Pavement Distresses on Addis Ababa City Arterial Roads, Causes and Maintenance Options

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By

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DECLARATION

I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in any other university and that all sources of material used for the thesis have been duly acknowledged.

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VITA

Fiker Alebachew was born in Debre Tabor, South Gonder on May 5, 1964. He graduated from A.A University in 1977 with B.Sc in civil engineering. After graduation he joined the

Transport Construction Design Enterprise (TCDE) where he worked in different roads and airport construction for nine years. In addition he has worked as Technical manager in the Addis Ababa City Roads Authority for one year, in SOLMA general Contractor (GC-1) as General manager for three years and for the last five years working with China Roads & Bridge Corporation in the Addis Ababa Ring Road project as Contracts & planning engineer. He is married and a father of three children.

His experience encompasses several construction projects, among which the following may be cited:

- July 2004 - to date: CRBC Addis Engineering Plc, Deputy General Manager.
- July 1999 -June 2004: CRBC Addis Ababa Ring Road Project, Contracts and planning Engineer.
- Nov. 1997 - June 1999: SOLMA Pvt. Ltd. Co. (GC-I Contractor),General Manager,
- Apr. 1997 - Nov. 1997: Addis Ababa Roads Authority, Technical Manager
- July 1992 - Mar. 1997:TCDE, Head Contract Administration Division
- May 1991 - June 1992:TCDE, A/Head, Construction Division
- Dec. 1989 - Apr. 1991:TCDE, Assab International Airport, Resident Engineer,
- July 1989 - Nov. 1989:TCDE, Addis Ababa Stadium Running Truck and Sports Ground (Akus truck) Project , Resident Engineer,
- Feb. 1989 - June 1989:TCDE, Holeta - Geode Asphalt Rehabilitation Project, Resident Engineer,
- Oct. 1988 - Jan 1989:TCDE, Southern Ethiopia Region Rural Roads, Regional Supervision Co-coordinator,
- Mar. 1988 - Sept. 1988:TCDE, Asphalt road & Parking Project Soviet Relief Service A.A head office, Resident Engineer,
- Sept. 1987 - Feb. 1988:TCDE, as Trainee at head office and supervisor at Nekempt – Bure feeder road project.

Table of contents — Page

Chapter 6- Conclusion and Recommendation

List of Figures

List of Tables

ABBRIVATIONS

1. AACRA : Addis Ababa City Roads Authority
2. AADT : Average Annual Daily Traffic
3. AASHTO : American Association of State Highway & Transport Officials
4. CBR : California Bearing Ratio
5. CDV : Corrected Deduct Value
6. CESA : Cumulative Equivalent Standard Axle Load
7. DCP : Dynamic Cone Penetration
8. EAL : Equivalent Axle Load
9. ERA : Ethiopian Roads Authority

10. FHWA : Federal Highway Authority

11. IRI : International Roughness Index

12. MERLIN : Measuring Roughness using Low cost Instrumentation

13. PCI : Pavement Condition Index

14. PMS : Pavement Management System

15. PSI : Pavement Serviceability Index

16. RRD : Representative Rebound Deflection

17. RTRRM : Response Type Road Roughness Meter

18. TRL : Transport Research Laboratory

19. VDF : Vehicle Damaging Factor

20. WASHO : Western Association of State Highway Officials

ABSTRACT

Paved roads in tropical and sub tropical climates often deteriorate in different ways to those in temperate regions, because of the harsh climatic conditions, lack of proper design and quality control, high loads and inadequate assessment for identifying causes of distresses before carrying out maintenance and rehabilitation.

A pavement distress that occurs at the surface can have a number of different causes which must be properly identified before corrective action is taken. The visible manifestation of the problem at the surface may be the same; however, the solution for each cause may be different. Therefore, if the remedial action is to be effective, the cause of the problem must be identified and corrected.

The present road condition of Addis Ababa shows rapid deterioration. The severity of pavement distresses is even more critical on the major arterial roads were the traffic volume of busses, heavy trucks, passenger vehicles and taxies is comparatively

higher than other road network. Such severe distresses summed up with inadequate road signs and markings are resulting congestion and consequently causing further deterioration of roads due to maximum static load sustained from the vehicular traffic waiting in a queue on the pavement.

This research mainly focuses on making assessment of asphalt pavement condition, identifying causes of pavement distress and proposing maintenance options for the arterial roads of Addis Ababa. These roads are most widely utilized, and therefore prone to severe distress and consequently exhibiting repeated maintenance and repair. Visual distress assessment, roughness tests, DCP tests and other necessary laboratory investigations were carried out on selected test sections in order to have better understanding of the pavement response and come up with identification of probable causes. Major causes of pavement distress associated with load, drainage and durability are tried to be identified.

