costs of road maintenance and vehicle operation for each year. These costs are then discounted back to the base year and summed over the road life to obtain the total cost (Parsley and Robinson 1982).

To simplify the economic appraisal of road investments in developing countries, a new version of the model (RTIM3) was issued in 1993 by the overseas centre at the Transport Research

Laboratory based on RTIM2, but is more flexible and easier to use (Cundill and Withnall 1995) The main features of the RTIM3 are:

- the model operates as a series of linked spreadsheets which deal in turn with traffic flow, road deterioration, vehicle operating costs and economic analysis;
- it can analyse up to five links, each with its own traffic levels, road type and maintenance policy;
- road condition and maintenance costs can be specified by the user or calculated by the model;
- user-friendly as it is easy to understand and operate, needs a Personal Computer (PC) of one megabyte of RAM (Random Access Memory) and few megabyte of hard disk space;
- The model program is supplied on one 3.5 inch high density (1.44 megabyte) diskette with licence fee of £150 (1995 prices).

The HDM and RTIM investment models are ideally suited for evaluating the effectiveness of maintenance policies in developing countries. The two models generate financial cost streams for the annual costs of construction, maintenance and road users. The models have been used in road investment projects in Africa, Asia and Central America. The main problems experienced during their application in developing countries are lack of adequate computer facilities capable of running the models and the reluctance by the engineers and planner in these countries to adapt to computer technology (Kerali 1986). The modified RTIM3 model would run on many more computers than HDM owing to its smaller size. Therefore, for a city like Benghazi, this size of investment model may be easily adapted by the engineers and planners and significant progress could be achieved in construction and maintenance investment in the city.

3.7.3 Whole-life costing of pavement

Life- cycle costs refer to all costs, which are involved in the provision of a pavement during its complete life cycle (AASHTO 1993). These costs include construction, maintenance and road users cost. The objective of any road investment appraisal is to minimise the total transport cost. However, a road of high design standard will be of high construction cost which will be outweighed by low maintenance and road users costs (Kerali 1986).

The components of transportation improvement costs can be classified as follows; firstly the cost of new road construction which comprises the site preparation, earthworks, pavement construction, services and overheads. Secondly, the cost of road maintenance which is the annual costs of the maintenance activities carried out during the life cycle of the road to keep it in serviceable condition (e.g. routine, recurrent, periodic maintenance). Thirdly the road users costs, which are those associated with vehicle operation, the value of the vehicle user travel time and traffic accidents. In a life cycle study, it is important to be able to compare costs incurred at different times (Knapton and Cook 1995). However, a discount rate (5-15 percentage) has to be introduced during the life cycle cost analysis to find the alternative with the lowest total cost as benefits are generally measured in terms of a decrease in user costs.

The most common economic criterion used in comparing the alternatives and then selecting the project with high economic returns is the present value method (PV) (Kerali 1986). The PV is the translation of specified amounts of costs or benefits occurring in different times into a single amount at a single instant (present) (AASHTO 1993). For example, the sum of £1000 in cash today at a 10% discount rate is equivalent to £1100 in the following year, £1210 at the end of the second year, and £2590.37 at the end of the tenth year. Correspondingly, the amount of £2590.37 to spend in the tenth year discounted at 10% has a present value of

£1000. The net change in costs is related to a decision or proposal compared to some other alternative, which may be keep the existing road situation or what is known as "do nothing" alternative. Table 3.6 illustrates the principle of NPV analysis where discounted cash flow of "do nothing" and project alternative are C_0, M_0, V_0 and C_p, M_p, V_p respectively. In the case when $C_p>C_0$, $M_p>M_0$ but $V_0>V_P$ which is common in most project appraisal, the costs of carrying out the project alternative are given by;

$$(C_p - C_0) + (M_P - M_0) \tag{3.2}$$

and the benefits of carrying out the project alternative is given by;

$$(V_0 - V_p) \tag{3.3}$$

where C_0, C_p are the construction costs, M_0, M_p are the maintenance costs and V_0, V_p are the road users costs. The annual discounted benefit streams is calculated by subtracting the project alternative discounted cash flow from "do nothing" discounted cash flow (Table 3.7). The calculation is repeated for all project alternatives, then the project of largest net present value (NPV) is assumed to have the highest economic return.

3.8 Discussion

Developing countries have lost highway networks worth billions of dollars (Harral and Faiz 1988) through the deterioration of their roads, and more billions could be lost if maintenance activities to preserve the highway networks do not immediately start. In a study carried out by the World Bank in eighty-five developing countries (Harral and Faiz 1988) receiving assistance and funds from the World Bank to improve their maintenance organisation, and to reduce the maintenance backlog in optimum time. The choices in pavement maintenance management were found to depend on several factors, among which are; climate, traffic flows, input prices, road characteristics and conditions, vehicle types and axle load, efficiency of maintenance work

Table 3.6 Discounted cash flow for the transport cost components

DO NOTHING ALTERNATIVE			
Year	Construction cost	Maintenance cost	Road user costs
1	$C0_1$	$M0_1$	$V0_1$
2	$C0_2$	$M0_2$	$V0_2$
3	$C0_3$	$M0_3$	$V0_3$
4	$C0_4$	$M0_4$	$V0_4$
5	$C0_5$	$M0_5$	$V0_5$
6	$C0_6$	$M0_6$	$V0_6$
7	$C0_7$	$M0_7$	$V0_7$
:	:	:	:
:	:	:	:
	C0	M0	V0

PROJECT ALTERNATIVE			
Year	Construction cost	Maintenance cost	Road user costs
1	CP_1	MP_1	VP_1
2	CP_2	MP_2	VP_2
3	CP_3	MP_3	VP_3
4	CP_4	MP_4	VP_4
5	CP_5	MP_5	VP_5
6	CP_6	MP_6	VP_6
7	CP_7	MP_7	VP_7
:	:	:	:
:	:	:	:
	CP	MP	VP

Table 3.7 Calculation of benefit streams for a project alternative

Year	Construction cost	Maintenance cost	Road user costs
1	$C0_1$-CP_1	$M0_1$-MP_1	$V0_1$-VP_1
2	$C0_2$-CP_2	$M0_2$-MP_2	$V0_2$-VP_2
3	$C0_3$-CP_3	$M0_3$-MP_3	$V0_3$-VP_3
4	$C0_4$-CP_4	$M0_4$-MP_4	$V0_4$-VP_4
5	$C0_5$-CP_5	$M0_5$-MP_5	$V0_5$-VP_5
6	$C0_6$-CP_6	$M0_6$-MP_6	$V0_6$-VP_6
7	$C0_7$-CP_7	$M0_7$-MP_7	$V0_7$-VP_7
:	:	:	:
:	:	:	:
	C0-CP	M0-MP	V0-VP

and available resources. The traffic volume has the most effect among other factors in pavement maintenance choices (Harral and Faiz 1988). In case of limited budgets, it could be better to maintain roads of high traffic volume in fair or good condition and undertakes less maintenance to those of lower traffic volume. Therefore, the study recommends developing countries that have difficulty enforcing load limits to build roads to higher initial standards. Although this results building fewer roads, as the cost of premature pavement failure is much higher than the savings from staged construction of the road.

Another study carried out by the Transportation Research Laboratory (TRL) (Robinson 1988) on the effect of introducing modern management systems in some countries. In order to improve the organisation of maintenance has showed that the introduced management system must be appropriate to the recipient country. However, not just applied without any consideration of the different maintenance problems and social condition of the country and the system must be fully understood by the team whose expected to operate it. The study has emphasised the significant role of efficiency in maintenance organisations, as inefficient maintenance organisations will limit the level of maintenance benefit on highway network, even with increased funding levels of maintenance organisations (Robinson 1987)

Therefore, in the case of the city of Benghazi, although the municipality has a large labour force, the productivity gained is much lower than it should be. Because of poor management, lack of training and lack of resources to carry out maintenance activities, in addition to a failure to establish priorities by the maintenance authority. The maintenance problem in the city of Benghazi (and in Libya in general) is broad and needs the support of all aspects from the government. However, by recognising the high cost of the maintenance backlog, start adopting the high technology related to pavement maintenance management systems by commencing in regular training courses of different level. Moreover, introduce the maintenance problem in the country to experts like Word Bank and the Overseas Unit of Transportation Research Laboratory. Which means increase the maintenance budgets to level covers the expenses of establishing proper maintenance management system with all its components (para. 3.3) and requirement.

The time required to reach this stage is relatively long, and the city's highway network is already in poor condition and needs an immediate solution to relieve even part of the maintenance crisis. Therefore, in this stage the implementation of the simple procedures and components of maintenance management cited in the Overseas Road Note 1 and 2, together with developing simple and low material cost monitoring systems for road condition, will play a significant role in improving the maintenance strategy in the city.

CHAPTER 4

THE CITY OF BENGHAZI

Contents

CHAPTER 4

TRANSPORTATION AND ROAD CONDITIONS IN THE CITY OF BENGHAZI

4.1 Introduction

In the thesis objectives, it was mentioned that a comprehensive knowledge of pavement history and special factors and conditions in the city of Benghazi which militate against the use of high technology monitoring systems for road conditions will play a significant role in establishing appropriate systems to monitor the road conditions in the city. Transport policies and the growth in wealth and population in the city are some of these factors, as a result of which the city roads and infrastructure need immediate aid to restore and keep roads in a serviceable condition throughout the network.

The city of Benghazi is the capital of the North East of Libya and the second largest city in the country, with a population approaching 1,000,000 (Brown & Root 1996). Benghazi is a major economic centre of different commercial and industrial activities, with a port which is the focus of imports and exports for the whole Eastern part of Libya (Figure 4.1), and an international airport linking the city with many cities in Europe and Asia (before the UN air embargo in 1992).

In addition to the difficulties inherent in a large city in a developing country, Benghazi has additional special factors which have come about as a result of sanction imposed in 1992. These sanctions mean that the effective employment of limited resources is particularly crucial. For these reasons, the outcomes of the research are particularly relevant and could

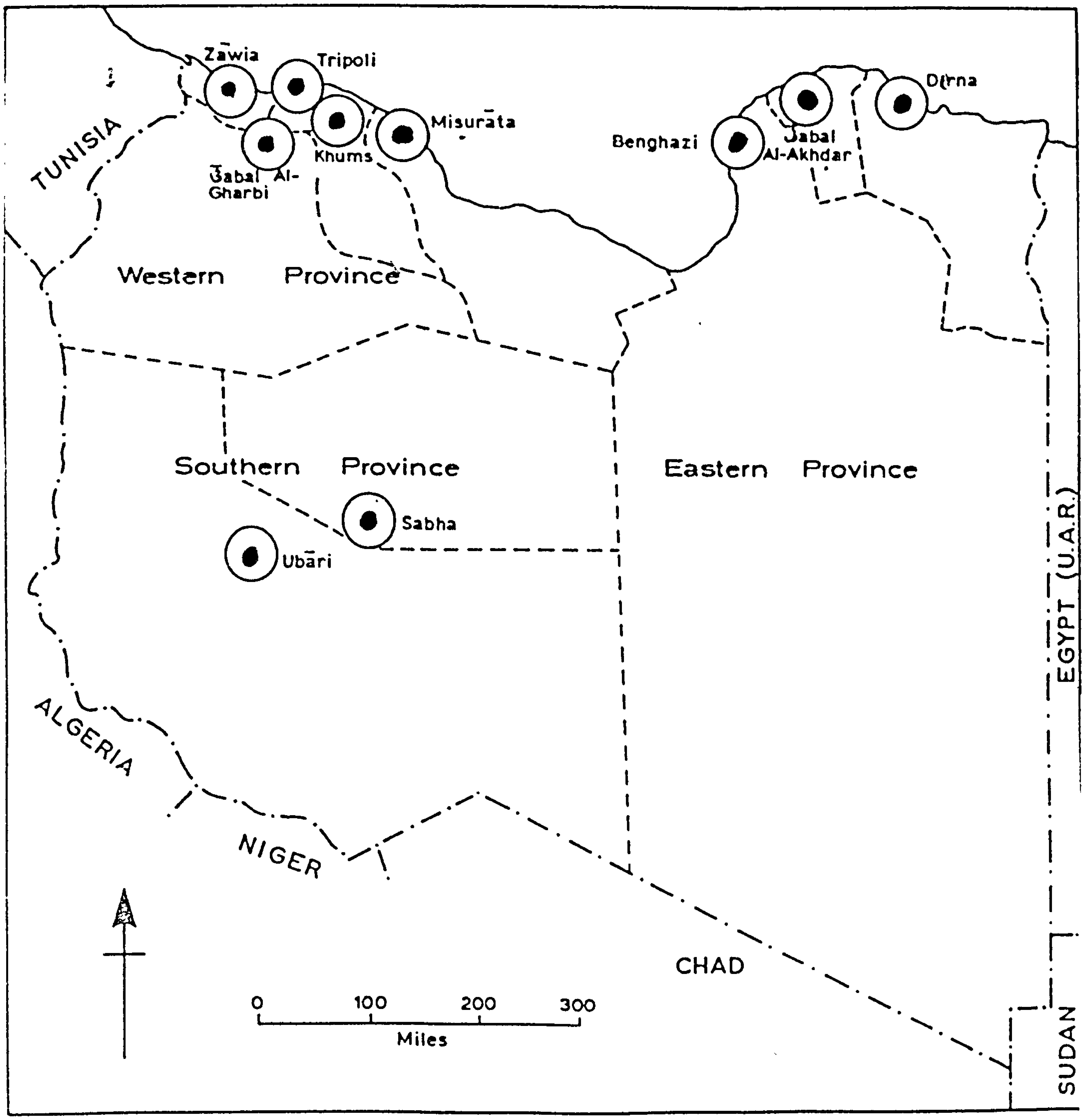


Figure 4.1 Libya: The geographical provinces and border

be transferred to other authority working against similar background. Therefore, the city has been selected to be a case study for this particular research for the following reasons:

- the city contains different roads categories,
- it is a strategically important city and will need enhanced communications when the international embargo is lifted,
- the availability of information for this particular study for the author,
- it is a typical example of most cities in developing countries in terms of size, population and in terms of lack of maintenance resources and skilled labour,
- it has received less attention and care than the capital city, Tripoli, in terms of upgrading the road networks and in maintenance expenditure,
- it deserves an attempt to evaluate the damage, which has occurred on the city network, and rescue the remaining serviceable roads.

The city of Benghazi was devastated during the Second World War. It was occupied by the Italian (since 1911) and then by the British and the American forces in 1945. In the early sixties, after oil was discovered in Libya, the city of Benghazi was reconstructed and remarkable growth in all aspects of life was recognised: in roads, factories and buildings. In addition to the increase in people's wealth and population, this has had a great effect in increasing the number of vehicles of different types and sizes. However, this dramatic increase in population (Table 4.1) and vehicles ownership (Table 4.2) has put great demands on the city infrastructure (Ove-Arup 1978). Therefore, during the last two decades, several orbital high standard highways were constructed linking the essential radial routes into the city (Brown & Root 1996)

The city of Benghazi is divided into two main parts owing to the large salt marshes, which exist in the middle of the city (Figure 4.2). The central area, which is around the harbour, has the highest density of residences, shops and offices, and as a result has the busiest roads in the city, especially in the morning. Therefore, this part of the city is always busy with different types and sizes of vehicles; Table 4.3 shows the different journey purposes throughout the city during the daytime.

The rest of the city is used for residential areas of different densities, depending on how far they are from the city centre, with the outskirts of the city being mostly used for industrial activities and warehousing.

4.2 Transportation and traffic review

During the last two decades, the Municipality of Benghazi (MOB) has appointed three British companies, experts in roads and transportation, in order to study and evaluate the present situation of transportation and traffic in the city. These companies are listed below by the date of appointment:

i- Ove Arup and Co.(Libya) Ltd in 1978,

ii- Howard Humphreys & sons in 1986,

iii- Brown & Root North Africa Ltd in 1996 (still at the proposal stage)

4.2.1 Ove Arup study.

Ove Arup was appointed by the Municipality of Benghazi (MOB) in February 1978, to study the traffic and transportation characteristics of the city (Ove-Arup 1978). The study aimed in four parts to evaluate the existing situation and to discus problems and recommendations for future work. The outline contents of the study were as follows.

Table 4.1 The natural population increase and immigration to the city of Benghazi

Year	Natural increase	Total including immigration
1977	311,000	311,000
1980	363,000	385,000
1990	601,000	723,000
2000	977,000	1,262,000

Table 4.2 Number of cars and commercial vehicles in the city of Benghazi

Year	Cars	Commercial vehicles	Total
1978	73,000	35,000	108,000
1980	98,000	40,000	138,000
1985	174,000	58,000	232,000
1990	265,000	81,000	346,000
1995	372,000	110,000	482,000
2000	500,000	146,000	646,000

Table 4.3 Journey purpose during the day in the city of Benghazi

Journey purpose % of all trips	To work	From work	Business	Shopping	Education	Social	Others
a.m. peak	50	5	13	4	11	3	14
p.m. peak	15	25	12	10	3	18	17

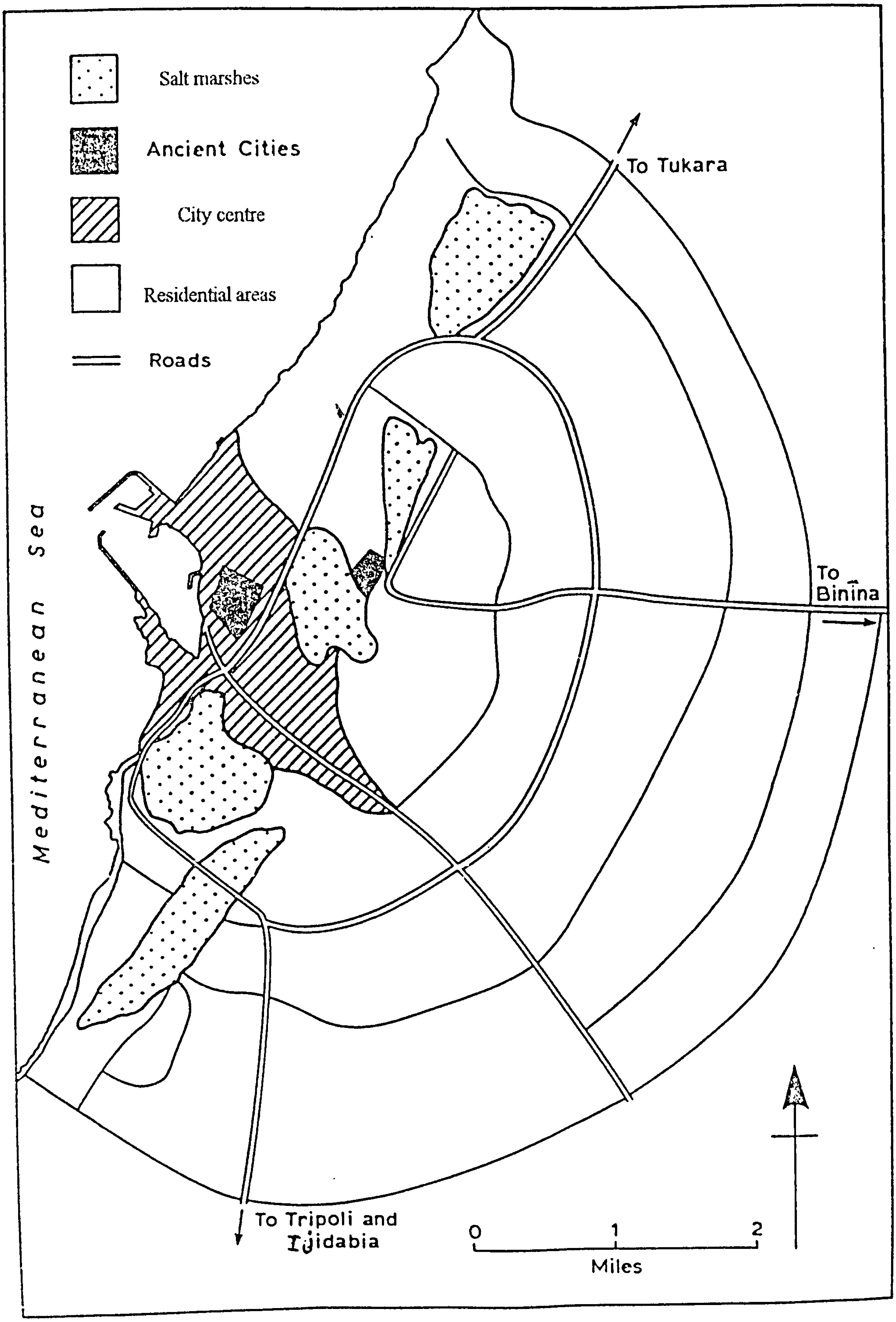


Figure 4.2 The city of Benghazi: The different areas in the city

• Part 1 Existing situation

This stage of the study covered the following points:

- roads inventory, including lane number, physical condition of roads, and street lighting,
- plans of major service routes,
- parking densities within the central area,
- traffic flows by vehicle type on some main streets and junctions,
- movement between various parts of the city,
- assessment of bus and taxi transport,
- journey speeds in the city,
- assessment of control and behaviour of traffic (e.g. accidents, driving habits).

• Part 2 Analysis

This part was based on origin-destination information and data about the existing network, plus roads under construction or pending contracts.

• Part 3 Discussion

This stage included the following issues:

- identification of points of traffic congestion,
- physical condition and maintenance of streets,
- traffic control and management,
- public transportation,
- assessment of the central area's capacity in terms of traffic, parking, environment and accessibility.

• Part 4 Recommendations

Ove Arup concluded the study with a number of recommendations to be carried out by the municipality of Benghazi in the immediate future. These recommendations were as follows:

- immediate road construction programme,
- geometric design standards for roads,
- control of Heavy Goods Vehicles(HGV) movement,
- traffic control systems (e.g. traffic signals, road marking..),
- public transportation.

4.2.2 Howard Humphreys study

Howard Hamphreys was appointed by the Municipality of Benghazi in 1986 to undertake a traffic study of the city of Benghazi. This study commenced a few years after Ove Arup's study, carrying out similar work and drawing up similar recommendations, significantly:

- marking of parking and no parking places,
- renewal of traffic signal equipment,
- marked priorities at junctions,
- lane and signal stop line marking,
- radical changes to the public transport system,
- establishment of a traffic office.

Despite the importance and value of these recommendations in terms of improving network standards, only some of those recommendations have been followed through during the last decade. Therefore, this study was followed by another proposal in 1996 to accommodate the significant expansion and change in the city's network.

4.2.3 Brown & Root proposal

In December 1996, Brown & Root submitted to the Municipality of Benghazi a proposal for consultancy services for transportation improvements. The key problems presented in the proposal were as follows:

- congestion,
- highway maintenance strategies,
- parking,
- roundabout operation,
- durability and provision of road marking traffic signal operation.

The problems are classified into three main stages according to the time required to workout compatible solutions.

- **Stage A Short-term traffic management strategy**

The objectives of this stage are defined:

- to reduce congestion on key routes and at key locations within Benghazi,
- to improve driver behaviour and road safety through engineering measures,
- to identify areas where parking should and should not take place,
- to improve traffic circulation around and through the city,
- to recommend improvements for pedestrian provision.

- **Stage B Medium-term transport strategy**

In this stage the main objectives are as follows:

- to recommend a long term maintenance strategy for roads in Benghazi,
- to review the processes which define vehicles as being road worthy,
- to investigate methods of payment for parking,
- to identify suitable methods for slowing traffic in residential areas,
- to provide recommendations to improve road safety,
- to recommend enforcement levels to the traffic police to assist in achieving these objectives.