A statistical analysis is also made to check how each investigation results showing pavement response variables and material properties interact with each other to identify the cause of distresses. The visual survey analysis indicates that almost all test roads have very low PCI value. Raveling, corrugation, Bumps and sags are the most dominant type of distresses constituting more than 75% of the distress densities in the arterial road network. The majority of test sections showing low PCI values are observed to have a base material of low bearing value sandwiched between the asphalt and other pavement layers. The investigation and analysis also showed that moisture and drainage associated distresses are predominant in the arterial roads and most likely on the whole network as well. Moreover, it is also observed that most of the existing pavements lack structural adequacy and hence require reconstruction than doing a routine maintenance and/or rehabilitation.

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First of all, I would like to praise and give thanks to the Almighty God who gave me wisdom and strength from the inception until completion of this research.

There are many organizations and people to whom I am grateful for the successful completion of this research. The following organizations have particularly assisted me a lot by providing me necessary labor, material and equipment for running different tests: Ethiopian Roads Authority, Addis Ababa City Roads Authority, Transport Construction Design Sc co, United Consulting Engineers, Beza Consulting Engineers and Zewde Engineering.

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Finally, yet very importantly, I would like to thank my wife Tsigereda Robi, without whom I never could have done this.

1.0 Introduction

1.1 History of road construction in Ethiopia

A road construction work, just like any other social endeavor or undertaking, has vast and wonderful history of its own, since it evolved with the social development of mankind.

Amidst those early Emperors that ought to be mentioned in line with those that played a significant role in this constructive field of endeavor in early Ethiopia, are Emperors such as Emperor Fasil, Tewodros, Yohannes and Menelik[20].

The main reason that prompted these Emperors to give emphasis to the need for development of road construction was because of their appreciation of the value that could be gained from the expansion of territory and from ensuring the unity of the nation.

If we look back to Ethiopian history and briefly try to visualize the genesis of road construction works, we note that some roads and bridges were constructed in early times. Emperors during their royal trips, used to exert efforts to make the roads suitable for their trips by having forests cleared and difficult terrains leveled. Some of the achievements that need to be quoted as an example are the bridge built on the Abay River during the times of Emperor Fasil in order to connect Gojam with Gondar.

The populace, being pleased with the bridge that is located on the Gondar -Gojam route, and built by Emperor Fasil, used to tell tales to traders and other pioneers who traverse this bridge. Emperor Tewodros frequently used these routes that start from Debretabor leading to Mota Keranio and Mertu-Lemariam and then through Wadla Delanta to reach Mekdela. The population always remembered the Emperor. The enormous effort exerted by the Emperor in 1859 G.C. to connect Debretabor, the capital city at the time, with Gondar, Gojam and Mekdela was an achievement that could not be easily ignored. Tewodros has contributed in the expansion of road construction works not only during his reign but also during the declining days of his rule.

The English army that came to Ethiopia on a military expedition to free its citizens had to construct roads to transport its heavy weapons and wagons from Zula, a red sea port to Senafe, Adigrat, Lake Ashange,Ambalage and finally to Mekdela. It is believed that Emperor Yohannes during his war campaign against the Derbuishes, the Egyptians and the Turkys did contribute to the expansion of roads in order to facilitate his military expedition.

It is to be recalled that the Italian occupants having occupied Massawa and settled there in defiance of Ethiopia's territorial integrity in 1885 did start road construction works to connect them with the hinterland.

The modern approach in road construction work commenced during the reign of Emperor Menelik. Blasting of mountains with dynamite was unknown during that period. And, as such, when a hard rock was encountered during road construction, it was told that a fire is lit and the rock is subsequently heated up and then cooled with water in order that it may crack when a change from a hot medium to a cold medium occurs. The bridge built on Awash River with the supervision of the Swiss, Alfred Elg, the Emperor's consultant and the bridge that was also built over Gibe were some of the major examples that need to be quoted to show how much emphasis was given for road works.

The Diredawa -Harar road was built as result of the agreement reached by the Emperor in 1894 GC in connection with rigging of railway line from Addis Ababa to Djibouti. And as consequence of which, the road connecting Addis Ababa with Gulf of Aden provided a good opportunity for road development. Subsequent to this development, Emperor Menelik in order to set an example to the nobility and orient them the application of the art of modern engineering skill, he himself went and participated in road construction work with ordinary workmen. The Gore - Gambella road which was constructed in by the late 1890 and the Addis Ababa to Addis Alem Mariam road were ones that needs to be awarded first place in the annals of Ethiopian road construction history.

It is recalled that when the road that was begun in 1902 GC with the participation of the Italian war prisoners and other foreign nationalities, was completed, the Emperor traveled on this road on a Roller driven by steam power. The Roller was imported to Ethiopia for the 1st time in 1904 GC and did participate in road construction work. In the ensuing years and particularly in 1907 GC the arrival of two vehicles in Addis Ababa has contributed in invoking emphasis to the importance and the necessity of road construction development.

1.2 Road Construction and maintenance in Addis Ababa

Although Ethiopian history has been recorded for thousands of years, its present capital city, Addis Ababa, is comparatively new, the first settlement occurred during the time of Emperor Minelik in 1886. It was during the Italian occupation (1935-41) that a network of good roads radiating from Addis Ababa, and connecting the capital with the main administrative regions was constructed. These roads were built almost by human power and the pavement structure was made of Telford base constructed by hand laid stones.

It was since 1942 that road maintenance and rehabilitation duty within Addis Ababa was made to be the responsibility of the Roads and Building Department of the Addis Ababa municipality. However, the municipality was unable to cope up with its maintenance duties due to lack of resource particularly experienced personnel in the field of road construction (7).

Besides lack of resource in the road and building department, the maintenance and rehabilitation operation was at a very dangerous position when a new city organization formed in 1981.This new organization had created three administrative levels namely the Kebele Urban Dwellers Association (UDA), Higher UDA and Central UDA. Each of the three Administrative levels was responsible for the city roads construction, maintenance and rehabilitation without proper coordination and clear division of work.

No proper engineering work was done in advance or during construction of a kebele road. The road construction and maintenance division was not even consulted during preparation of the annual program leave alone making of proper pavement evaluation and site investigation. Little attention was given to drainage and pedestrian walk ways. A motor grader levels the existing path or trail usually to a width of about six or seven meters. About 20cm thick selected gravels dumped, and leveled by the motor grader. The fine grading of the sub grade, cleaning of debris and spreading of selected material was done by assistance of a labor crew. Since no compaction is done, the completed surface was very rough and eventually washed out by surface water after the first rainy season.

In general, the road construction and maintenance works in Addis Ababa until 1996 were not organized with proper human power, equipment and material resources. Such inadequate resources coupled with organizational shortcomings within the municipality such as lack of formal policy and standards for road construction and maintenance has resulted in substandard maintenance services which directly or indirectly affect the pavement performance as follows [(23)]:

- Materials and construction quality control & tests were not performed at all. As a result, it was not uncommon to encounter pavement failures distresses within short time after the new roads are opened to traffic.
- Different administrative bodies of the city government such as Higher, Woreda, Kebele and other agencies constructed most of the Road network without following the master plan and appropriate standards.
- Lack of integrated infrastructure development is the other problem affecting the road network. There is no proper coordination with local

Agencies, which carry out utility constructions such as water works, telephone lines, power lines, sewer lines and etc. Due to this, there is repetitive destruction of the existing road pavement and drainage structures, which consequently cause bumps, sags, patch deterioration and other damages on the asphalt due to water infiltrating in to the cracks.

- Sub-grade soil type of the city especially in the southern zone is predominantly of black cotton type, which has high swell potential. However, many roads were constructed on this expansive soil without due treatment which consequently reduce the pavement performance.
- There is high rural-urban interaction in the city of Addis Ababa. As a result, there are many open-air mini markets in many different locations including core areas. This in turn has resulted in the use of traditional means of Transportation such as horses and donkeys. This has resulted traffic congestion on the road network and damage on the asphalt and drainage system.
- Lack of adequate parking area is the other major problem that greatly affects the road network. It is especially critical on commercial zones such as Merkato & piazza. On these areas drivers usually make on street parking which led to minimizing the effective carriageway width and moreover aggravate the rate of pavement damage.
- Many of the city roads do not have footpath. Due to this, pedestrians move on the carriageway. This on the other hand reduces the effective road width that still aggravates pavement deterioration and accident rate.

1.3 The Addis Ababa Road Network Condition

According to the reference system (or hierarchy) developed by the Addis Ababa Master plan, the Roads fall within the following classifications:

.	Urban Arterial (AS)	50mts width
.	Urban Sub Arterial (SAS)	40mts width
.	Urban Collector (CS)	30mts width
.	Urban Local (LSR)	10-20mts width

The city of Addis Ababa covers a total area of 54,000 hectares out of which around 29,000 hectares are built up areas. There are 1750 kms of road network, out of which around 500 kms are bituminous surfaced. Around 205 kms of the roads have pedestrian walkways and drainage lines. From the above data, the road density of Addis Ababa can be estimated to be 1.8% and 4.3% of the built-up area when considering the asphalt roads and total roads respectively. This road density is relatively low when compared with the required density for similar urban network, which mostly ranges from 15% to 25% and even some times more depending on the desired level of standards.