• Stage C Longer-term development plan strategy

The objectives of this stage are:

- to identify the effects of planning strategies on the road network in Benghazi,
- to test options for further traffic management or infrastructure improvements,

The main objectives in reviewing the outline content of these studies were firstly to show the genuine concern of the highway authority in Benghazi to improve the engineering characteristics of the highway network in the city. However, owing to poor management and shortage of technical skills resulting from lack of training facilities, part of the study's recommendations have not been fulfilled as requested by the experts, and most of them have been filed away on shelves. Therefore, each study has been followed after a period of time (8-10 years) by another one to take account of the significant changes in the network size, and to include the new problems which have appeared throughout the network.

Secondly, an objective was to illustrate that, in the absence of proper management, the budget allocated for road section might be wasted on excessive overheads or on replicating work. Therefore, the remaining money is usually insufficient to carry out the required maintenance activities. There is a glut of engineers working in the municipality of Benghazi, but most of them are charged either with site supervision, without any practical experience, or with tedious chores. Therefore, the advantage of employing a high labour cost maintenance system instead of high equipment cost option is justified for the municipality, as they pay labour cost in either case.

Thirdly, the objective was to illustrate the consensus of experts regarding the standard of the highway network of Benghazi. Road construction in the city since 1974 has been carried out by specialist foreign contractors (e.g. Daewo, Belfinger&Berger), using local materials in pavement construction (e.g. Bituminous materials) and imported materials for electrical work (street lighting). However, during the last two decades, the city highway network has had a significant change in size, capacity and quality of highway construction.

Finally, reviewing the background of the previous efforts to prolong highway network life, although those efforts could not achieve their full objectives, they will enhance subsequent efforts to avoid the mistakes of the past. Over optimistically following western technology without good planning, particularly in terms of intensive training courses abroad and locally to upgrade and improve the engineering and management skills of employees.

4.3 Road hierarchy through the city network

The highway network in the city of Benghazi has been classified into four main categories according to location of road, traffic volume and the road layout. Table 4.4 and Figure 4.3 presents the Benghazi highway network and the different road categories. Because of the scale of the drawing, category IV roads cannot be shown, as they are minor streets linking residential areas. The other three categories, which constitute the most important roads in the network, have been significantly extended during the last decade.

4.3.1 Category I Roads

This road category has two or three lanes per single carriageway, depending upon the traffic flow. Parking and frontage are prohibited within this category; the existing shop frontage in this road category must have another alternative frontage on secondary roads. The speed limit in this category is 80 km/h and the minimum distance between the junctions within this

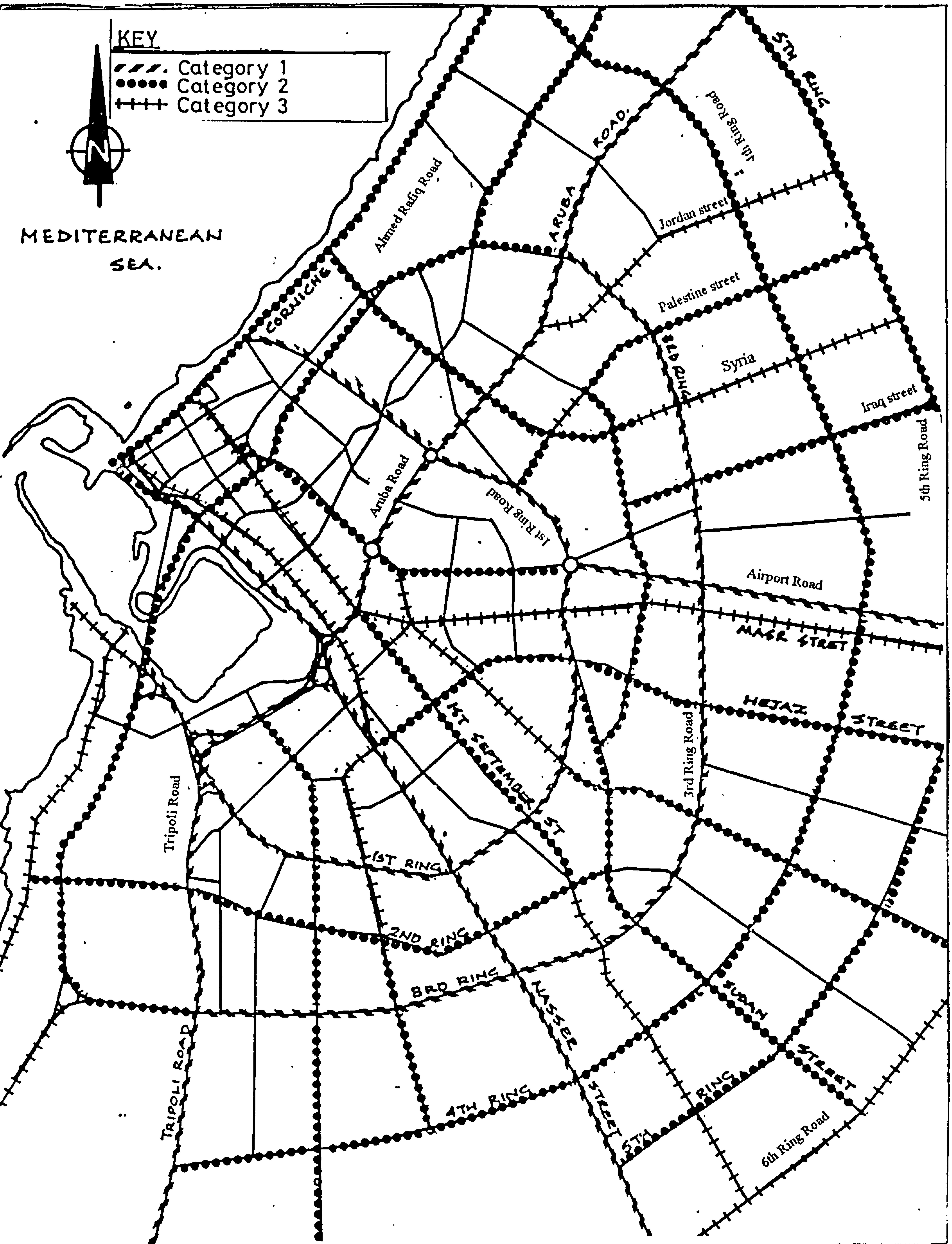


Figure 4.3 Road hierarchy in Benghazi network

Table 4.4 The city of Benghazi network road hierarchy

Road category	Number of lanes per carriageway	Lane width m	Speed limits Km/hr	Median m	Side walk m
Category I roads	Two	7.65	80 Km/hr	5.5	2.5
	Three	11.65		5.5	2.5
Category II roads	Two	7.65	60 Km/hr	5.5	2.5
	Three	11.0		5.5	2.5
Category III roads	Two	7.0	50 Km/hr	3.5	2.5
Category IV roads	One	2.5	40 Km/hr	N.A.	2.0

category is 750 to 1500 metres. Figure 4.4 shows a typical cross section of category I roads. Typical examples of this category in city's roads are, most of the Third Ring Road, the Aruba Road, Airport Road, Tripoli Road, part of the First Ring Road and Nasser Street.

4.3.2 Category II Roads

Most of the roads in this category consist of two lanes in each carriageway without any frontage. The distance between the junctions in this category is 250 to 500 metres and the speed limit is 60 km/h. Typical examples of this category are most of the Second Ring Road, the Fourth and Fifth ring roads and part of the Third Ring Road. Typical cross section of this category is shown in Figure 4.5.

4.3.3.Category III Roads

This category receives the greatest traffic flow in the network, as it carries traffic to the city centre and the residential areas. Therefore, this category is busy with private and light goods vehicles most of the day and with commercial vehicles coming from the harbour in the morning time. However, this category is in a worse condition compared with the other categories owing to the great demands on the infrastructure with most utilities in bad condition and needing immediate maintenance. Part of this road category has been reconstructed recently, but the largest part is still in a very bad condition. Figure 4.6 shows a typical cross section of Category III roads. Typical examples of this category are Maser Street, Jordan Street and Syria Street.

4.4 Existing road maintenance organisations

The Municipality of Benghazi, which is the road authority in the city, extends to about 80 km around the city (i.e. east, west and south)(Figure 4.7). Within the city, the municipality is responsible for maintenance of about 1,500 km of roads. However, outside the city limits,

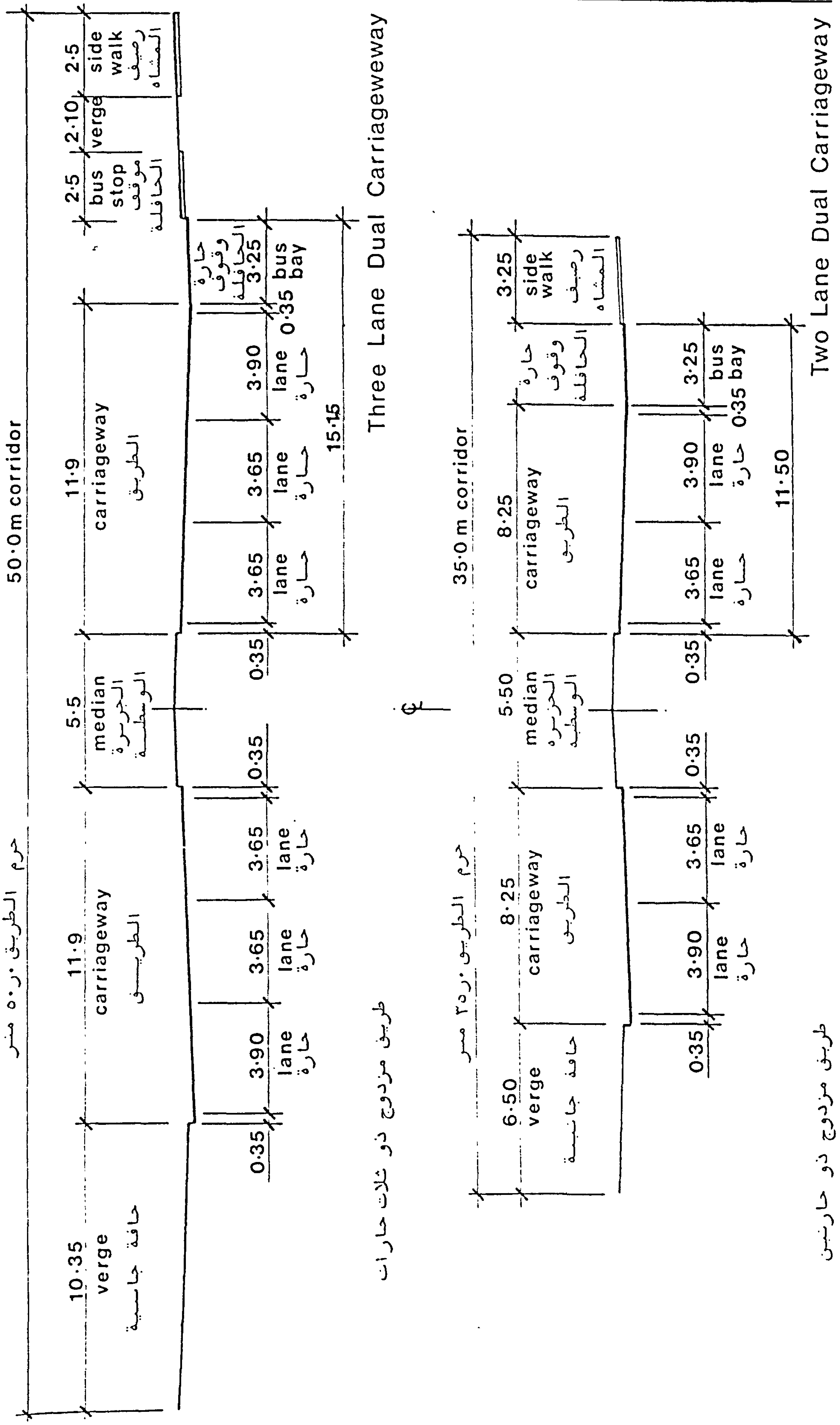


Figure 4.4 Typical cross-section of category I road

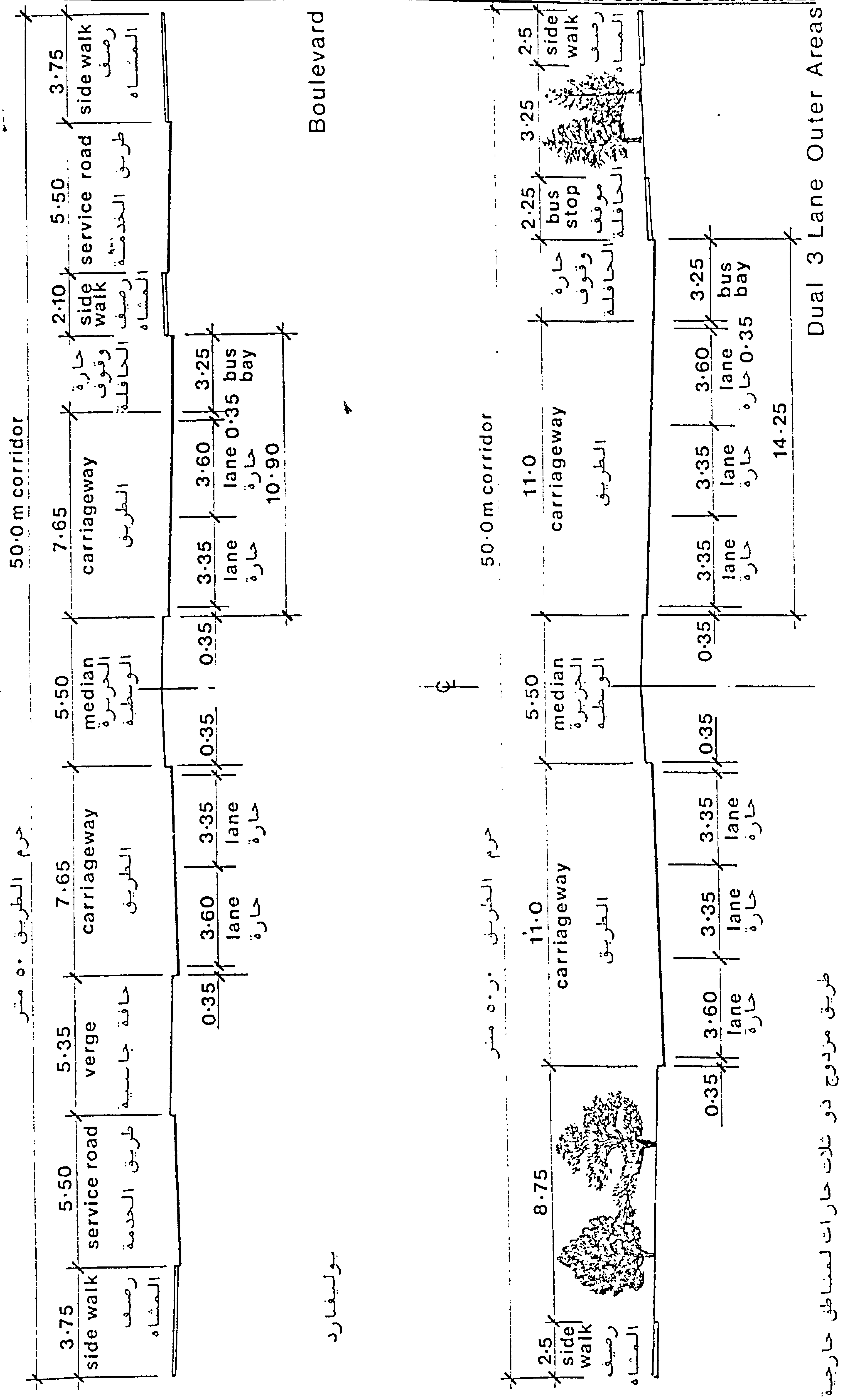


Figure 4.5 Typical cross-section of category II road

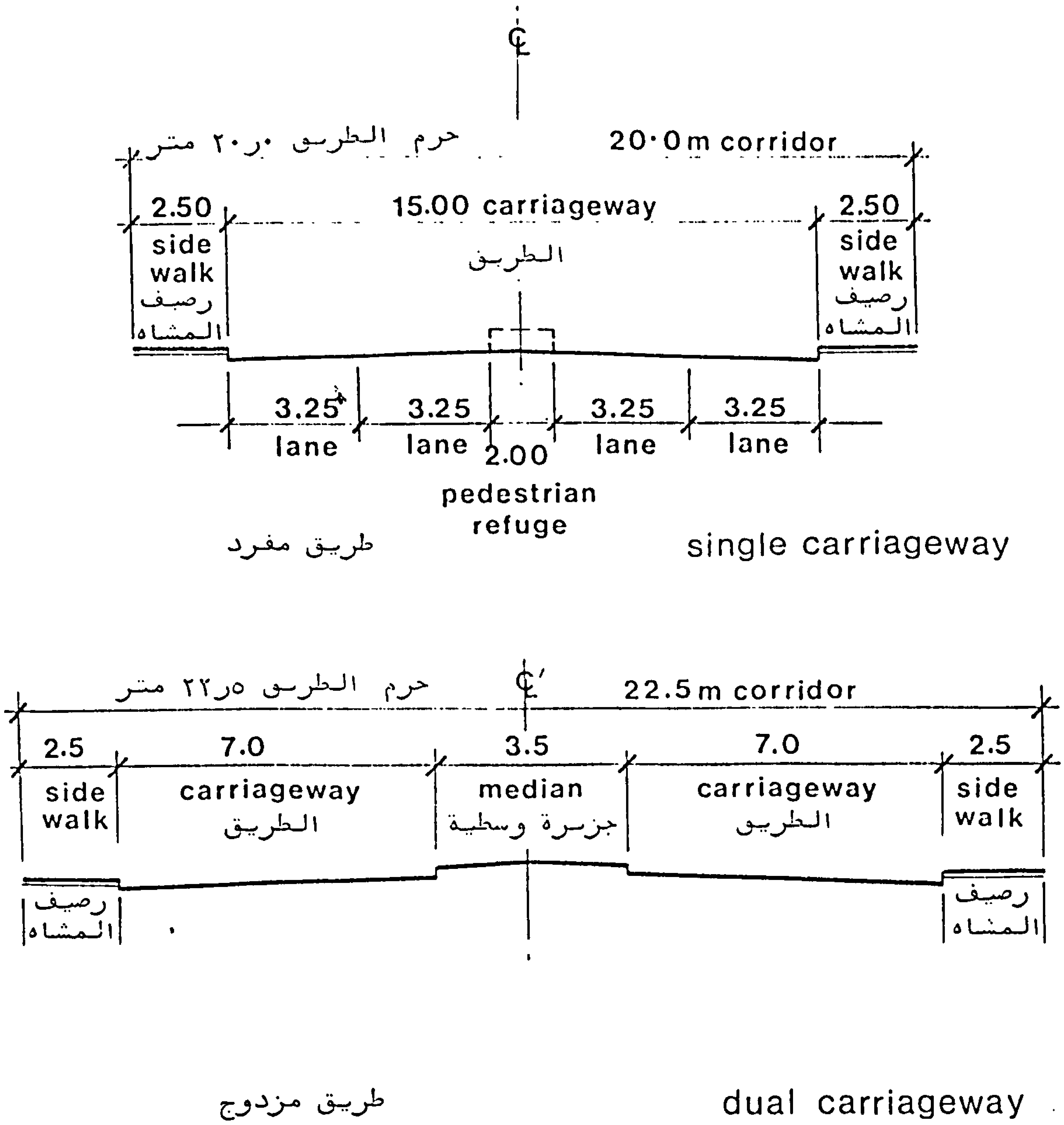


Figure 4.6 Typical cross-section of category III road

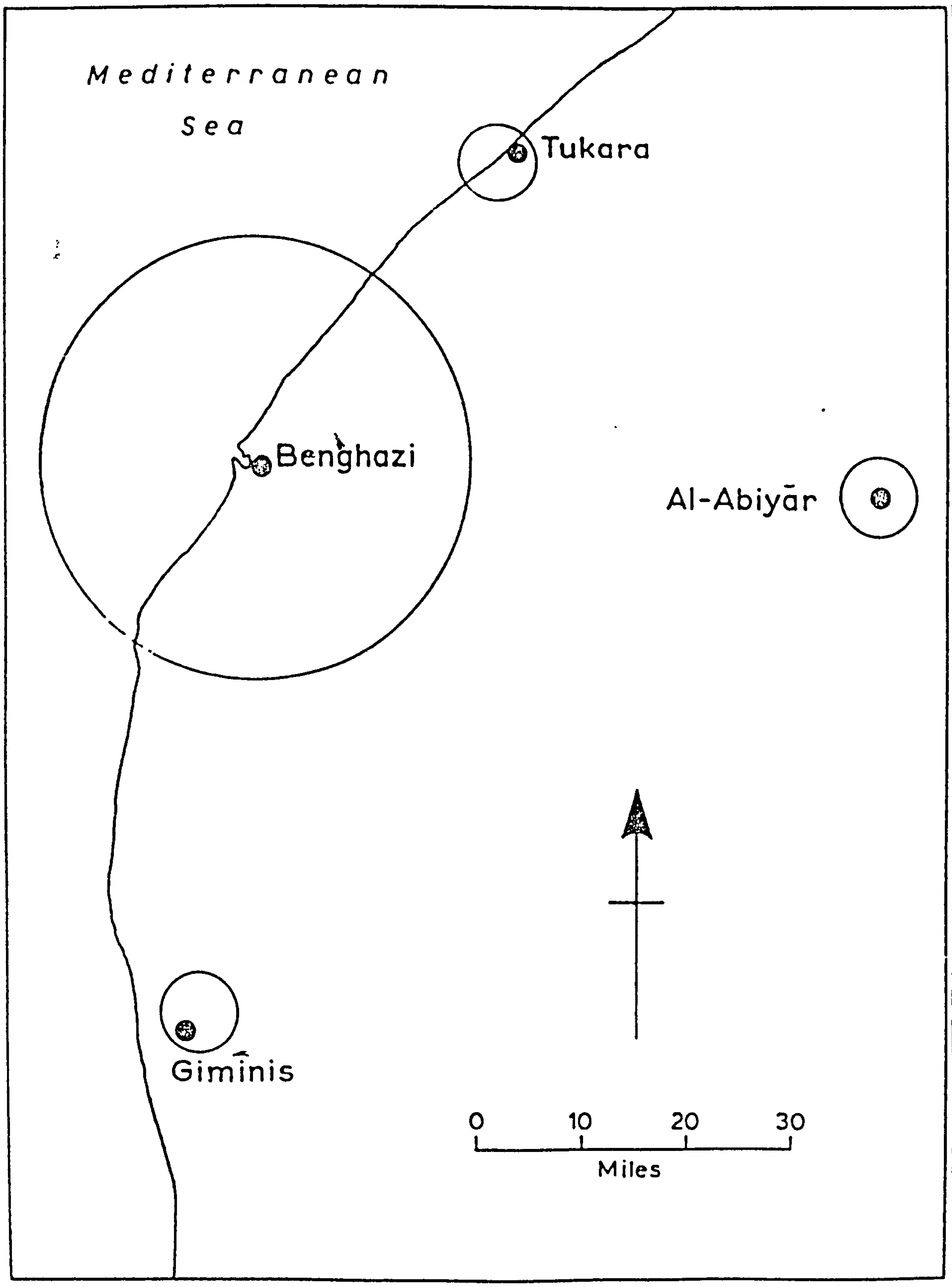


Figure 4.7 The geographic extent of the Municipality of Benghazi

the municipality maintains all road categories except trunk roads, which have a separate capital budget, and fall under the responsibility of the Ministry of Municipalities in the capital city, Tripoli. The Operation & Maintenance Department (OMD), one of the departments in the municipality of Benghazi (Figure 4.8), is responsible for road maintenance after the final hand-over of the project from the contractor. However, the contractor has to submit As-Built-Drawings, showing pavement cross-sections, utilities routes and any future extensions.

The OMD comprises different sections which are expected to work together to maintain the whole project in an acceptable condition from the date of the final handing-over of the project. The main maintenance sections in the OMD are:

- road maintenance,
- drainage,
- workshops,
- water services,
- general management,
- street lighting.

The largest three sections within the OMD, in terms of work load and staff level are road section, drainage section and workshops. Unfortunately, these sections lack overall co-ordination between each other in all aspects (Ove-Arup 1985), though they are supposed to be working to the same strategy, budget and resources. Consequently, the road section team may carry out surface treatment to a section requiring drainage or water maintenance or sometimes the same road section may be excavated twice in the same week to repair drainage and water pipes. As a result, these kinds of problems and many other problems have caused conflict and over-spend on extravagant maintenance expenditure.

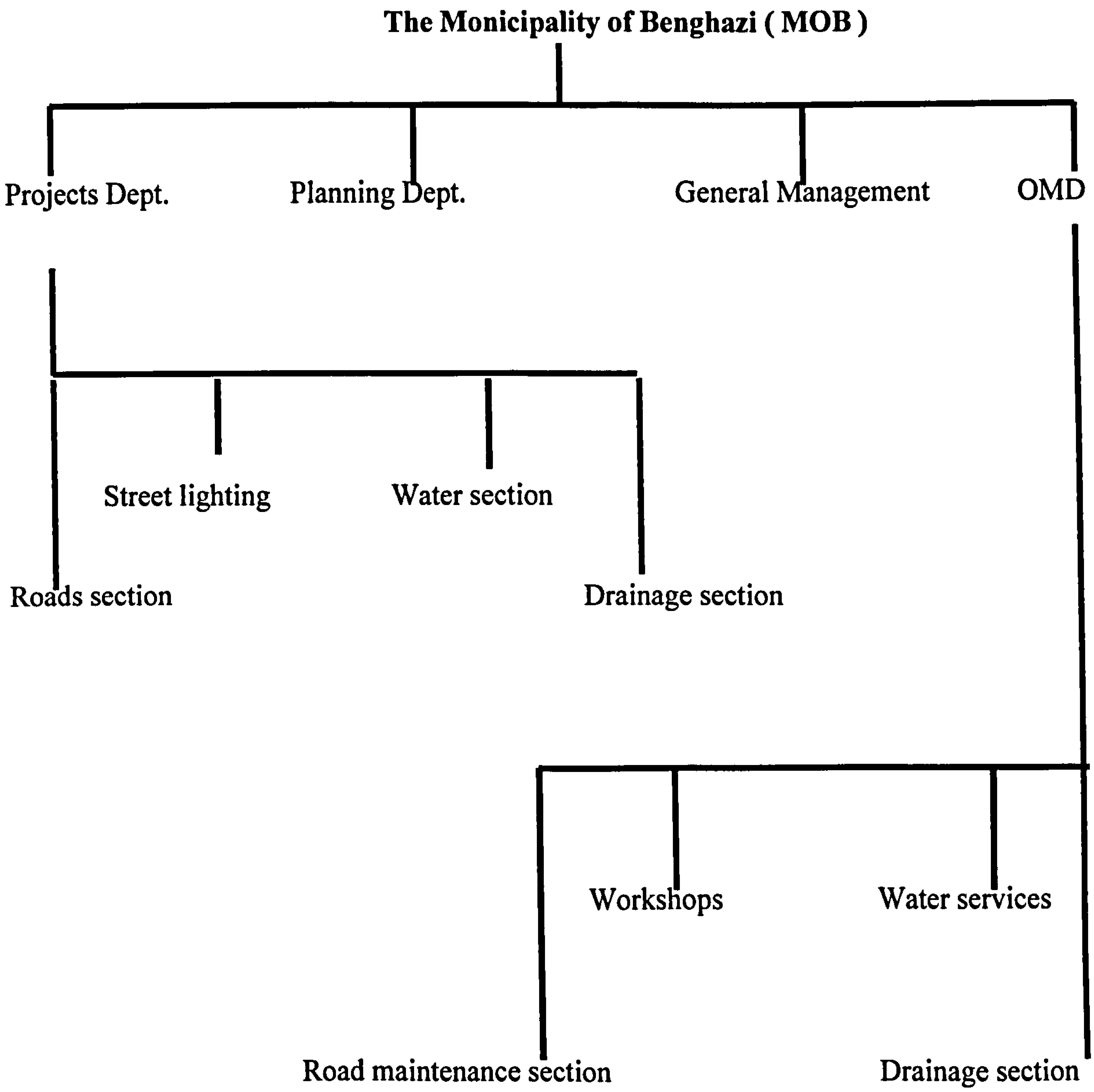


Figure 4.8 Departments and sections among the MOB

Despite the problems cited above, the roads section is comparatively well organised owing to the capabilities and compatibility of the maintenance team. But this team, however well organised, is not sufficient to cater for the needs of the whole city network. At the same time, it is not possible to estimate the required staffing levels, as the city's maintenance needs and priorities have not been determined. Therefore, establishing proper maintenance management is an essential, in order to gain optimum benefit from the available resources.

The workshop section has a high degree of mechanical skill, and a high quality of mechanical maintenance (Ove-Arup 1985), in spite of a shortage of spare parts. This may justify the intention to explore mechanical systems, without electronic sensors, to monitor road conditions. The workshops are well equipped with most tools and materials required to maintain the OMD plant, which includes a number of dumpers, graders, finishers, trucks, rollers and bitumen boilers.

The drainage section is responsible for a huge foul and storm water sewer network relative to the staffing level and the available resources within the section. Responsibility may extend to minor construction works, and maintenance of treatment plants and pumping stations. The section is understaffed for the work required so most of drainage problems in the highway network are due to inadequate maintenance of utilities.

The Water service section is not much better than the drainage section, but the scope and size of work in this section is much smaller. The main tasks in the section are emergency drainage maintenance and the construction of new building connections. Major tasks are carried out either through a local contractor or the project contractor, by issuing a variation order to cover and validate the task financially.

In general, all sections within the OMD are suffering from lack of resources, technical skills, proper management and sufficient budget. Consequently, the municipality of Benghazi has compensated for this shortfall by shifting major maintenance tasks to foreign contractors, who are mainly appointed to road construction work. There are two main foreign contractors working with the municipality of Benghazi on road construction, Deawo (a Korean company) and Bilfinger & Berger (a German company). The roads projects are divided between them without any competition. Other foreign contractors were smaller in terms of size and resources, and as a result, they couldn't proceed in their work because the municipality failed to pay invoices of completed and approved work on time (six weeks after submission and approval of invoice), with some invoices being frozen for several years without justification.

For a long time foreign contractors have tolerated the delay in paying their invoices, although they have built high standard roads within and outside the city of Benghazi. Nowadays, if a contractor is asked to submit a tender to carry out maintenance work in the city, the cost of the contract will be two or three times the actual cost, in order to compensate for payment delays. In a case in point, Bilfinger & Berger submitted an offer to the municipality of Benghazi in December 1994. This offer was to carry out remedial work and maintenance for two steel bridges passing over roundabouts for the sum of more than 2 million Libyan Dinars (LD 2,457,702: LD 1 = $ 3.2).

As mentioned above, the OMD is a department in the Municipality of Benghazi which includes two other Departments, the Projects Department and Planning Department. The Projects

Projects department is concerned only with the construction of new road projects, which are mostly carried out by foreign companies. Consequently, the Projects Department has the largest part of the municipality budget, as the road authority prefers to fund new road projects instead of road maintenance. Figure 4.9 presents the annual development budget assigned to all municipalities in Libya (10 municipalities in 1993), the budget assigned to meet expenses on new road projects and road maintenance. But because the rate of expenditure on the municipalities has significantly decreased from L.D. 274 millions in 1981 to L.D. 90 millions in 1993, and because most of the budget is spent on new road projects, the remainder for road maintenance is insignificant. Table 4.5 shows a significant underfunding in bids claimed by the municipalities sector during years 1994 to 1996 by more than 50%. The problems and obstacles which militate against establishing proper maintenance management systems in the city of Benghazi are extensive, starting from a shortfall in the budget to a lack of technical skills and reluctance of engineers and planners to adapt to computer technology. But for the sake of preserving the highway network in an acceptable condition, and to enhance and boost previous studies, efforts in all aspects of road maintenance must persevere for the next few years using available resources and materials, consideration needs to be given to the importance and necessities of establishing regular training programs to encourage engineers, planners and technicians to adopt and employ the high technology systems in maintenance management, to be readily when those obstacles dwindle.

4.5 Present road condition in Benghazi

The city of Benghazi has the second largest highway network in Libya. Within the city, there is a total of about 1500-km of roads of different categories. The roads in general are in a bad state and need immediate action towards establishing a proper maintenance strategy. During a

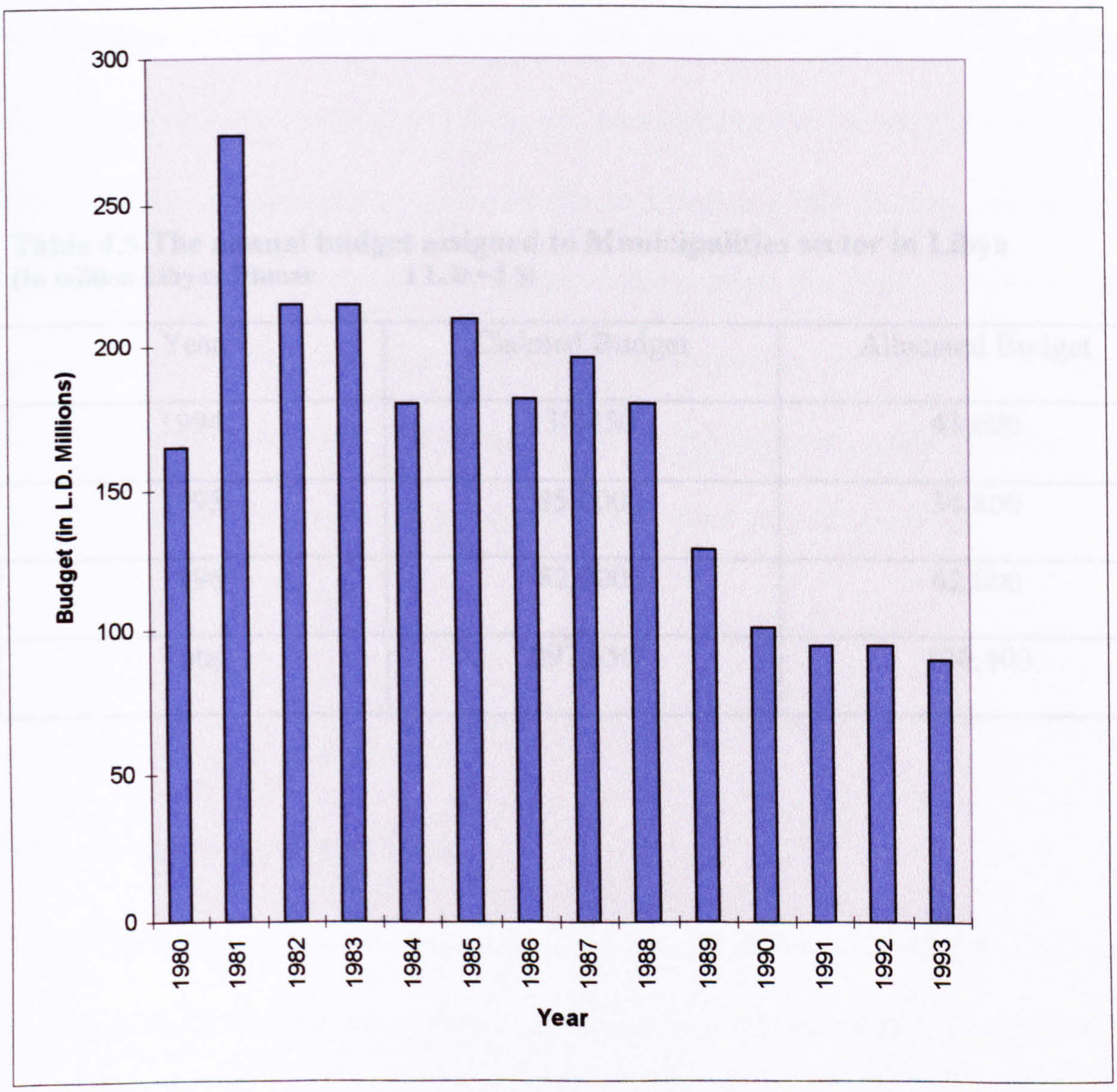


Figure 4.9 Development Budget allocated to the municipalities sector in Libya

Table 4.5 The annual budget assigned to Municipalities sector in Libya
(In million Libyan Dinnar 1 L.D.=3 $)

Year	Claimed Budget	Allocated Budget
1994	130,450	43,600
1995	85,000	34,800
1996	82,000	62,000
Total	297,450	140,400

personal visit to the city of Benghazi in 1996 for a field study to collect data about the present road condition, a team of four engineers and 12 technicians has been appointed to investigate the condition of the city road network. The road investigation list has included road construction date, pavement structure layers, maintenance history and the traffic volume. The main causes of deterioration appear to be due to disrepair of the drainage system, poor trench reinstatement and delays in repairing surface defects. From the photos which have been taken to the most road categories and according to the information provided from the investigation list and the visual inspection carried out by the inspection team, roads constructed in the city during the last three decades can be classified into three present conditions:

- roads in good condition,
- roads in reasonable condition,
- roads in unserviceable condition.

4.5.1- Roads in good condition

Despite this category constituting a minor percentage of the highway network, roads in this category confirm the conclusion that it is possible to maintain roads in the city and keep them serviceable. Figures 4.10 and 4.11 demonstrate some of roads that have existed for more than 35 years in the busiest areas in Benghazi (city centre). During this period, these roads have received regular and adequate maintenance, because of the great demand on them from road users and their location in the network.

4.5.2- Roads in reasonable condition

This category of road is widely distributed all over the network, and lacks even minimal maintenance activity. Some of them have been recently constructed (between 4 to 8 years), and the remedy requires either surface dressing or resurfacing. Figures 4.12 and 4.13

demonstrate roads still in reasonable condition and maintenance costs in this stage are much lower than any later stage.

4.5.3- Roads in unserviceable condition

Roads in unserviceable condition that need to be entirely reconstructed constitute the majority of roads in the network. Figure 4.14 illustrates a case study road which was recently opened to traffic (less than 5 years old), but owing to the failure of an old foul pipe underneath (600∅ mm), the entire pavement failed as well. Figures 4.15 and 4.16 demonstrate roads which are in the worst condition owing to excessive deterioration in all aspects; surface, structure and foundation.

4.5.4- Aftermath of the existing road condition

The existing road condition has reached a stage which cannot be covered by the regular maintenance budget. The effects of this level of deterioration have extended beyond the economic issues into social and environmental effects.

4.5.4.1 Social effect

The condition of highways in close proximity to residences greatly influences the community view of their property. Figures 4.17 and 4.18 demonstrate the disregard towards roads from residents living adjacent to roads in bad condition. People discard refuse and building rubble with no regard for the general appearance of the road. This demonstrates that the condition of roads has a direct bearing on the quality of life in residential zones. Therefore, when roads are unserviceable and cause harm to residents, people will start to neglect them.

In some cases in Benghazi, the public health of residents has been affected by spillage of sewage resulting from broken sewers beneath the roads. The impact of such events is serious in view of the high temperatures (25° to 40° C) experienced in Benghazi during most of the year. This can be a particularly serious issue in areas where children play on or near the highway and where disease is a common place.

4.5.4.2 Economic effect

The Vehicle Operation Cost (VOC) associated with the road condition demonstrated in Figures 4.19 and 4.20, is significant. Vehicles may experience difficulty in negotiating roads which fall into significant disrepair. Moreover, additional costs for tyres, suspension systems and other vulnerable components in vehicles are a particular problem, especially since all Libyan vehicles and spare parts are imported and road repairs have a negative impact on foreign exchange.

Diversions, which are common in such road condition, also lead to delays and additional use of fuel. In some extreme cases, factories have been closed as a result of the inability of goods and supplies to be delivered between factories and customers. The road conditions shown in the photographs occur extensively throughout the network during the onset of the winter season.

4.5.4.3 Environmental effect

The environmental effect of poor road conditions is self evident: sewage spillage and building rubble will cause significant harm to the environment and the general appearance of the city. Gases and particles emission from the exhausts of standing vehicles also contributes to the environmental problems.

4.6 Discussion

Owing to a shortfall in the highway maintenance budget allocated to the Municipality of Benghazi, it is impossible to address roads in both reasonable and unserviceable condition.

Figure 4.10 Category III road in good condition: The city centre

Figure 4.11 Category III road in good condition

Figure 4.12 Part of the second ring road: Reasonable condition section

Figure 4.13 Category II road in reasonable condition: The sport city area

Figure 4.14 Category I road: Opened to traffic for two years only

Figure 4.15 Category III road connecting 4th and 5th ring roads: Excessive cracks and potholes

Figure 4.16 Category III road in unserviceable condition: Foundation failed

Figure 4 17 Category IV road: high-density residential area at the city centre

Figure 4.18 Category IV road: residential area at the city centre

Figure 4.19 Category III important road in very poor condition

Figure 4.20 Category III road: high vehicle operating cost in very important road

When maintenance budgets are severely limited, it is preferable to use the limited resources available on improving the condition of the reasonable roads, rather than attempting to bring those roads which are already unserviceable back to good condition. This is because compared with the cost of rehabilitating those roads in reasonable condition, the cost expressed in a unit rate basis of rehabilitating those roads in an unserviceable condition is particularly high.

It is estimated from the visit undertaken in June 1996, that over 50% of the roads in the City have reached an unserviceable condition and are in need of immediate repair. Owing to a shortfall in the maintenance budget, it is clear that the necessary remedial work cannot be undertaken. Moreover, it would seem that a more sensible approach would be to allocate those resources towards preventing other roads falling into a condition similar to those described.

Effectively, the road authorities in Benghazi have now reached a situation, which is difficult to manage. There is regular day-to-day conflict in spending prioritisation between the maintenance of a minority of roads in good condition and the major repairs needed to roads which have deteriorated to level which require major civil engineering work. In any country, it is imperative that a maintenance budget is allocated to any highway network in order to firstly maintain the roads in serviceable condition and secondly to undertake any repairs when roads become unserviceable.

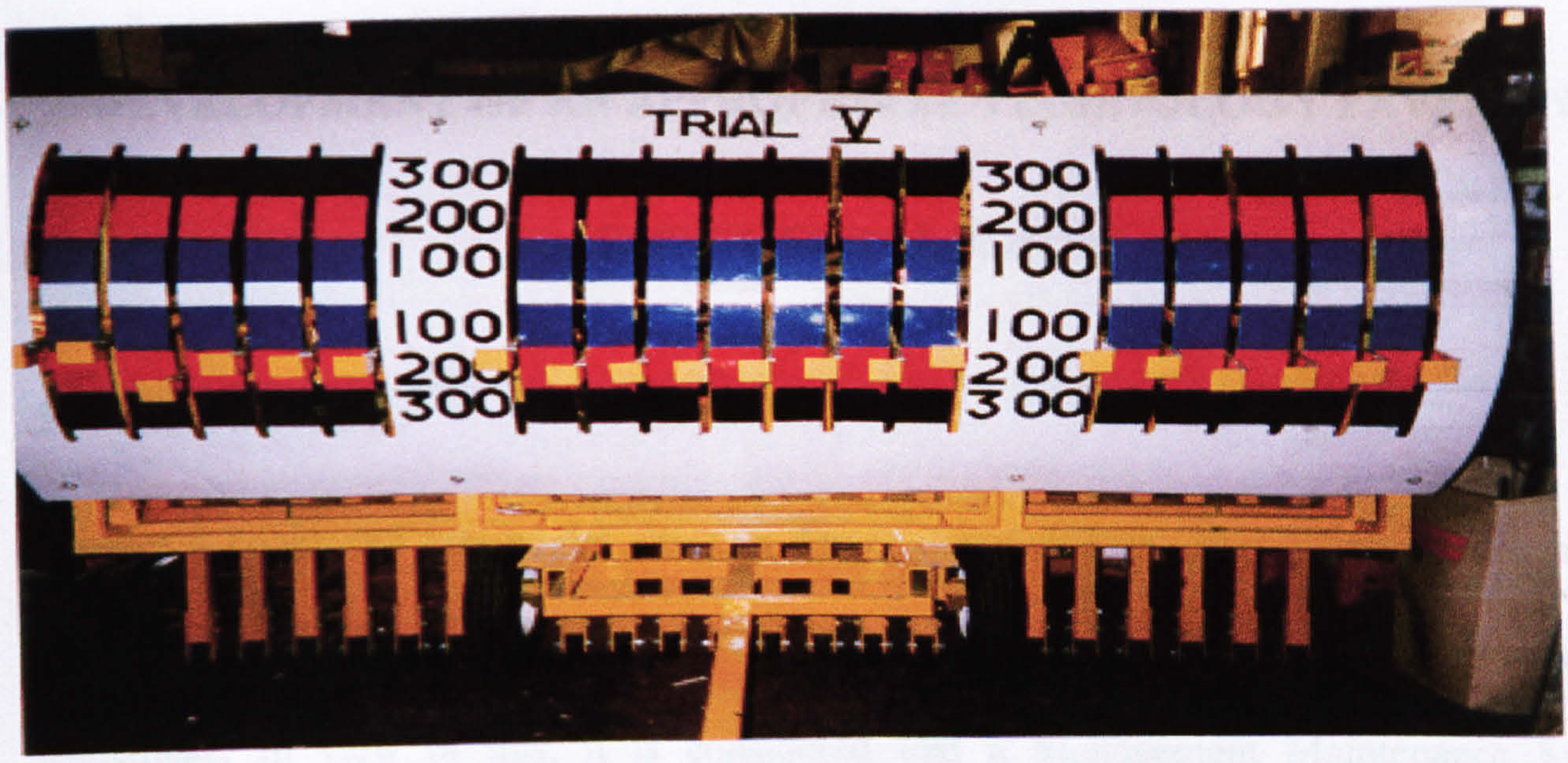
At some level of deterioration, it would be relatively inexpensive to maintain roads and keep them in good condition by carrying out regular and adequate maintenance. In the city of Benghazi, the major problem within the highway network is water, either from leaking sewers or through unsealed cracks, which weakens the ground underneath. This level of deterioration is severe, as shown in photographs with repair unaffordable within the budget allocated to the maintenance sector. Therefore, to avoid exacerbating the situation in the future, there must be a strategy to link road maintenance and services maintenance. To achieve this, there must be enhanced co-operation between the road authorities and utility services.

The situation in Benghazi does not make it impossible to maintain roads in good condition because as illustrated in the photographs, there are some roads still in good condition despite their long life and the high level of traffic. Therefore, with the available resources roads can be repaired according to the following list of priorities:

- roads with serviceable surfacing materials,
- roads with unserviceable surfacing materials,
- roads with base failure,
- roads with foundation failure.

In order to avoid the intractable problems of maintaining the whole highway network with a limited budget and to achieve the optimum benefits of this budget, it is necessary to give those roads which are currently in good condition the first priority in spending. The next priority should be to look at those roads where only new surfaces are needed, and install those surfaces to prevent any further deterioration. The third priority should be to look at those roads where bases have failed and finally those roads where foundations have failed. As roads in the last category have reached their worst state, and there is no sense in spending the whole available budget on repairing them.

Once first priority is given to those roads in good condition, it is essential to keep monitoring them, in order to be able to undertake timely maintenance within the limited budget allocated, the resources available and the surplus of engineers in some departments within the Municipality of Benghazi. Therefore, the above strategy can only be achieved with the using of an appropriate road condition monitoring system in the city Benghazi.



CHAPTER 5

DEVELOPMENT OF AN APPROPRIATE TECHNOLOGY PAVEMENT ASSESSMENT MACHINE

Contents:

CHAPTER 5

DEVELOPMENT OF AN APPROPRIATE TECHNOLOGY PAVEMENT ASSESSMENT MACHINE

5.1-Introduction

Chapter 4 concluded that whilst cities in developing countries often have many qualified engineers available, it is frequently the case that budgets for capital equipment are inadequate. In view of this, it is considered that a Management Maintenance System appropriate to cities in developing countries should use equipment designed to minimise capital cost and to use the available skilled engineering personal as a substitute for those automated processes which are appropriate only in western situations.

This conclusion forms the basis for the construction of a prototype-monitoring device which has been used in a pilot monitoring exercises, thereby evaluating the benefit which such appropriate technology can bring to the issue of monitoring pavements in cities in developing countries, having similar conditions to those pertaining in the city of Benghazi.

The aim was to develop simple low-cost equipment by means of which engineers and technicians could monitor the condition of a city roads network in order to enhance and facilitate the goal of establishing an effective pavement maintenance management system in the city of Benghazi, and therefore, in similar cities. The prototype described in this Chapter is purely mechanical which eliminates electronic and laser sensors in monitoring the road condition. The design of the prototype is geared towards the conditions and difficulties which exist in the Municipality of Benghazi (e.g. maintenance, budget). The only electronic component is a video camera, which can be mounted on a towing vehicle roof to record the data gathered for each road section. Video cameras have been available in the city's markets for more than 15 years at reducing prices and comprise a wide range of well-known low cost brands. Therefore, the road authority can afford to purchase and maintain such equipment (for example by replacing a faulty camera and purchasing a new one). Effectively, the electronic part of the equipment has been condensed into one low cost durable consumer product. This concept of separating the monitoring equipment into one appropriate technology mechanical component and one consumer electronic product is the essential innovation in this project.

Although other monitoring systems which are based upon sophisticated technology have been developed and have been available for use in western countries for more than two decades, the road authority in the city of Benghazi (and in Libya in general) would find them inappropriate owing to the factors and conditions cited in Chapter 4.

None of the reviewed monitoring systems (western technology systems) has truly dealt with the kind of high-labour low-finance situation which is the common case in most developing countries. However, high technology road monitoring systems are based upon minimising labour cost. Therefore, the prototype road monitoring system described in this Chapter is designed and developed to be used in cities similar to Benghazi. Therefore, it was considered (because this research has a practical outcome) important to collaborate with industry, particularly in relation to the manufacturing of the equipment. Discussions have taken place with a local manufacturer of trailers (Sunderland Trailer Centre), who facilitated the research by contributing their management and technical skills in developing the monitoring equipment and its trailer. The benefit gained from this contribution was to ensure that the prototype equipment would be practical and could be manufactured from standard components for cost-effectiveness and would be appropriate to those cities in developing countries with similar conditions and situations to those encountered in the city of Benghazi in Libya.

5.2 The preliminary version of the prototype

Several types of defects can be measure by mechanical systems: factors such as skidding resistance and longitudinal profile are important, but in a situation as existing in Benghazi, where the primary need is to distinguish between roads experiencing minor structural defects and those with serious structural problems at base and sub-base levels, the most important defect is rutting. Therefore, the project focussed upon the development of an appropriate technology rut depth measurement system.

An initial small scale prototype was built in order to establish the viability of the proposed system and to facilitate the introduction of design development during the manufacturing and trials process. The small-scale model consisted of two main parts, the special monitoring apparatus and its mounting trailer which was designed to suit the road monitoring equipment size and weight. Trials were carried out using the preliminary versions of the prototype which ensured that the first full scale production machine operated efficiently.

5.2.1 The monitoring equipment

The preliminary model (Figure 5.1) comprises 4 square hollow steel section legs of dimension 40x40x3.2mm, arranged at 100mm centres to move vertically reflecting the road surface condition. A sensing rubber wheel of 80 mm diameter is bolted to the lower end of each leg by flat steel section of dimension 300x20x2 mm at each side using 2 bolts at the leg and 1 bolt at the centre of the wheel. Each monitoring leg passes through two parallel rectangular holes of dimension 50x50mm formed in a hollow timber box of dimension 550x250x200mm.

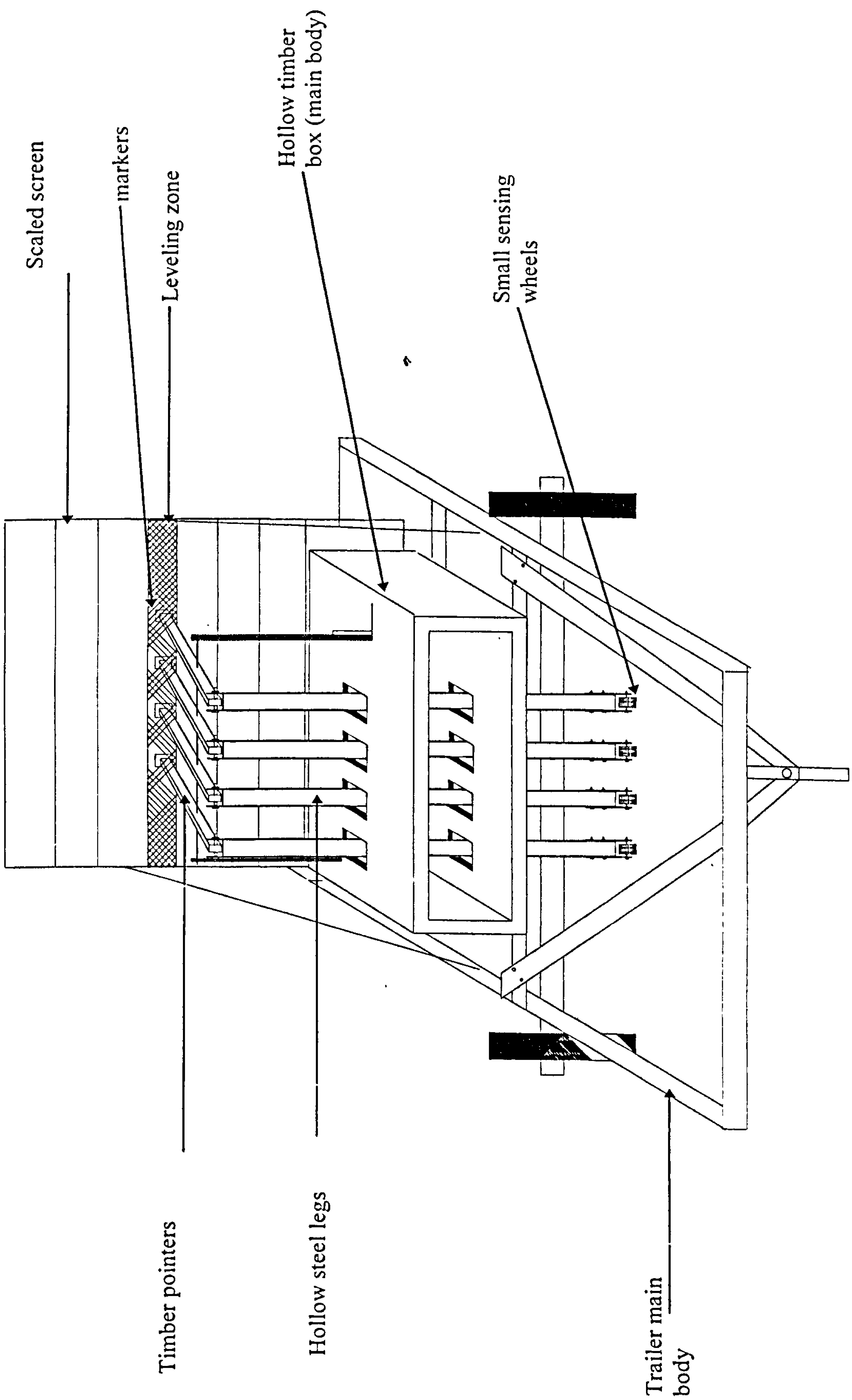


Figure 5.1 The small-scale monitoring equipment

A timber pointer of 700mm length is connected to the upper tip of each steel leg through two pivot connections arranged to create a magnification of 1:10, in order to magnify the vertical movement of the sensing wheels on the road surface to 10 times on the measuring screen. The screen was manufactured from 18mm thickness timber with dimensions of 1000mm high and 800mm wide. The screen is screwed to the bottom of the trailer body and is supported by two steel levers at each side. At the end of each pointer, there is a square marker of dimensions 50x60mm fixed to move parallel to the screen. The markers are used as visible indicators of the magnified vertical movement of the sensing wheels on the screen, which is divided into different vertical zones of 100mm corresponding with 10mm on the road surface.

The first pilot exercise using the small-scale model took place in May 1997. The model was mounted on a special trailer prepared to suit this model. The trailer was towed by a saloon car through a medium duty coupling, using a draw bar of 3000mm length (from the coupling to the centre of the sensing wheels), in order to minimise the influence of vertical movement of the towing car suspension on the sensing wheels. The road section to be monitored using this prototype is a 300 metre long of minor road heavily used by concrete mix trucks gaining access to a nearby concrete plant. Figures 5.2 to 5.7 demonstrate the manufacturing process of the small-scale model.

This inspection run was successful from different aspects. It illustrated many points to be taken in consideration before moving to build the full-scale apparatus:

* it showed several negative points from a manufacturing point of view, such as the horizontal movement of the pointers; at the end of the inspection, the pointers at the middle were touching each other,

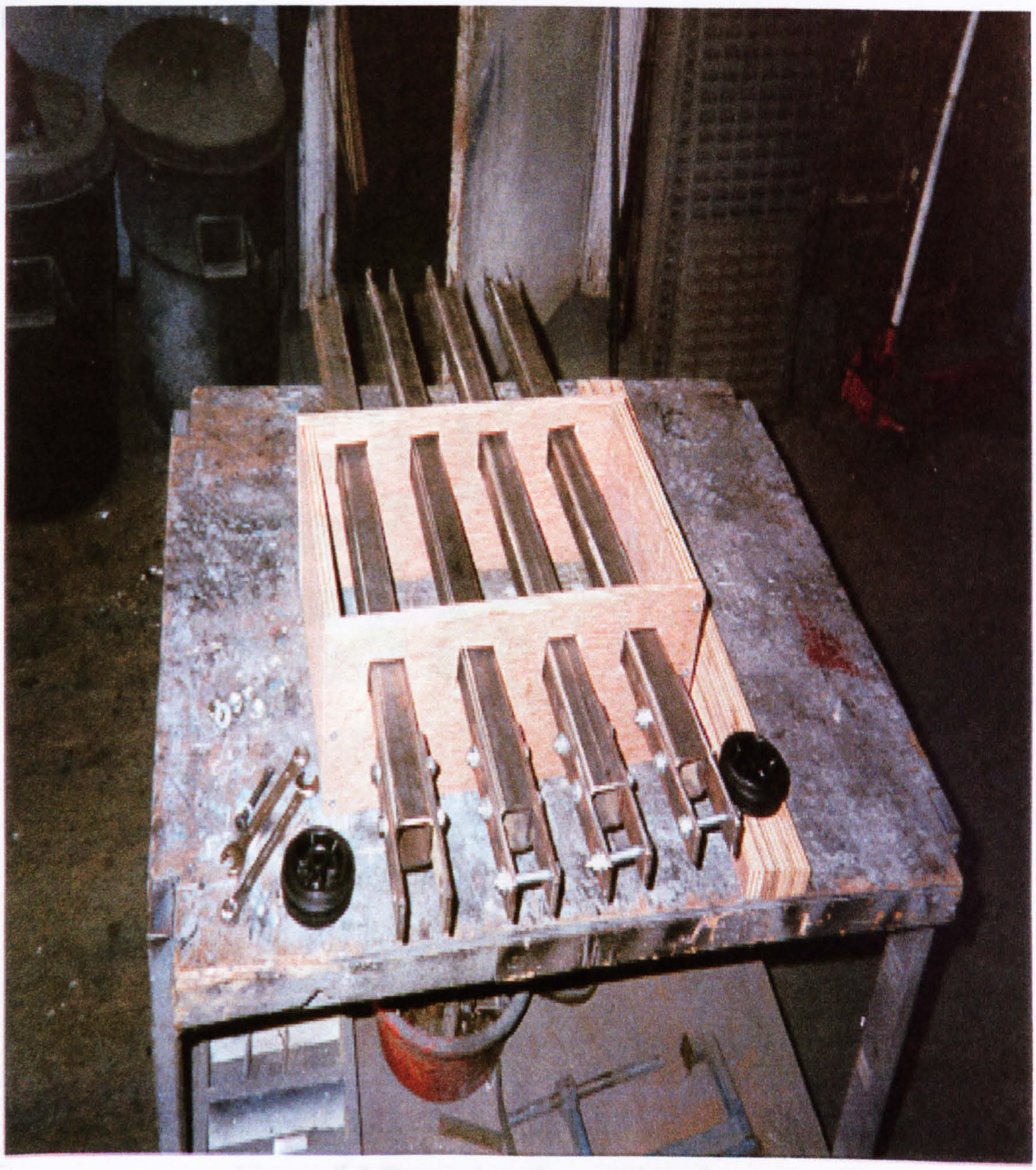


Figure 5.2 Fixing the steel legs to the timber hollow box

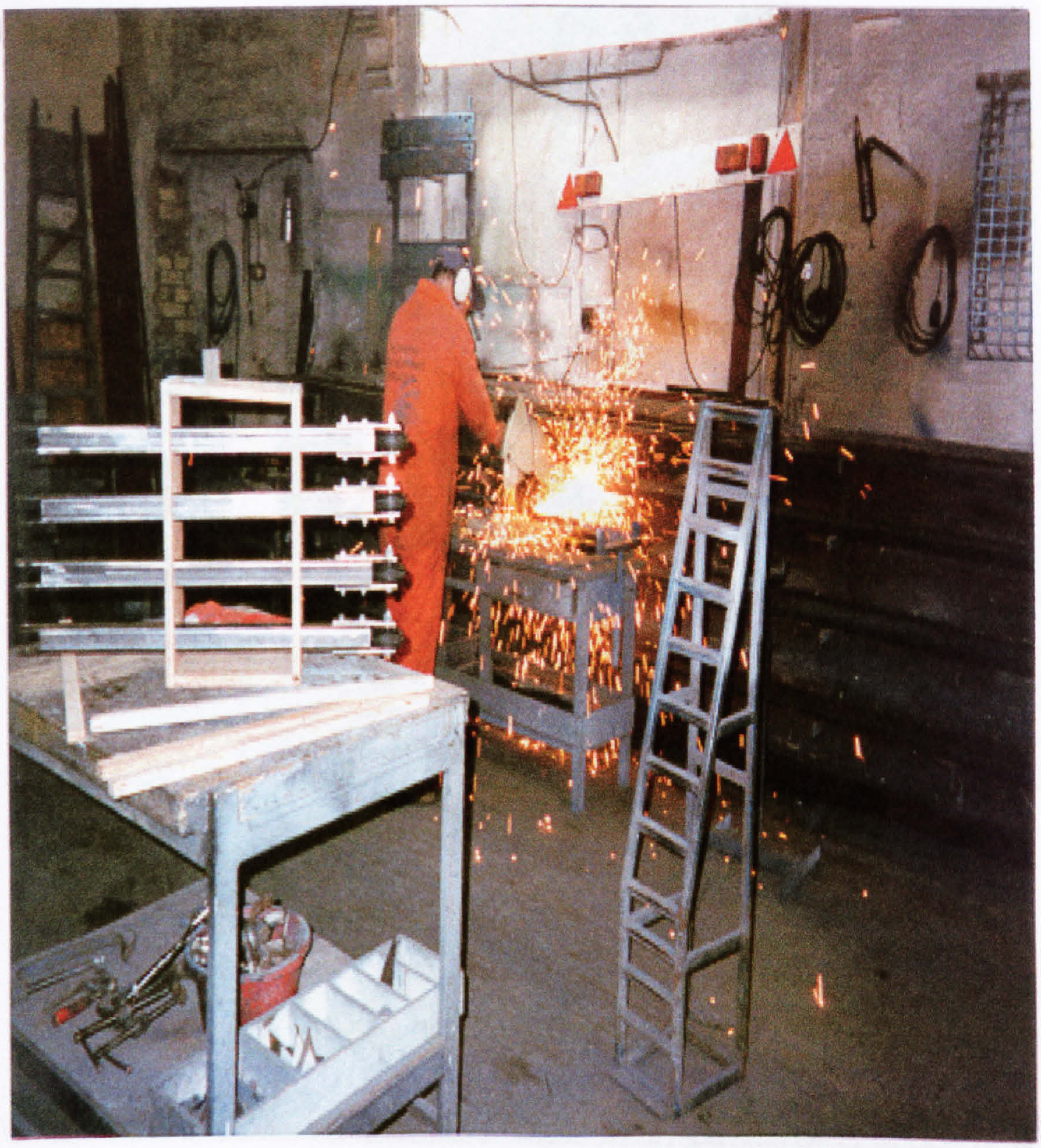


Figure 5.3 Preparing the pointers for connection

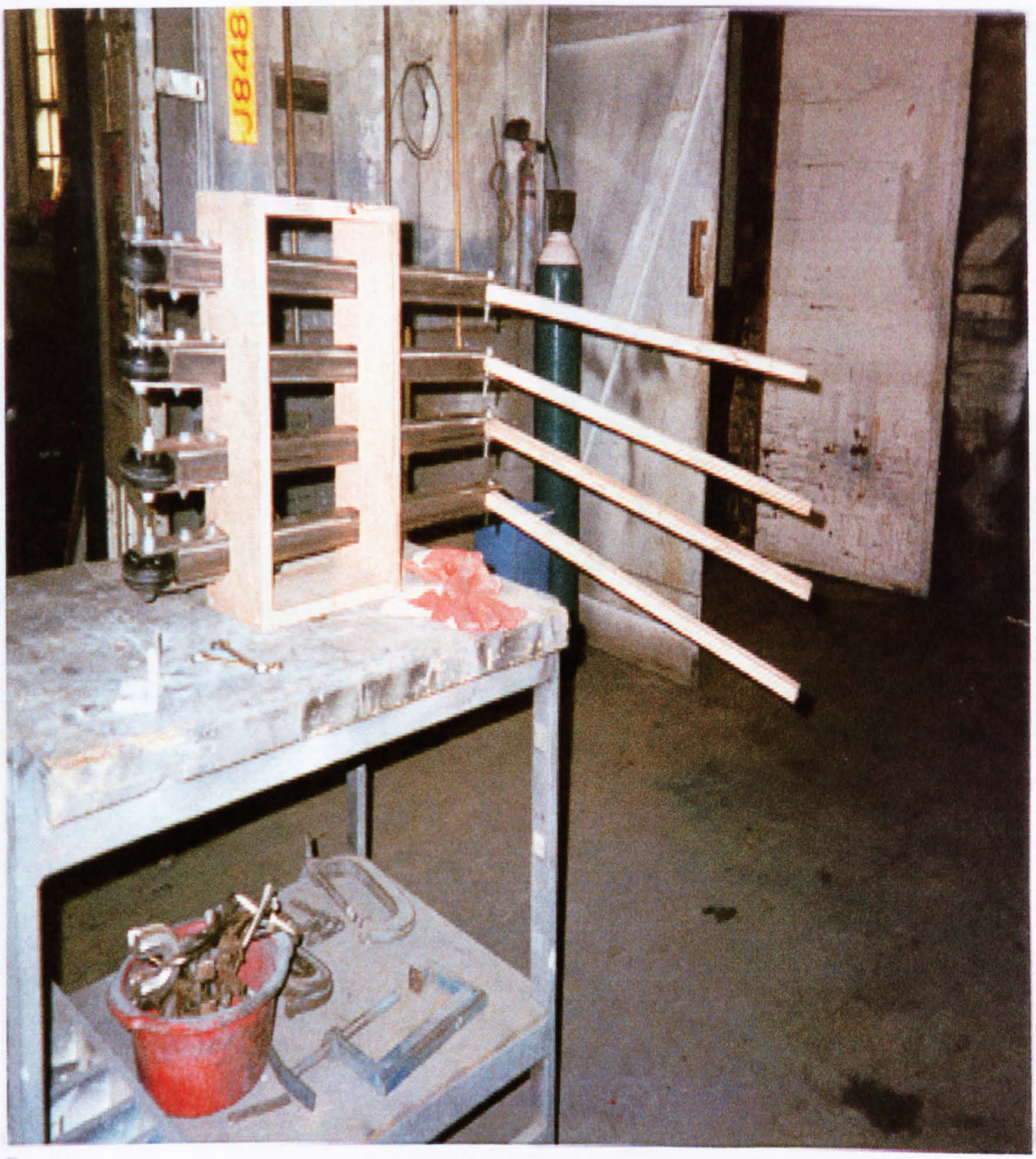


Figure 5.4 Connecting the pointers with monitoring equipment

Figure 5.5 The small -scale model at final stage

Figure 5.6 Calibrating the apparatus using flat steel beam

Figure 5.7 The preliminary version of the prototype on the road

* the sensing wheels were bouncing during the inspection even at low speed,
* the space between the trailer axle and the centre of the sensing wheels must be the minimum, as larger spaces make the sensing wheels very sensitive to the movement of both, vehicle and trailer wheels,
* the position of the pointers between the screen and the video camera obstructs a clear view for accurate measurement,
* it was discovered on the road test that the maximum monitoring speed should not exceed 15 km/h,
* for transporting the test equipment from depot to test area, another trailer built to conventional trailers regulations and construction has to be used , as the monitoring equipment cannot be towed on the highways at speed.

The second small-scale model was significantly different. In order to avoid the above factors, each pointer is connected to the hollow timber box via strong elastic bands, which prevented the sensing wheels from bouncing. Each pointer is held by four elastic bands to counteract the weight of the legs, pointer and the wheel (about 4 kg in total). In the second version, the whole system is turned around to ensure a clear view between the screen and the camera. In this case the screen has a number of grooves equal to the number of pointers, but a little wider to allow the pointer to pass through and at the same time to restrict it from any horizontal movement. The model in this trial is mounted in line with the trailer axle, in order to eliminate the effect of towing vehicle vertical movement and coupling position. Figures 5.8 and 5.9 demonstrate the modifications made to the original small-scale model to improve its application.

A second pilot monitoring exercise was carried out in June 1997. The trial showed significant progress in the development, manufacture and operation of the prototype. The pointers were steadier and were in their position at all times during the monitoring operation. The height of the towing vehicle had no effect on the pointers setting on the screen.

The elastic bands eliminated wheel bounce to maintain intimate contact between the wheels and the pavement surface, even in extreme situation where the wheel could pass over a pothole without bouncing. The same pavement section has been inspected repeatedly in this trial, in order to assess the difference between the two trial runs, to determine repeatability.

5.2.2 The mounting trailer

The mounting trailer is constructed according to the specifications and regulations for trailer manufacturing, in relation to the material used and the trailer dimensions. These regulations are cited in the manufacturing catalogue. The maximum length of any trailer using public roads is 7 metre, unless the trailer has 4 wheels and is towed by a commercial vehicle having a Gross Vehicle Weight (GVW) at more than 3.5 ton, and the maximum width is 2.3 m for trailers towed by light vehicles.

The trailer used in the preliminary trials was 1.2 m long and 0.9 m wide, fabricated from steel angle sections of dimensions 40x40x3mm and the chassis was located at the centre (0.6 m) of the trailer and was fabricated from hollow steel section of size 50x50x3mm. The drawbar comprise two parts: a rectangular frame which is welded to the trailer main body and a straight bar which is bolted to the end of the rectangular frame. The electrical work and number plate were not included on the initial prototype since it was not the intention to use this version on public roads.

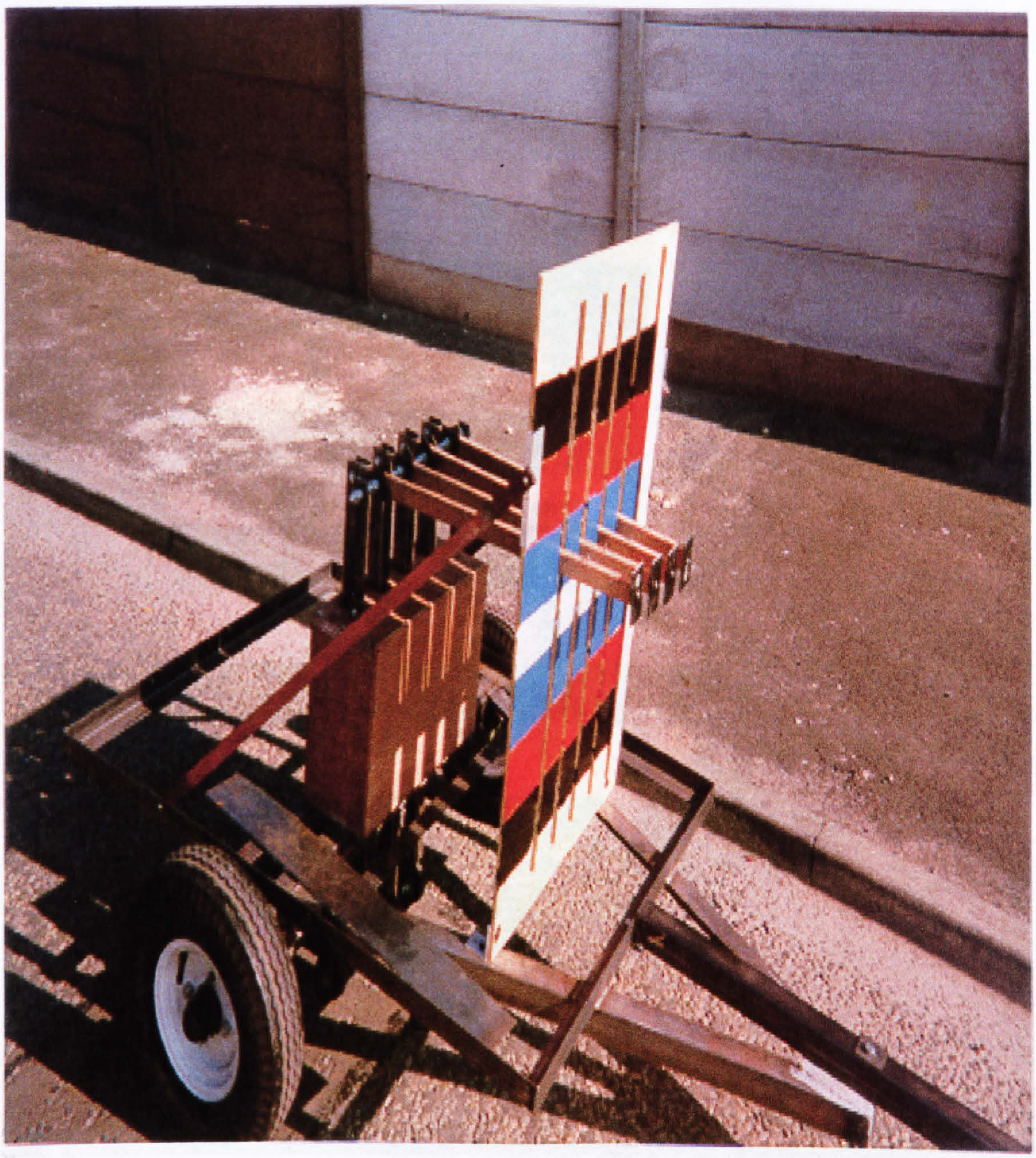


Figure 5.8 The second version of the prototype

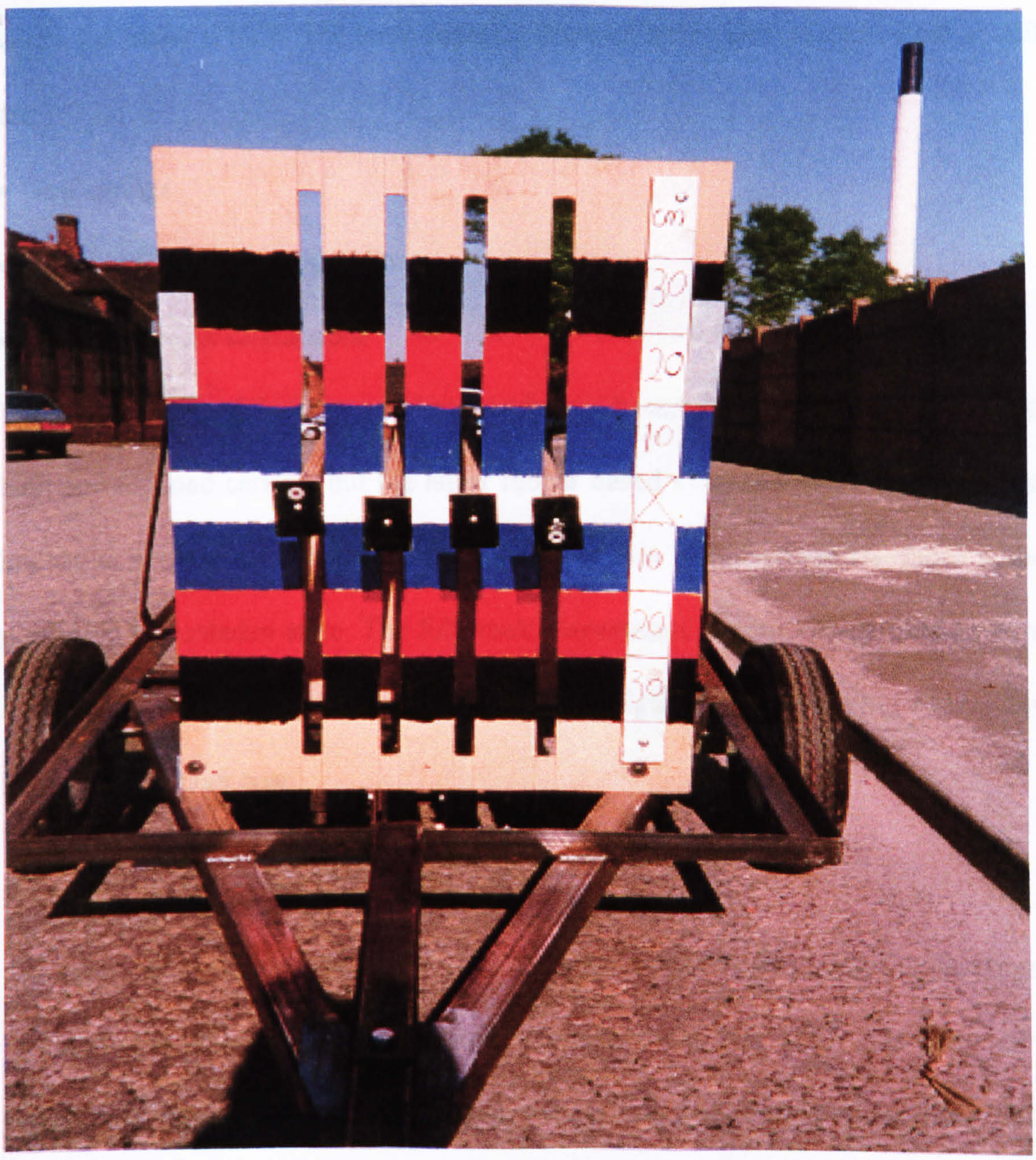


Figure 5.9 Position of the pointers on the coloured screen

5.2.2.1 The trailer suspension system

Trailer suspension systems are the fundamental components in trailer construction, around which the trailer is built. The most common types of suspension systems used in trailer design are:

- leaf springs
- independent rubber suspensions
- full track beam suspensions

The choice between these types of suspensions is based on the purpose for which the trailer is built and the load carried, but the latest rubber based systems are provide extra damping and improved performance as the harder the suspension characteristic the more bounce will be noticed in the unladen state. The full-track suspensions are commonly used to carry loads of over 750 kg, which is equivalent to 7 times the weight of the monitoring system developed, in addition to its high cost.

5.3 Details of Prototype Equipment

The results of the trials with the two small-scale devices were used in the development of the prototype machine. The prototype equipment adopted in this research is designed to measure the depth of wheel track rutting and assess the general condition of a road section throughout its full lane width. It consists of a 2.3 metre wide main body beam (variable according to the lane width) comprising detachable hollow steel boxes of different widths (Figure 5.10). Through those boxes, 30 legs fabricated from square hollow steel section (40x40x3.2 mm) are fitted at 100-mm centres. Each leg is 890 mm long and weighs 3.36 Kg/m, at the lower end of each leg, a rubber-tyred sensing wheel of 80 mm diameter is fixed by a castor fabricated from steel plate section (150x25x2 mm), bolted by two bolts to the leg and one bolt to the wheel.

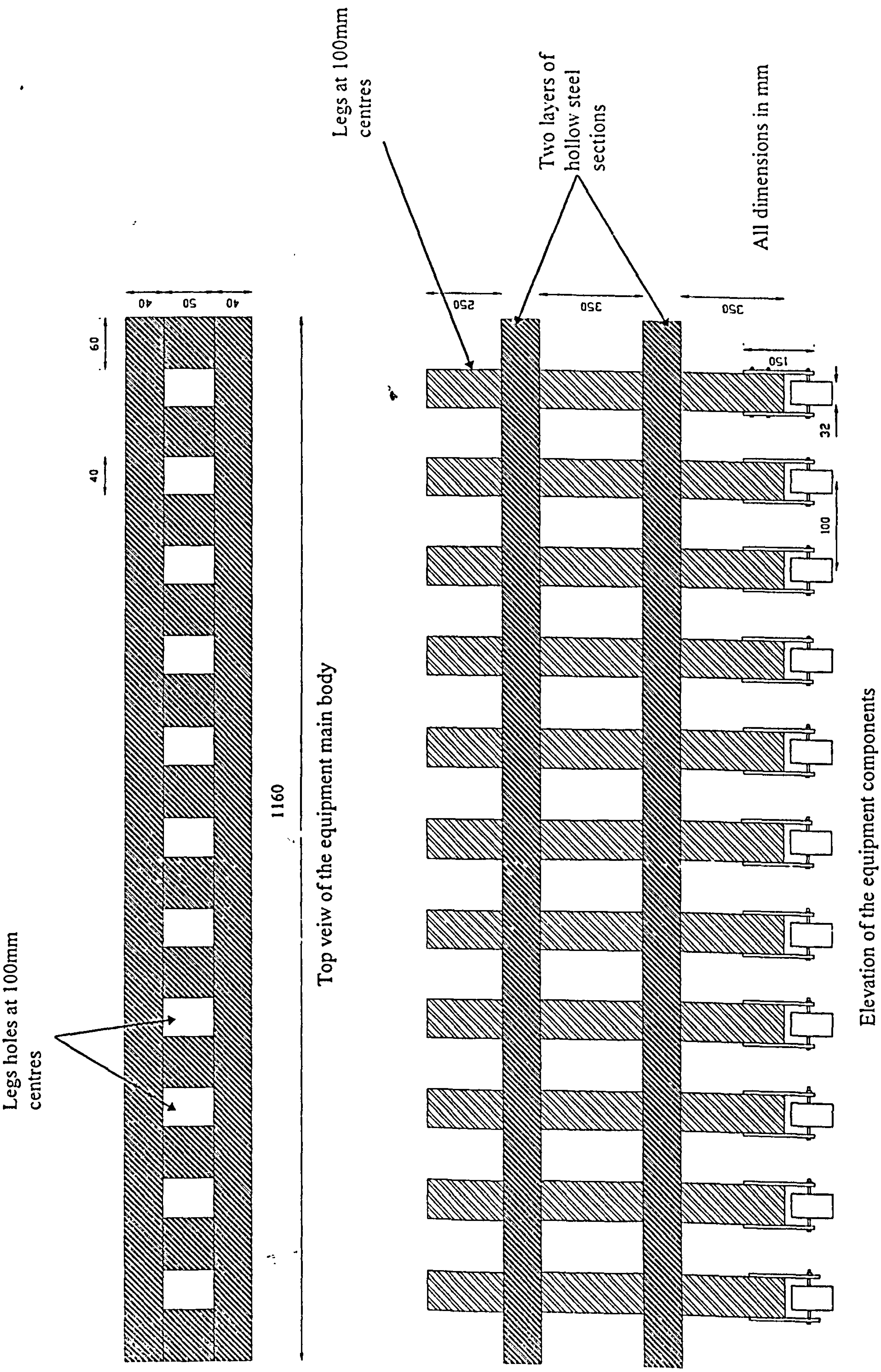


Figure 5.10 Design of full-scale apparatus

The wheel carrying capacity is 50 Kg, which is about 10 times the actual load carried by each sensing wheel. Each leg with its sensing wheel has independent vertical movement through its hollow steel box in response to the degree of rutting in the road. At the upper end of each leg, there is a pointer lever of length 670 mm fabricated from steel. The pointer is pivoted at two points with a mechanical advantage of 1:10, in order to magnify the vertical displacement of the sensing wheels on the road surface by 10 times. However, 1 mm displacement on the road surface will move the pointer 10 mm in the opposite direction on the monitoring screen. At the tip of each pointer, a square steel marker is bolted (50x50 mm). Each marker moves up and down on a scaled monitoring screen as the small wheels encounter road unevenness.

The monitoring screen is fabricated from three different parts of different material, inner, middle and outer parts. The inner part of the screen (Figure 5.11) is the screen's main body, which fabricated from three different steel sections, hollow steel section of dimension 40x40mm, angle steel section of dimension 40x40mm and flat steel section of dimension 40x3 mm. The middle part of the screen (Figure 5.12) is fabricated from galvanised sheet of light and durable material (1mm thickness steel). This galvanised sheet has grooves of 25mm width to allow each pointer to pass through whilst suppressing horizontal movement and so allowing a clear view between the video camera and the screen. The galvanised sheet is curved to a radius equal to the pointer length (670 mm), to ensure constant distance between the markers and the screen during monitoring process. The outer part of the screen (Figure 5.13) is fabricated from fibreglass sheet (1.3 mm thickness). This component has the same dimensions as the galvanised sheet with narrower grooves (20mm) in order to protect the pointers from direct contact with the galvanised sheet to prolong their functional life. The screen is marked with different zones each of different colour; each zone is 100 mm deep

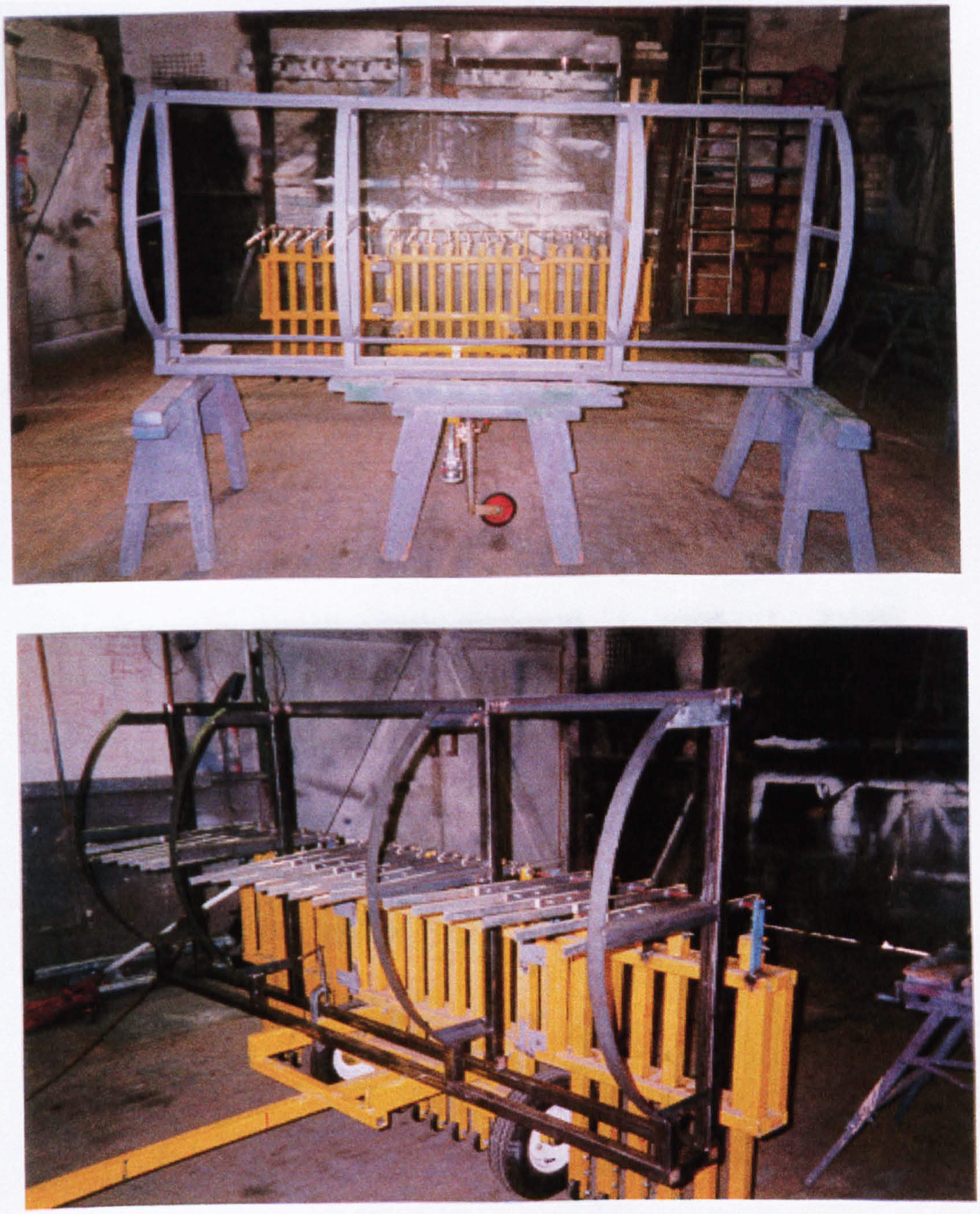


Figure 5.11 The inner part of the monitoring screen

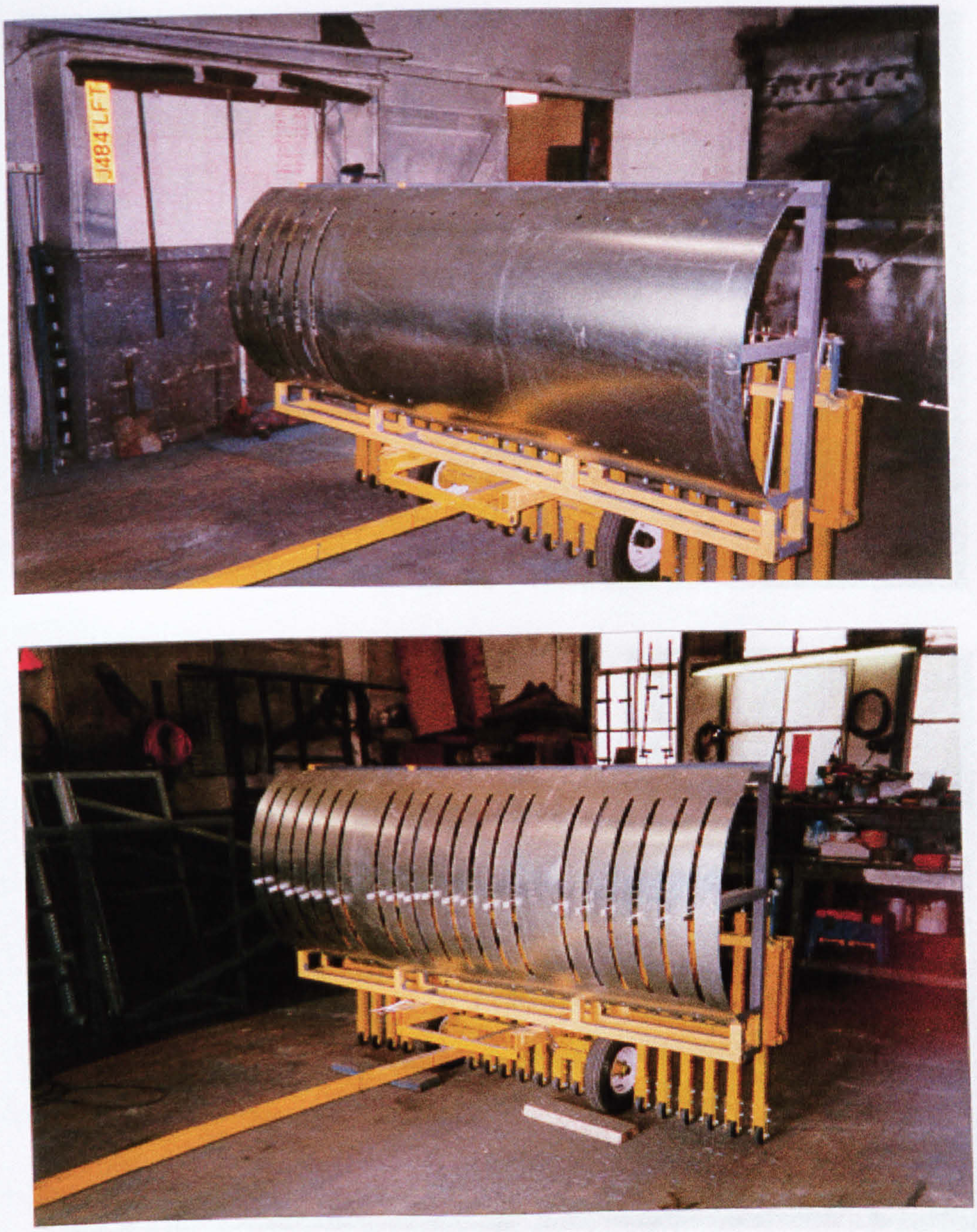


Figure 5.12 The middle part of the monitoring screen

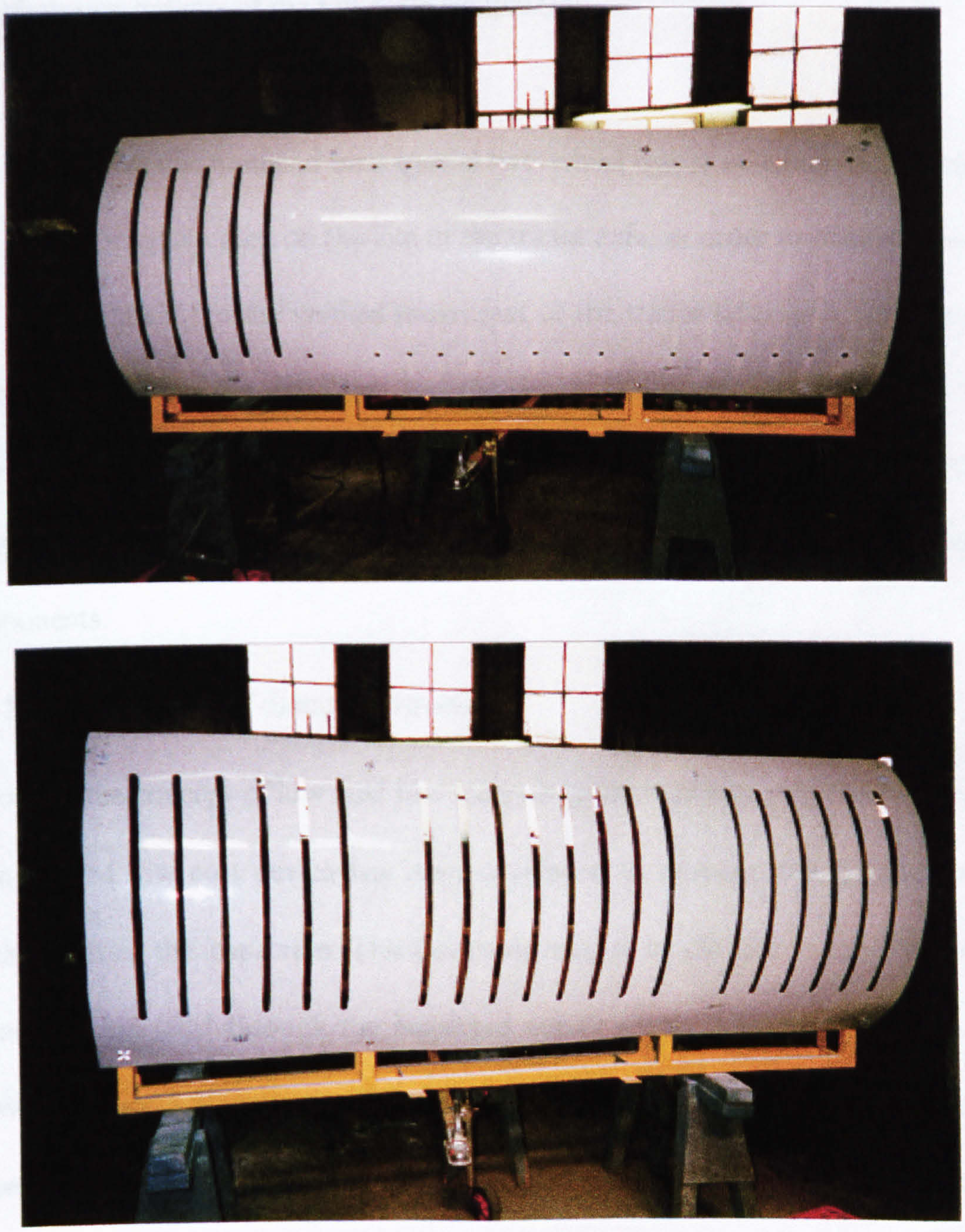


Figure 5.13 The outer part of the monitoring screen

which represents 10 mm vertical displacement on the road surface, and the level position zone has the same thickness as the markers (50mm). Figures 5.14 to 5.19 demonstrate the manufacturing process of the full-scale equipment.

The whole system is mounted on a special two-wheel trailer of 1.0 m width and 3.0 m length. The prototype is mounted on the line of the trailer axle, in order to eliminate any effect which may develop owing to the vertical movement of the trailer wheels. A surveying vehicle tows the trailer using a 3.0m draw bar, in order to minimise any effect from the towing vehicle suspension. Table 5.1 shows details of shape, section, number and weight of the prototype components, in order to assess the total weight of the equipment and the total cost of the components.

5.3.1 Measurement of distance travelled

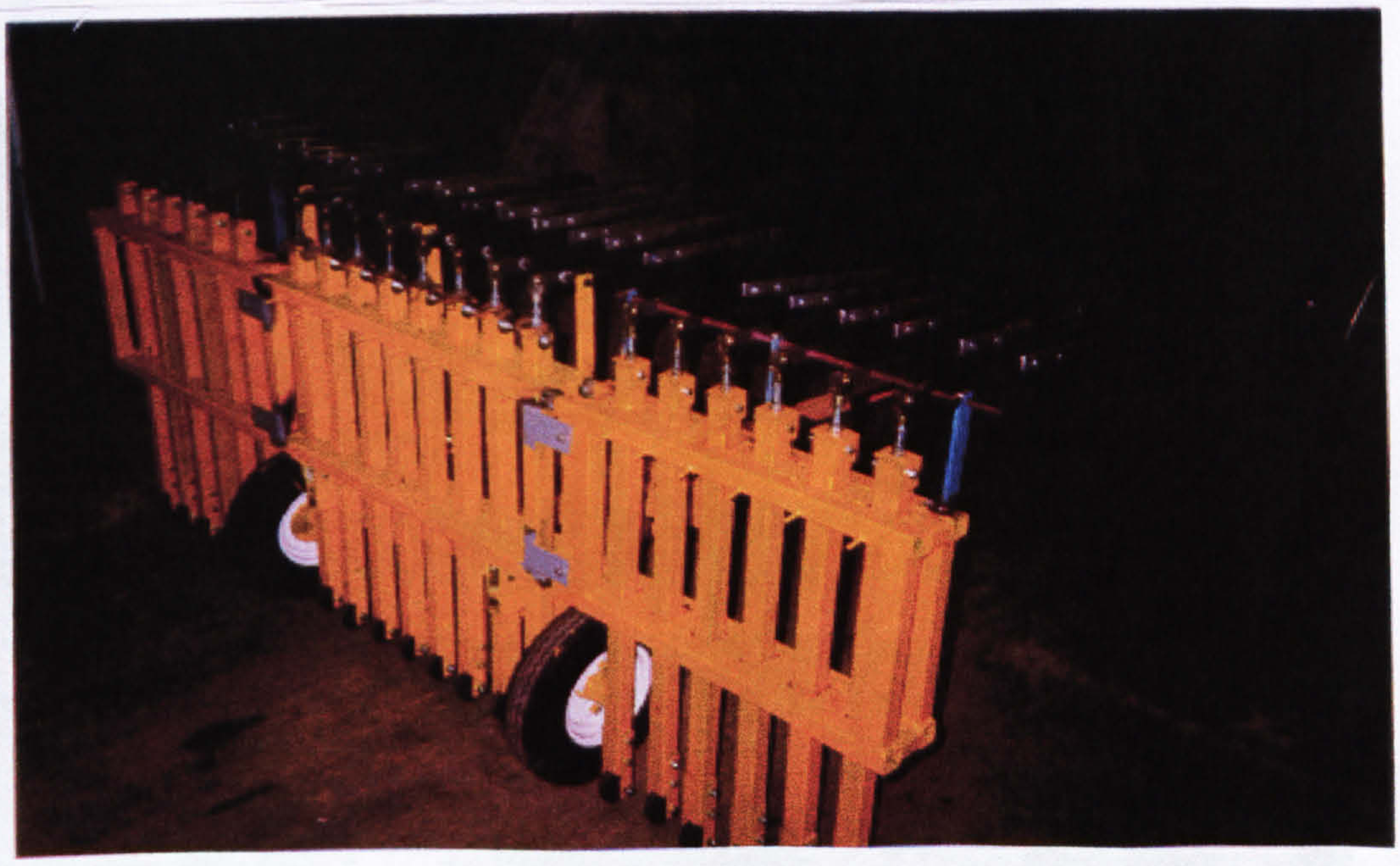
Following the concept of low cost low technology in manufacturing the prototype equipment, a simple and low cost device has been developed to measure the distance travelled by the machine during the inspection. This device developed to allocate in approximate the positions of intervention level through the inspected road section. The distance measurement device shown in Figure 5.20 comprises a set of wheel pulleys arranged behind the monitoring screen. These pulleys allow a steel line of 2mm thickness connected to a bicycle wheel (650 mm diameter) from one end and a load of 2.5Kg from the other end to run smoothly during the inspection process. The steel line is connected with a pointer moving horizontally on a scaled screen to measure the distance travelled during the inspection. The bicycle wheel is connected to the machine through a pivot connection in order to allow it to swivel during travelling.

Figure 5.14 Preparing the prototype components for assembling

Figure 5.15 Welding the main body components

Figure 5.16 Positioning the main body on line with the trailer axle

Figure 5.17 Splitting the main body to three parts



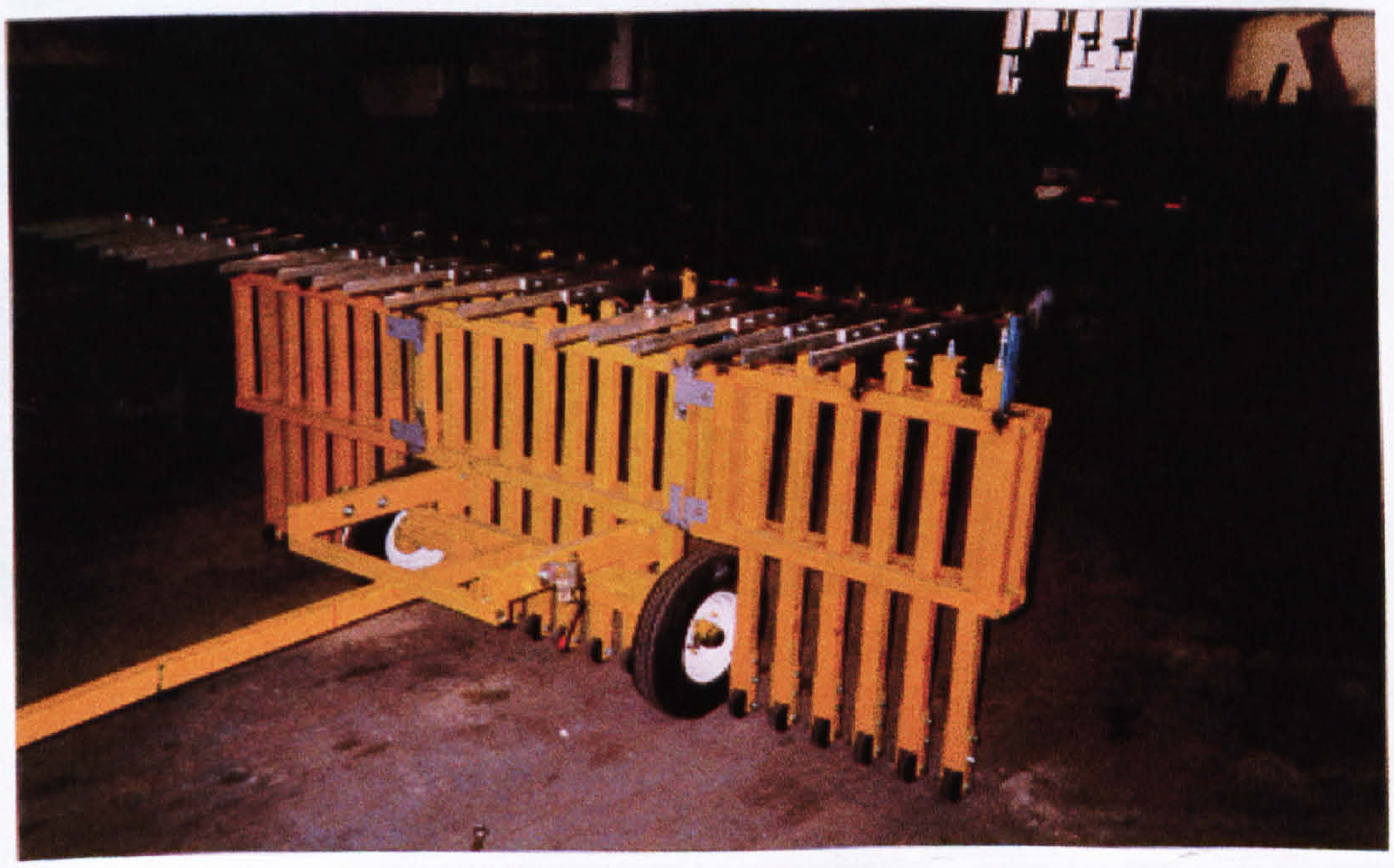


Figure 5.18 Connecting the full-width apparatus with all pointers

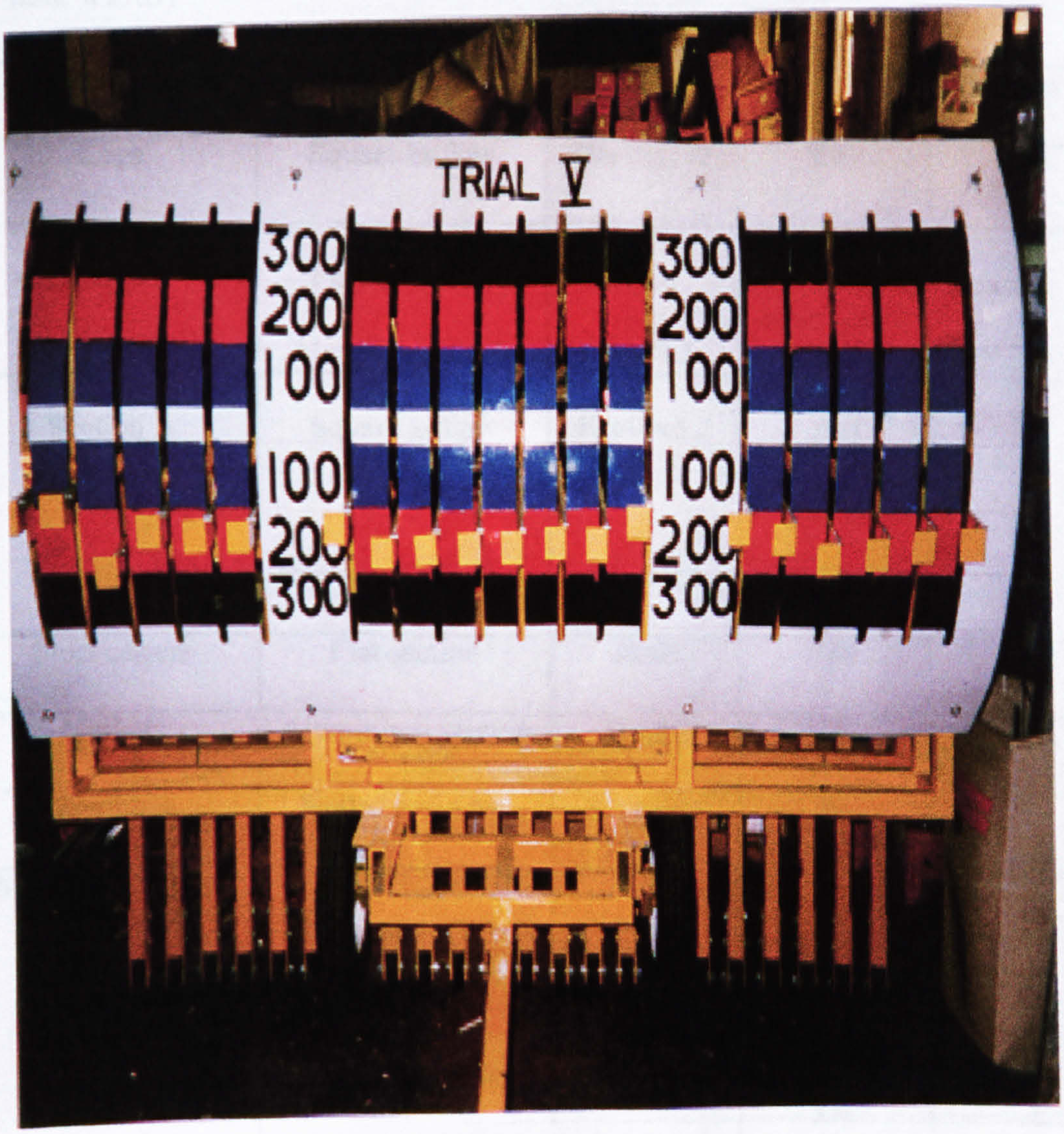


Figure 5.19 The full scale machine ready for a trial run

Table 5.1 Details of monitoring equipment components and parts (for 2.3 metre lane width)

Member	Shape	Section mm	Length mm	Number No.	Weight Kg/m
Legs	Square hollow	40x40x3.2	890	20	3.66
Pointers Section A Section B	 Flat mild steel Aluminium angle	 30x6 25x10.5	 400 over lab 13 400	 20 20	 1.41
Main body Section A Section B	 Square hollow Rectangular hollow	 40x40x3.2 60x40x4	 700 350 870 50	 8 12 4 46	 3.66 5.72
Steel casters	Flat section	30x6	150	40	1.41
Markers	Aluminium section	50x50	50	20	
Pivot bar	Rolled tread bar	ϕ 12 mm	85 75	1 2	
Monitoring screen **Inner par** Section A Section B Section C **Middle part** **Outer part**	 Hollow section Angle section Flat section Galvanised sheet Fiber glass sheet	 40x40x3.2 40x40x3 40x3 1 1.3	 2300 1070 2300 370 180 2300 1070 2300 2300	 2 4 1 4 8 2 4 1 1	 3.66 1.82 0.94
Pivot supports	Flat section	30x10	195	9	

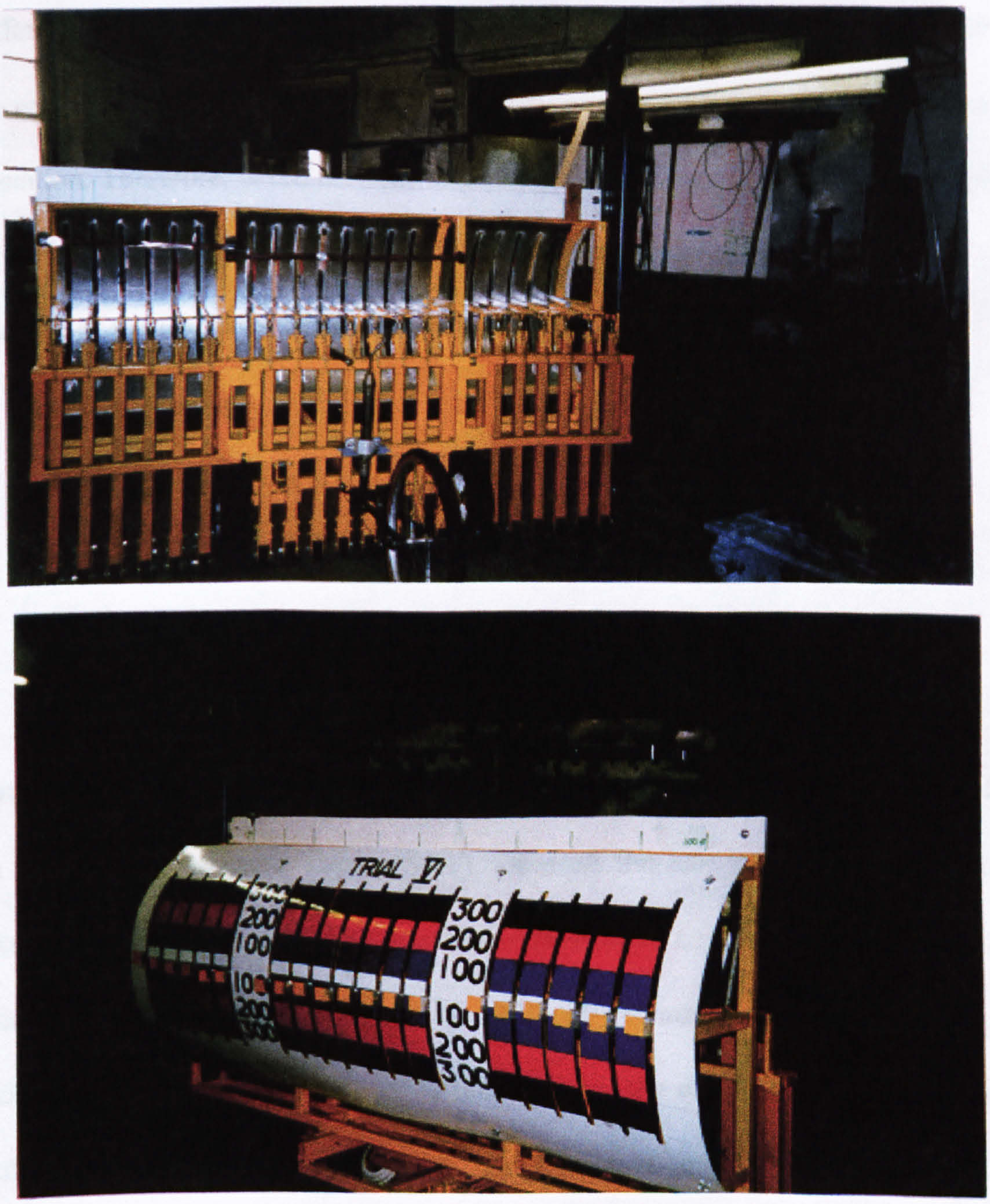


Figure 5.20 The distance travelled device

5.4 Assessment of road-section condition

The aim of using the prototype pavement monitoring equipment by any road authority suffering a shortfall in their allocated maintenance budget is to gather information describing the road condition, as the machine will present an approximate indication of each road section condition. Therefore, based on trials undertaken with the machine, a method has been adopted to assess the condition of different road sections whereby sections of the road are classified into one of the following categories:

- A as new condition section,
- B reasonable condition section,
- C nearly failed section
- D failed section.

Data has been gathered for pavements in each of these categories as reference data and kept on Standard Assessment Tapes (SAT). Because the interpretation of the data is to some extent subjective, an empirical Standard Assessment Tape (SAT) is necessary in ensuring uniformity in recording the data by different recording engineers. This represents the calibration process which is crucial to the in service use of the monitoring system.

After training the surveying team on those reference sections, and after providing the team with experience, they will become capable of differentiating between the different road section conditions. They will then be able to assign the correct condition category to the inspected pavement section according to the following classification system:

- roads in good condition category A
- roads need attention soon category B
- roads need attention now category C

- roads failed category D

The screen in the prototype is divided to three different zones excluding the level zone. Each zone denotes a certain level of deterioration. Therefore, based on Table 2.20 an intervention level for each reference section can be assigned to identify each of the above categories. This method based on estimating by how much in percent the pointers move through each zone. If the pointers remain within 50% of the first zone (0 to 5-mm depression) through a section, this section would be classified as category A, which means that the section is in good condition. However, 50% of the first zone corresponds with 50mm on the screen and therefore 5mm depression in the pavement. Applying this concept of assessment levels, the limits of each road category are shown in Figures 5.21a, b, c and d:

- Category A; pointers are between zero to 50% of zone one on the screen (0-5mm)
- Category B; pointers are between 50% to 100% of zone one on the screen (5-10mm)
- Category C; pointers are between zero to 50% of zone two on the screen (10-15mm)
- Category D; pointers are within the upper half of zone two and zone three (15-20mm).

The inspection team can use the assessment form shown in Figure 5.22 to assess the road section condition, in order to make a decision about repairing priority to the inspected section according to the level of deterioration and location of the section in the whole network.

5.5 Discussion

This Chapter explained a road condition monitoring system that is been developed specially for highway agencies that have limited funds both for the assessment of road condition and for subsequent repairs. Moreover, the prototype has been developed to suits conditions and factors prevailed in some cities in developing countries such as lack of skilled labour to operate and maintain sophisticated equipment (Chapter 3). The prototype described in this

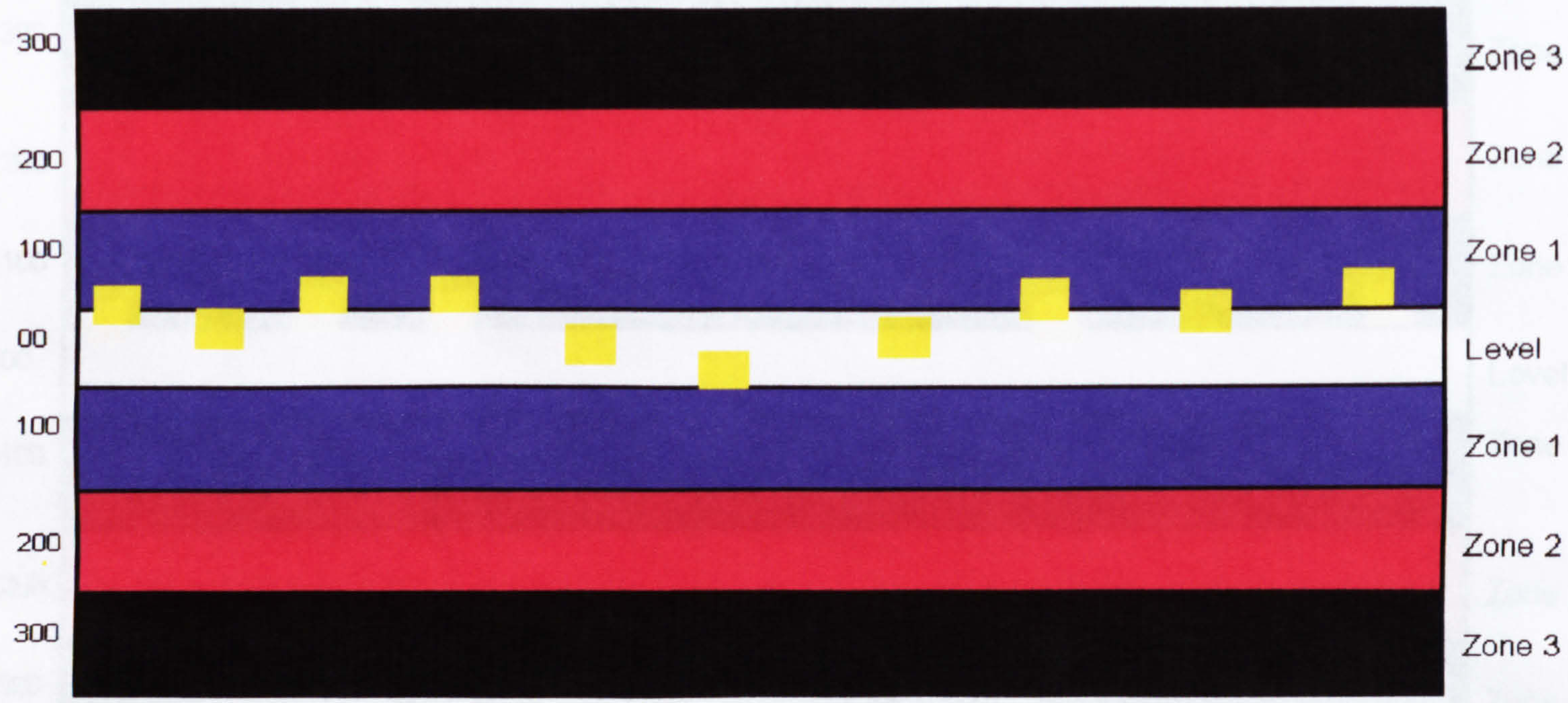


Figure 5.21a Road category A (section in good condition)

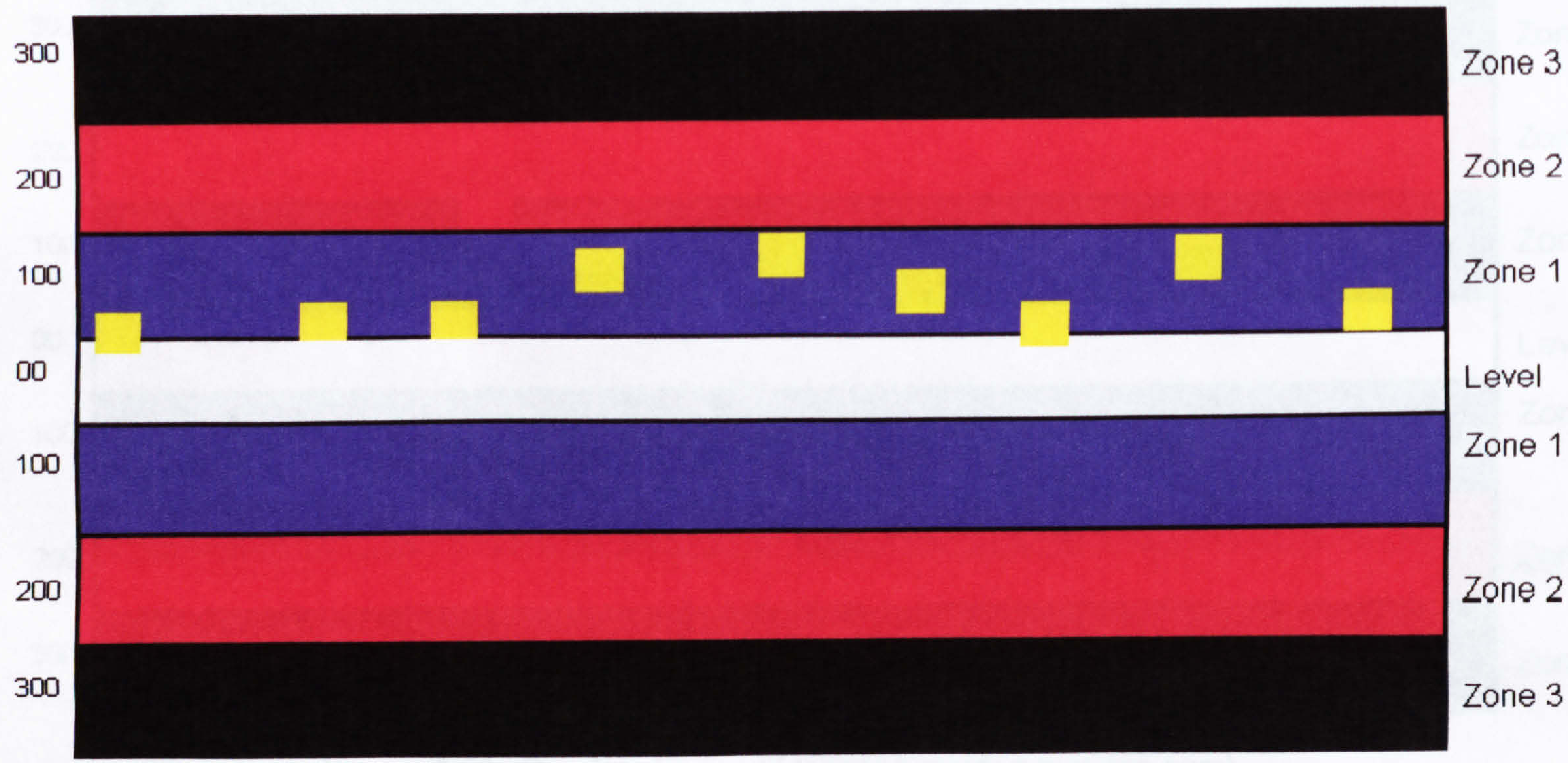


Figure 5.21b Road category B (section needs attention soon)

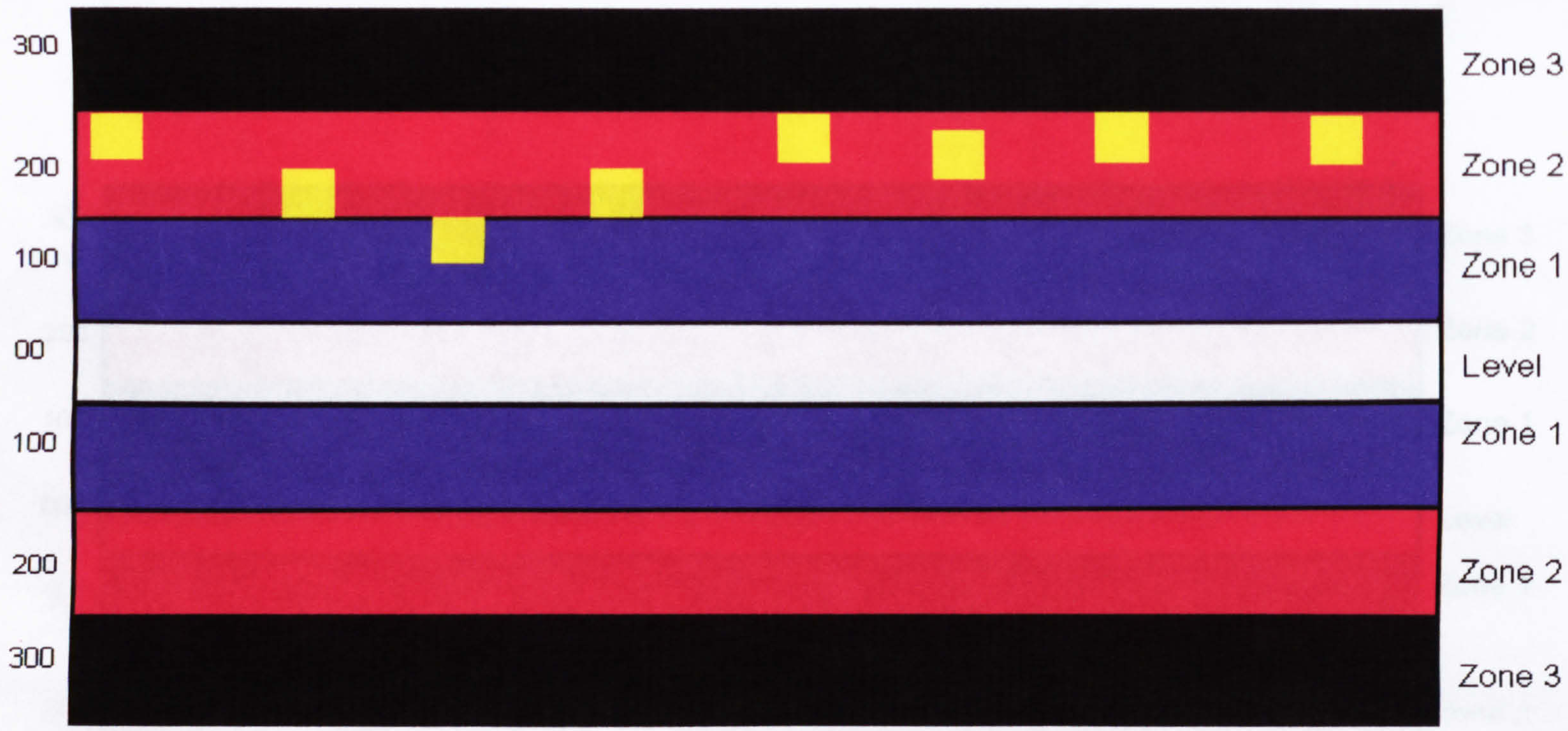


Figure 5.21c Road category C (section needs attention now)

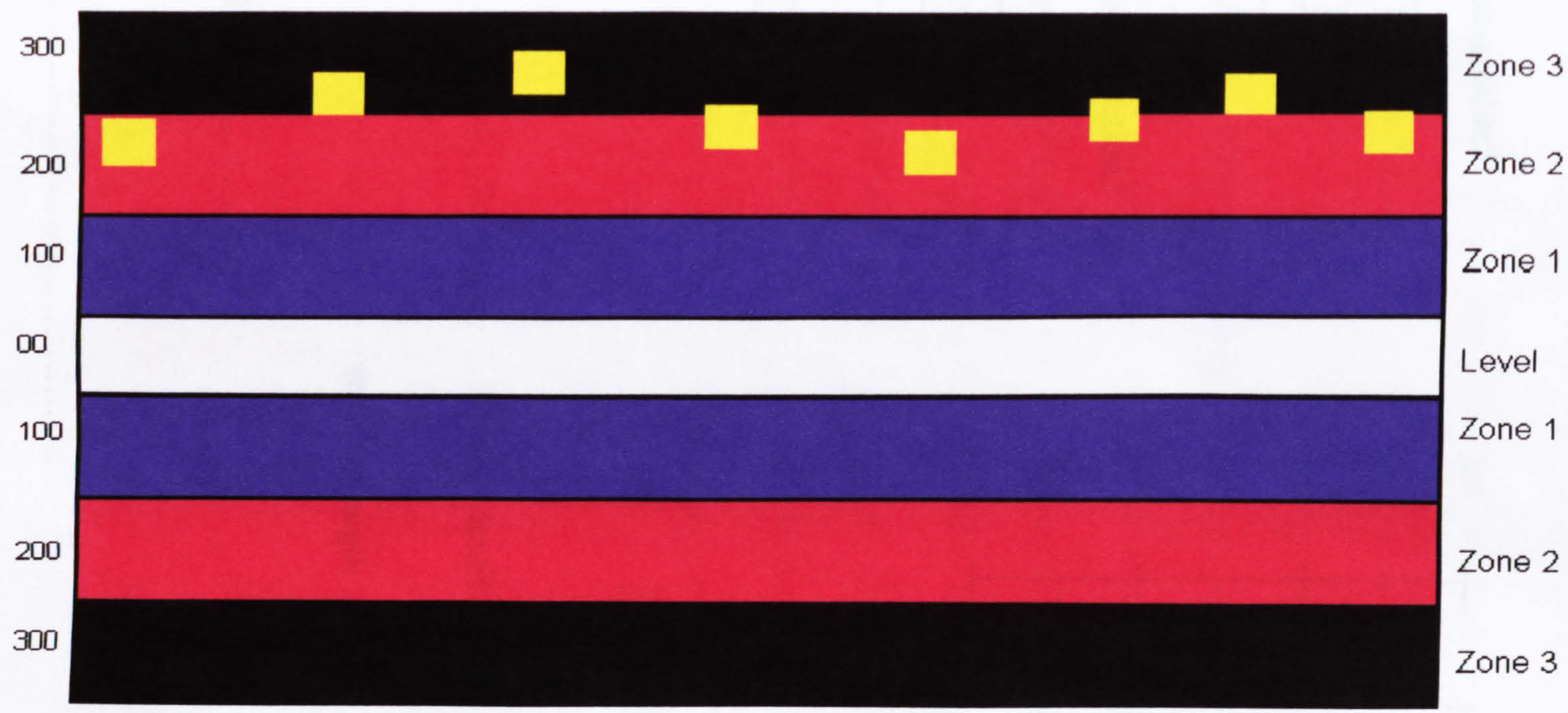


Figure 5.21d Road category D (section failed)

Road condition assessment form

Present Serviceability Index

Is the road section acceptable?

Yes ☐

No ☐

Undecided ☐

In which category is the section?

Category A ☐

Category B ☐

Category C ☐

Category D ☐

30	Failed
25	
20	Need attention now
15	
10	Need attention soon
05	**Good condition**
00	

Rating values in mm

Road name & No ....Section identification ....

Section length ....

Date ....Time ....

Remarks ....

Figure 5.22 Road section condition assessment form

Chapter has developed to monitor roads have a condition similar to those shown in Figures 4.10 and 4.11 and to keep them serviceable during their design life. However, roads of condition similar to those shown in Figures 4.15 to 4.20 are visually failed and their condition and state are apparent without any kind of assessment. Therefore, the machine mainly designed to be used for monitor and protect roads of better condition from being in apparent tremendous deterioration situation similar to those road sections.

This Chapter described a machine that is been developed in Newcastle University to assess the condition of roads. It is unique in that it uses no electronics and all of the parts of the machine could be easily maintained in any developing country. It is considered that this mix of consumer electronics and simple mechanical-specialist equipment is relevant in many engineering contexts in developing countries. Therefore, the apparatus described in this Chapter is not just relevant to road monitoring, but points the way towards the development of equipment in many engineering situations in developing countries.

CHAPTER 6

COLLECTION AND ANALYSIS OF ROAD CONDITION DATA

Contents:

CHAPTER 6

COLLECTION AND ANALYSIS OF ROAD CONDITION DATA

6.1 Introduction

The data collected from any road section using the prototype equipment can be analysed to allocate the appropriate maintenance strategy to each level of deterioration throughout that section and accordingly the general maintenance strategy for the whole network. The data collected describing the road condition can be used to develop a maintenance strategy. The prototype machine can provide and achieve the same conclusion as can sophisticated western road monitoring equipment in terms of road maintenance strategy. However, the purpose of monitoring the road condition is to provide the data which allows the maintenance budget to be prioritised.

The data and results gathered using the prototype equipment do not describe the condition of the road but describe the effectiveness in using the prototype equipment in developing a maintenance strategy. The prototype equipment is considered to be not only applicable to cities in developing countries but also for any road authorities suffering a shortfall in the allocated maintenance budget. Chapter 5 shows that the machine performs well at the technical level. What remains to be seen in whether it will work equally well at the management level. Used correctly, the machine can become an important factor in a highway maintenance authority approach to maintenance. There is an increase in the amount of labour in the use of the machine. This may not be an important issue since it is common for highway authorities in developing countries to have surplus of human resources but very little alternative resources. A secondary benefit of the system is in the training of engineers and technicians in the management of their road system. When staff are equipped with this type of machine, highway authorities will have the means to build up a significant database, which can then be used to priorities highway maintenance.

6.2 Data analysis

After completion of the prototype manufacturing process, two categories of data were collected to assess the importance and role of the machine in establishing maintenance strategy. These two categories of information were field data and office data.

6.2.1 Field data analysis

The prototype monitoring equipment has been used in a pilot monitoring exercise in four road sections. Three sections are in Newcastle inside the University campus and the other section is in Sunderland beside Sunderland Trailer Centre. The sections were of different lengths and conditions. A summary of the sections condition data collected by the prototype is shown in Table 6.1. The road section monitored in Sunderland (Simpson Street) was a minor road heavily used by concrete mix trucks gaining access to a concrete plant near the trailer workshop. Therefore, in addition to some potholes throughout the section there were spots of concrete spilled from the trucks during travelling. Figure 6.1 shows the section condition assessment using the assessment form developed in this study for use in conjunction with the prototype described in Chapter 5 (Figure 5.22). From the method adopted in Chapter 5 to assess the condition of different road sections (paragraph 5.4); this section is classified as category B which means the section need attention soon. Two sections from the three sections selected in Newcastle were resurfaced two years ago. Therefore, the two sections have been selected as an example of sections in category A (good condition) in order to confirm the reliability of the prototype's performance and the adopted assessment method.

Table 6.1. Condition data collection for road sections in Newcastle and Sunderland

Road name	Simpson street "Sunderland"	Kensington Terrace Section No.1	Kensington Terrace Section No.2	The university Car park
Section length (metre)	200	100	100	300
Section condition	Reasonable, category B	Good, category A	Good, category A	Reasonable, category C
Particular defect	Potholes, concrete spots	Small potholes, depression	Small potholes	Depression
Location of defect from start point (metre)	20 50 105 140 180	55 85	40 65 90	N.A
Remedy required	Cleaning Excavation, filling and compaction	Filling	Proper filling	Resurfacing
Proximate cost (£)	2,000	400	500	8,000

Road condition assessment form

Present Serviceability Index

Is the road section acceptable?

- Yes ☑
- No ☐
- Undecided ☐

In which category is the section?

- Category A ☐
- Category B ☑
- Category C ☐
- Category D ☐

30	Failed
25	
20	
15	Need attention now
10	Need attention soon
05	Good condition
00	

Road name & No ..Simpson..Street...Section identification ..Sund..1....

Section length .....200....m.........

Date 23..5..98..Time 4:8.Pm

Remarks ..Section..needs...attention. Soon

Figure 6.1 Condition assessment for simpson street in Sunderland

The sections are heavily used during the academic year (September to June) by the university staff and students in addition to heavy trucks gaining access to deliver goods and parcels (Figures 6.2). The condition assessment data for these sections are shown in Figures 6.3 and 6.4 using the adopted assessment form. The 4th section was the Newcastle University car park (Figure 6.5). The maximum capacity of the car park is 175 cars and it is always full during the academic year. The monitoring process has shown that the section remains in reasonable condition and may need attention for resurfacing (Figure 6.6) as the car park had received no maintenance for at least three years.

The sections monitored using the prototype were selected for the following reasons:

- the sections covered those roads categories adopted in the assessment method,
- the sections were in areas which were convenient to monitor without any arrangement being required with external agencies such as the police.

The Benghazi road network has been used as a case study. It shows how the road condition data collected from each area in the network in the whole City can be summarised in order to prioritise spending and use that information in formulating the optimum maintenance strategy. The procedures to establish a pavement management system cited in Chapter 3 (paragraph 3.2) are implemented in part of the city road network. The ring roads around the city (Figure 4.3) are divided into sections and referenced. Each section has been given a unique reference code using a combination of numbers and letters (Table 6.2); the lengths of the sections are varied between 900m and 1,500m. An inventory has been assigned to each road section consisting of its main characteristics (Figure 6.7). The historical information related to construction records for each road section has been assigned using the "as built drawing" and the other document submitted by the contractor. However, there are no sufficient data available related to the maintenance history to most road network in the city. Part of the city network shown in Figure 4.3 between the third

Figure 6.2 Section of Kensington Terrace inside Newcastle University

Road condition assessment form

Present Serviceability Index

Is the road section acceptable?

- Yes ☑
- No ☐
- Undecided ☐

In which category is the section?

- Category A ☑
- Category B ☐
- Category C ☐
- Category D ☐

Scale	Condition
30	Failed
25	
20	
15	Need attention now
10	Need attention soon
05	Good condition
00	

Road name & No Kensington..Terrace Section identification .Ken..No..1.

Section length ....100...m........

Date 01..11..98...Time 2:8 P.M

Remarks .Section...in..good...Condition

Figure 6.3 Condition assessment for Kensington Terrace section No.1

Road condition assessment form

Present Serviceability Index

Is the road section acceptable?

- [x] Yes
- [ ] No
- [ ] Undecided

In which category is the section?

- [x] Category A
- [ ] Category B
- [ ] Category C
- [ ] Category D

Scale	
30	Failed
25	
20	
15	Need attention now
10	Need attention soon
05	Good condition
00	

Road name & No Kensington Terrace Section identification Ken. No.2

Section length ....100...m...........

Date 01.11.98...Time 3.20 Pm

Remarks Section...in...good...Condition

Figure 6.4 Condition assessment for Kensington Terrace section No.2

Figure 6.5 The University of Newcastle car park

Road condition assessment form

Present Serviceability Index

Is the road section acceptable?

- Yes ☐
- No ☑
- Undecided ☐

In which category is the section?

- Category A ☐
- Category B ☐
- Category C ☑
- Category D ☐

30	Failed
25	
20	
15	Need attention now
10	Need attention soon
05	Good condition
00	

Road name & No .Car..Park...........Section identification ..Park1......

Section length .....300..m..........

Date01.11.98..Time 3:30PM

Remarks .Section..needs...attention..now

Figure 6.6 Condition assessment for the university car park

Table 6.2 Referencing part of Benghazi road network

Road Name	Road No.	Section No.	Start Node	End Node	Length "m"
FRR	1	FR01	100001	100002	1,200
FRR	1	FR02	100002	100003	1,000
FRR	1	FR03	100003	100004	1,500
FRR	1	FR04	100004	100005	1,100
SRR	2	SR01	200001	200002	1,200
SRR	2	SR02	200002	200003	2,000
SRR	2	SR03	200003	200004	1,500
SRR	2	SR04	200004	200005	1,200
TRR	3	TR01	300001	300002	1,500
TRR	3	TR02	300002	300003	1,100
TRR	3	TR03	300003	300004	1,700
TRR	3	TR04	300004	300005	1,050
TRR	3	TR05	300005	300006	1,100
TRR	3	TR06	300006	300007	2,300
TRR	3	TR07	300007	300008	2,400
4RR	4	4R01	400001	400002	1,070
4RR	4	4R02	400002	400003	1,100
4RR	4	4R03	400003	400004	1,500
4RR	4	4R04	400004	400005	1,000
5RR	5	5R01	500001	500002	1,100
5RR	5	5R02	500002	500003	0,900
5RR	5	5R03	500003	500004	1,050

FRR First Ring Road

SRR Second Ring Road

TRR Third Ring Road

4RR Forth Ring Road

5RR Fifth Ring Road

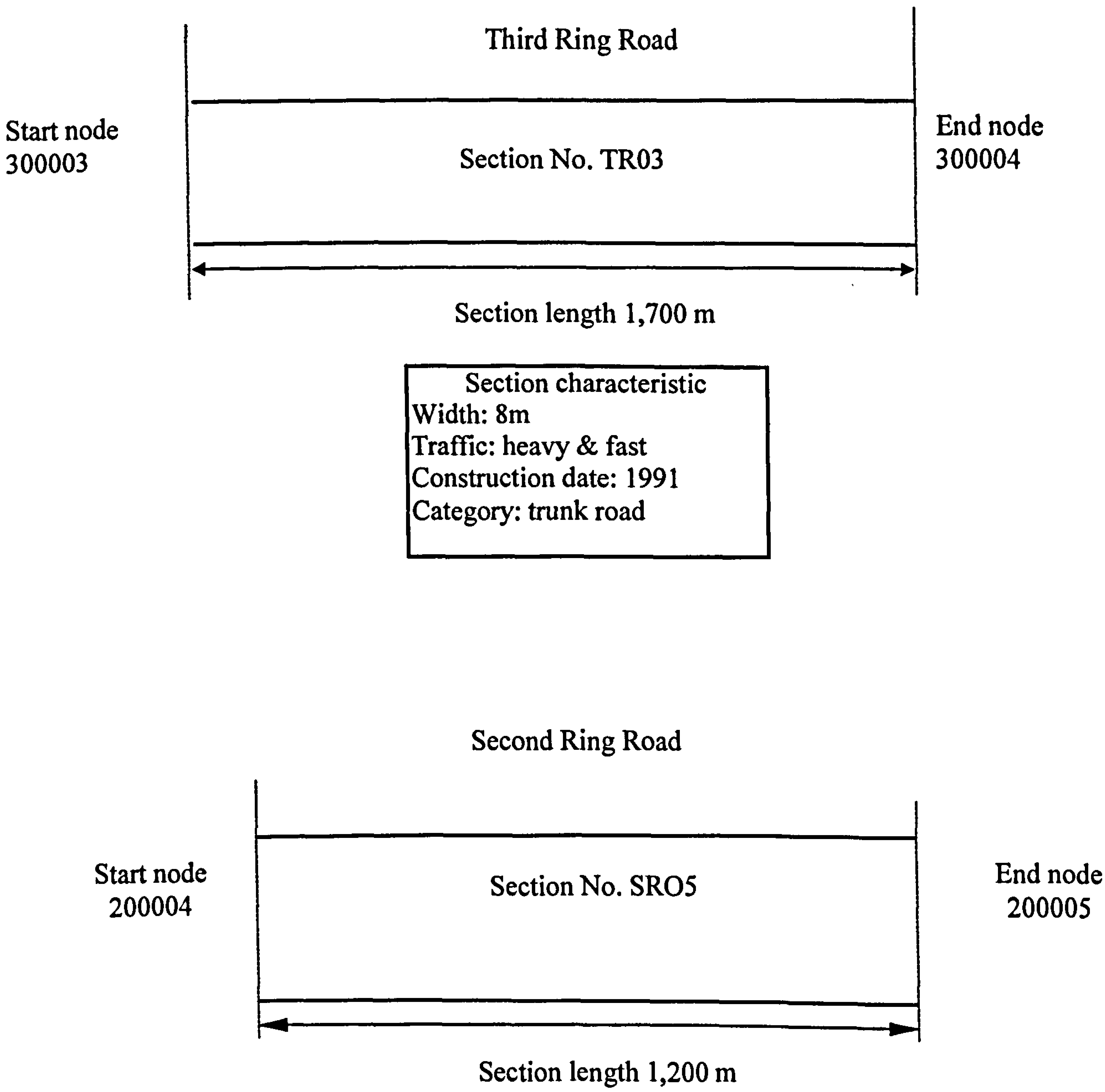


Figure 6.7 Road section characteristics for part of 2nd and 3rd ring roads

and first ring roads has been selected to be used as an example to implement the above procedures and concepts.

Randomly generated road condition data using the prototype have been developed in order to show the benefit which such appropriate technology equipment can bring to the issue of establishing a proper pavement management system and maintenance strategy in the City. The selected area comprises roads of different categories in terms of condition, size and importance in the network. The maintenance budget allocated to this area is £1,000,000, which is insufficient to retain the whole area in serviceable condition. The area is divided into 20 sections of 150m length. At the end of the survey and after assigning the correct condition category to each section from the Standard Assessment Tapes (SAT) and from Figures 5.21a,b, c and d in Chapter 5, the road condition categories were as follows;

Four section of category A,

Five sections of category B,

Five sections of category C,

Six sections of category D

The actual maintenance cost needed to completely repair the whole area according to local contractors' prices was as following,

Road category A	£ 50,000 for minor repairs
Road category B	£250,000 for minor to major repairs
Road category C	£700,000 for major repairs
Road category D	£1,500,000 for major to serious repairs

Consider the simple case in which the road maintenance budget is underfunded by £1500,000. The monitoring system has highlighted the fact that this is the amount needed to deal with category D repairs. In such a case, it becomes clear that the correct way forward is to abandon category D roads and spend the budget on the roads currently in better condition. Whilst this now appears to be an obvious strategy, it is one that is rarely followed in a real situation when pressure is often placed on the highway maintenance department to deal with the roads in the poorest quality category. By abandoning the category D roads, no additional future costs will be incurred since the roads cannot deteriorate further. By contrast, if the roads in categories A, B and C were not repaired, their future maintenance cost might rise by an order of magnitude. Therefore, the budget is allocated to the different road categories as following,

Road category A	£ 50,000
Road category B	£250,000
Road category C	£700,000
Road category D	Nil
Total	£1,000,000

Instead of using the whole budget to repair part of road category D, it is better to use it in keeping 75% of the whole area's roads in serviceable condition. The condition of roads in category D will be signed at each end of section in this category describing its condition so as to dissuade drivers from using these sections of the network.

6.2.2 Office data analysis

The prototype equipment was demonstrated during a residential course in flexible pavement and bituminous materials held at the University of Newcastle in September 1998. The delegates were from different road organisations such as local authorities, contractors, consultants, research establish and material suppliers.

The demonstration lasted half an hour and although the delegates made some comments about the machine operation process, all of them strongly agreed and accept the concept of developing low cost low technology equipment in monitoring road condition. During the demonstration, the delegates showed apparent admiration to the simplicity of the machine in manufacturing and operation. After the demonstration, a questionnaire (Figure 6.8)was distributed to gauge the effect of the machine on the observers. They stated that they were impressed with the machine and consider it to be an important component to improve pavement maintenance management. Moreover, they reported that they expect that the machine might be purchased by highway management organisations for a price of up to £5,000.

6.3 Discussion

The prototype equipment has been tested many times in different road conditions in order to assess the performance and reliability of the data obtained. As described in Chapter 5, the prototype is purely mechanical and designed to present an approximate indication of each road section condition to build a general maintenance strategy. Moreover, the prototype performance and reliability are based on mechanical advantage of 1:10 by pivoting the pointer levers at two points. In order to confirm this scientific fact, a simple model of this mechanical advantage was designed from smaller parts. This model is used to measure the thickness of known objects (e.g. one pound coin) by passing the sensing wheel over the object and checking the narrow pointer position in front of a scale ruler.

It is not claimed that the prototype is more accurate and precise than western technology, but it is more appropriate equipment in cities and situations where similar conditions to those in the city of Benghazi prevail. Western technology is appropriate if sufficient budget is allocated to the maintenance sector and skilled labour is available to undertake the required work efficiently. The prototype equipment described is developed to monitor the condition of roads that has depressions (5mm to 20mm) in order to classify the road section into different categories and undertake timely maintenance. Because the purpose of

UNIVERSITY OF NEWCASTLE

DEPARTMENT OF CIVIL ENGINEERING

Questionnaire

Your impression about the low cost machine

Normal ☐ Impressed ☐ So impressed ☐

How important are such low cost machines in pavement management

Not important 1	2	3	so important 4	5
☐	☐	☐	☐	☐

Do you think that such machines will contribute in improving the pavement maintenance management?

No	Maybe	Yes
☐	☐	☐

What would a highway management organisations be prepared to pay to purchase such a machine

Would not purchase machine	£1,000	£5,000	£10,000	£20,000	50,000
☐	☐	☐	☐	☐	☐

About yourself

Employer

- Local authority ☐
- Government/national authority ☐
- Consultant/consults engineer ☐
- Contractor ☐
- Material supplier ☐
- Research establish ☐
- Other ☐

Occupation

- Student ☐
- Technician ☐
- Graduate engineer ☐
- Charter engineer ☐
- Manager ☐

Figure 6.8 A questionnaire about the prototype performance

the monitoring is to make a decision on either to "do nothing" or "how to spend the budget" in maintaining roads network, the prototype is considered to be successful as it has fulfilled the requirement for which it was designed. The results from this particular research are not the condition of the roads but the results are assessing how to use that information collected by the prototype in formulating appropriate maintenance strategy.

CHAPTER 7

Conclusions and Recommendations

Contents:

CHAPTER 7

Conclusions and recommendations

7.1 A summary of conclusions

Most highway network agencies worldwide have insufficient funds to maintain their roads at the highest possible condition. Therefore, they need a management system which ensures that their limited funds are spent in a way which is of most benefit to the road users. Because of this, a whole range of sophisticated road monitoring equipment has been developed and is in use in most western countries. However, research is needed to develop efficient technologies for road maintenance and to develop lower-cost techniques for structural rehabilitation of all classes of road (Michel 1995). A report issued in HIGHWAYS magazine in April 1997 has shown that "a survey of local authorities in England carried out by the Refined Bitumen Association (RBA) has revealed a 67% increase in the number of visual defects including cracking and potholes during the last 10 years as inadequate funding forces local authorities to abandon planned maintenance programmes".

Therefore, the principal objectives of the thesis were to consider the special conditions relevant to cities in developing countries and some road authorities in western countries. Moreover, to show how these conditions (budget, labour, etc.) militate against the use of monitoring systems based upon sophisticated technology which need capital fund. These conditions draw conclusions regarding the type of monitoring systems which seem appropriate to the city of Benghazi in Libya and to situations where similar conditions prevail.

The monitoring equipment prototype described in Chapter 5 is the first member in a family comprising different items of equipment designed to monitor pavement defects such as cracking, skidding resistance, longitudinal profile and deflection. This set of monitoring equipment items should be considered in future research, following the concept of implementing low cost low technology technique which has been developed in this thesis.

7.2 Application of principles to skid resistance measurement

A similar simple machine to monitor road skid resistance could be developed using the same principles that have been established in developing the prototype described in Chapter 5. The equipment (Figure 7.1) should be fabricated from low cost low technology components such as a rubber belts, steel arms, pointer, elastic band, small wheels and the same electronic component which has been used in the rutting equipment, the video camera. The sensing wheel is connected from its sides to steel arms which are mounted on the supporting trailer and which are hinged to each other in order to make the frame move according to the sensing wheel movement. The sensing wheel is connected from its front to the supporting trailer through two rubber belts which operate as springs. Whilst the vehicle is moving along at constant speed, the gauge will move in front of the screen and the camera records the movement. If the road is rough, the sensing wheel and the steel arms will stretch the rubber belts, and cause the pointer system to move to give an indication to the skid resistance at that point.

The same principles may be used to develop a similar machine to measure the longitudinal profile of a road. The machine (Figure 7.2) may be fabricated from a steel beam 10 m long whit three wheels equally spaced connected in tandem. The centred wheel will have a special connection in order to ensure independent vertical movement in response to the longitudinal

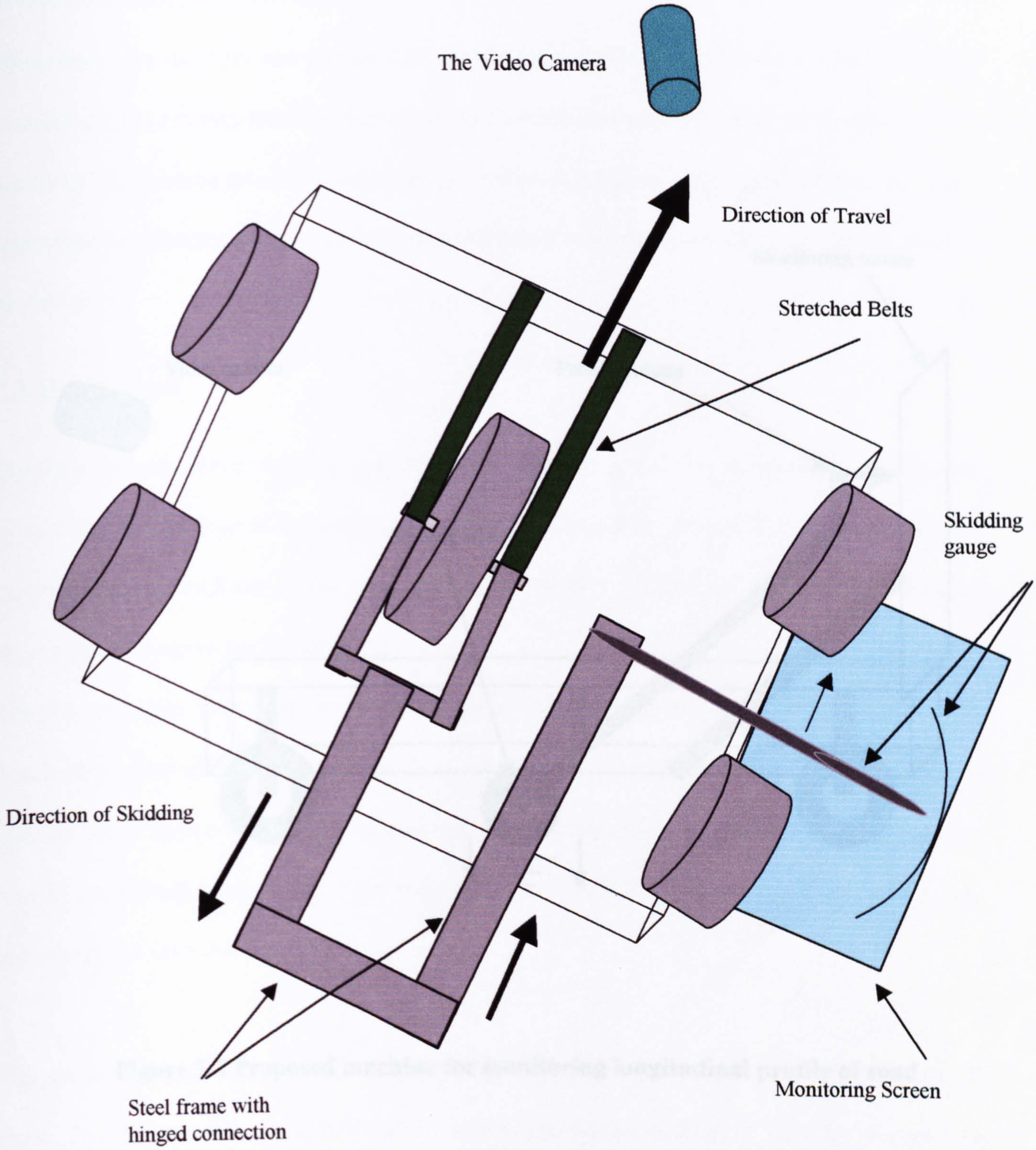


Figure 7.1 The proposed skidding machine

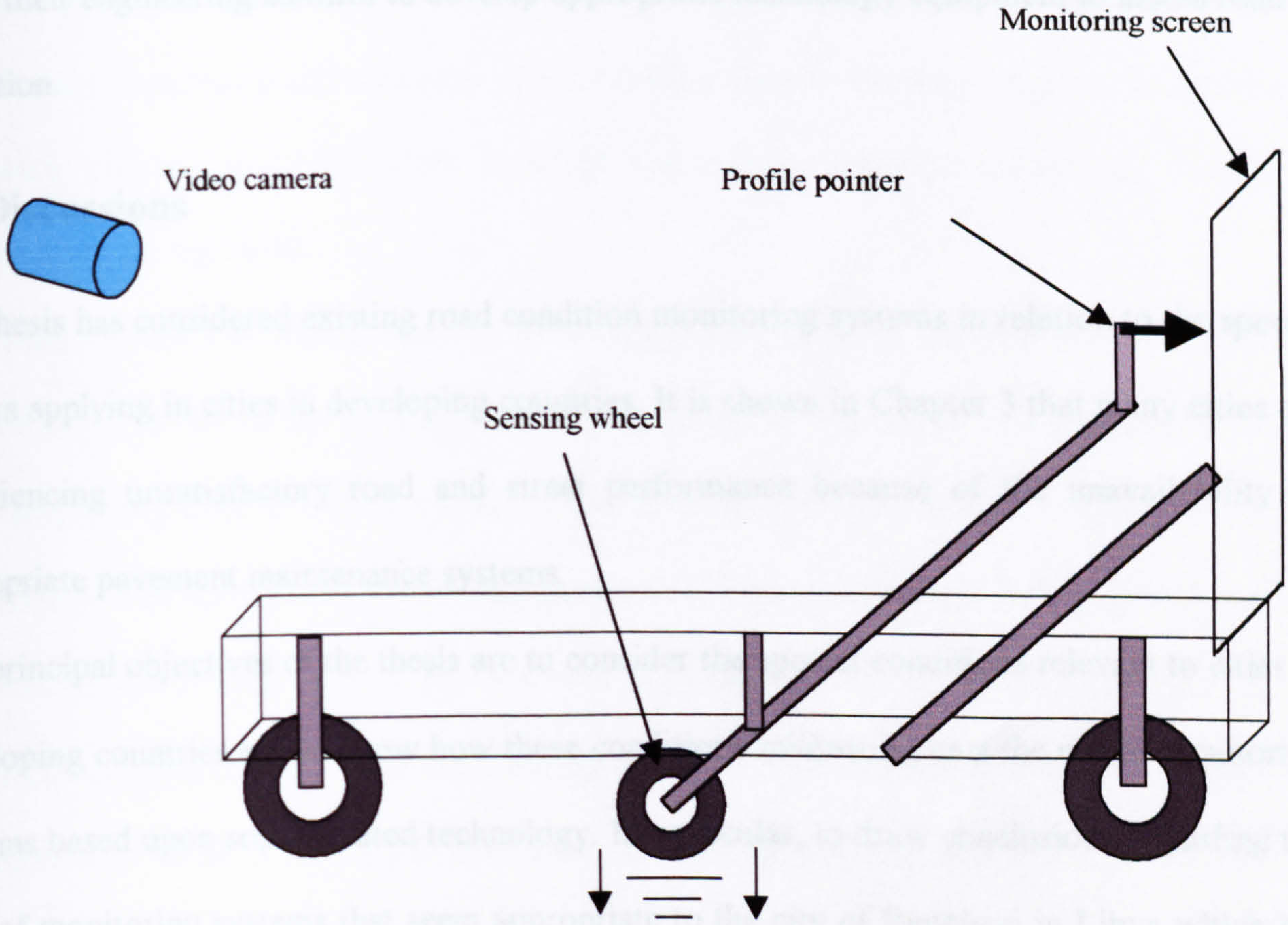


Figure 7.2 Proposed machine for monitoring longitudinal profile of road

profile of the road. A pointer system connected to the centred wheel moves on a screen while video camera records its movement.

These items of equipment and many others could be developed using the same principles used in developing the rutting machine described in this particular research. Therefore, one of the results of this research is to point engineers in similar conditions in the direction that they can apply their engineering abilities to develop appropriate technology equipment to assess road condition.

7.3 Discussions

The thesis has considered existing road condition monitoring systems in relation to the special factors applying in cities in developing countries. It is shown in Chapter 3 that many cities are experiencing unsatisfactory road and street performance because of the unavailability of appropriate pavement maintenance systems.

The principal objectives of the thesis are to consider the special conditions relevant to cities in developing countries and to show how these conditions militate against the use of monitoring systems based upon sophisticated technology. In particular, to draw conclusions regarding the type of monitoring systems that seem appropriate to the city of Benghazi in Libya which has been used as a case study.

The municipality of Benghazi has a large labour force but the productivity gained is much lower than it should be. This is because of poor management, lack of training and lack of resources to carry out maintenance activities, in addition to a failure to establish priorities by the maintenance authority. The maintenance problem in the city of Benghazi (and in Libya in general) is broad and needs the support of all aspects from the government.

The problems and obstacles that militate against establishing proper maintenance management systems in the city of Benghazi are extensive. These problems range from a shortfall in the budget to a lack of technical skills and the reluctance of engineers and planners to adapt to computer technology. Therefore, for the sake of preserving the highway network in an acceptable condition, efforts must be made in all aspects of road maintenance for the next few years, using available resources and materials. Moreover, consideration needs to be given to the importance and necessity of establishing regular training programs to encourage engineers, planners and technicians to adopt and employ the high technology systems in maintenance management.

This research has considered western technology equipment in the context of developing countries and describes the development of an alternative approach. This approach is based upon employing simple widely available low cost consumer electronic equipment used in conjunction with appropriate technology mechanical plant as the basis for a highway surface deformation monitoring system. The research is based upon actual conditions in the city of Benghazi and uses data obtained there during a field study in summer 1996. The conclusions are applicable to both municipal authorities in developing countries and to authorities in western countries where maintenance budgets preclude the regular deployment of expensive equipment.

The low cost prototype equipment developed in this study is unique in that it is purely mechanical and uses no electronics in monitoring road condition. Moreover, all parts of the machine are fabricated from materials available in most cities in developing countries and therefore such machine could be easily maintained locally. The prototype described in this study is not only relevant to road monitoring but points the way towards the development of similar equipment in many engineering situations in developing countries and where similar condition is prevailing.

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