In addition to the above shortcomings related with the network, the road construction and maintenance has the following problems:

- No proper pavement evaluation
- No proper quality control during construction and maintenance.
- No coordination between different bodies involved in the road construction and maintenance.
- Do not comply with the city master plan, appropriate design standards and construction practice.

The above construction and maintenance problems are aggravating deterioration of roads and consequently repeated maintenance and repair is being made. The pavement distress severity is more on major arterial roads. Such severe pavement distresses summed up with low road density, lack of pedestrian walkways, inadequate road sign and markings are resulting traffic congestion and subsequent accidents on the arterial roads.

According to AACRA’s 1996 (Ethiopian calendar) report, the Authority had annual expenditure of around 300 million Birr for road construction and maintenance out of which more than 30 million Birr was expended for routine maintenances. Such expenditure for construction and maintenance of the Addis Ababa roads is obviously too big and require special attention.

On the other hand, the Addis Ababa City Roads Authority had no proper strategy until recently for the identification of distresses or for the selection of treatment options. The Authority's position is now improving with the development of pavement management system (PMS), which, if properly implemented, can assist them to identify and quantify pavement distresses [2]. Hence, this research will have some input in upgrading the Authority’s maintenance management by indicating causes of pavement distress.

1.4 Objective

The aim of this research is in general to make initial assessment on performance of asphalt pavements and maintenance alternatives for the Addis Ababa City Roads. The study has the following main objectives.

i. Investigate major Asphalt pavement distresses and their severity in the Addis Ababa City Roads.

ii. Identify major causes with relation to condition of pavement structure, sub grade material and the surrounding environment.

iii. Come up with possible maintenance options.

1.5 Organization of the Thesis

The thesis is organized as follows in order to accomplish the above objectives. First of all attention is paid to literature review as noted in the second chapter. Basic concepts related to pavement performance and failure criteria, pavement evaluation and maintenance alternatives are covered in the literature review.

The applied procedures for pavement evaluation and treatment selection will be covered in the third chapter. Then the actual distress assessment and evaluation on a selected five arterial test roads will be presented. The existing type of distresses and probable causes will be discussed in the same chapter.

In the last two chapters to follow (i.e. chapter 5 and 6) attention will be paid to maintenance alternatives and conclusion respectively.

2.0 Performance and Maintenance of Flexible Pavement -Literature Review

Several types of data have to be collected to evaluate the condition of a pavement, identify the cause and then propose maintenance option. The evaluations include visual distress survey, surface roughness survey, surface deflection survey and surface friction (skid resistance) survey. All these methods of evaluation were performed in this research except for surface friction tests due to lack of instrument.

This chapter thoroughly discusses the following major topics:

- Performance & failure criteria of asphalt pavements
- Methods of distress surveys, and
- Methods of pavement maintenance and rehabilitations

Having good understanding of the above topics is very necessary, as they will serve as an input in the methodology, analysis, discussion and conclusion to be covered in subsequent chapters.

2.1 Performance and Failure Criteria of Asphalt pavement

Pavement performance evaluation is an important activity in the maintenance and rehabilitation works. It includes evaluation of existing distresses, road roughness, structural adequacy, traffic analysis, material testing and study of drainage condition. This section deals with types of bituminous surfaces, types and causes of distresses. Photographs all taken during distress surveys are incorporated for illustration.

A typical flexible or bituminous pavement structure consists of the following pavement courses: sub-base, base, and bituminous wearing surface. The wearing surface is the uppermost layer of the pavement structure. In a flexible pavement, it is a mixture of bituminous binder material and aggregate. The binder may be sprayed on the surface followed by application of aggregate and referred to as a bituminous surface treatment. The binder and aggregate may be mixed in a central plant or mixed in place on the road and referred to as hot or cold mixes. The wearing surface may range in thickness from less than 2.5cm, as in the case of a surface treatment, to several centimeters of high-quality paving mixture such as hot-mix asphalt concrete.

The wearing surface has four principal functions: to protect the base from abrasive effects of traffic, to distribute loads to the underlying layers of pavement structure, to prevent surface water from penetrating into the base and sub-grade, and to provide a smooth riding surface for traffic [24].

The base and sub-base are made using different materials designated the upper and lower base or sub-base. Where the soil is considered to be very weak, a capping layer may also be introduced between the sub-base and the soil foundation. This may be of an inferior type of sub-base material, or it may be the upper part of the soil improved by some form of stabilization (e.g. with lime or cement). The soil immediately below the sub base (or capping layer) is generally referred to as the sub grade and the surface of the sub grade is termed the formation level. The elements of a flexible pavement as defined above are shown in Figure 2.1.

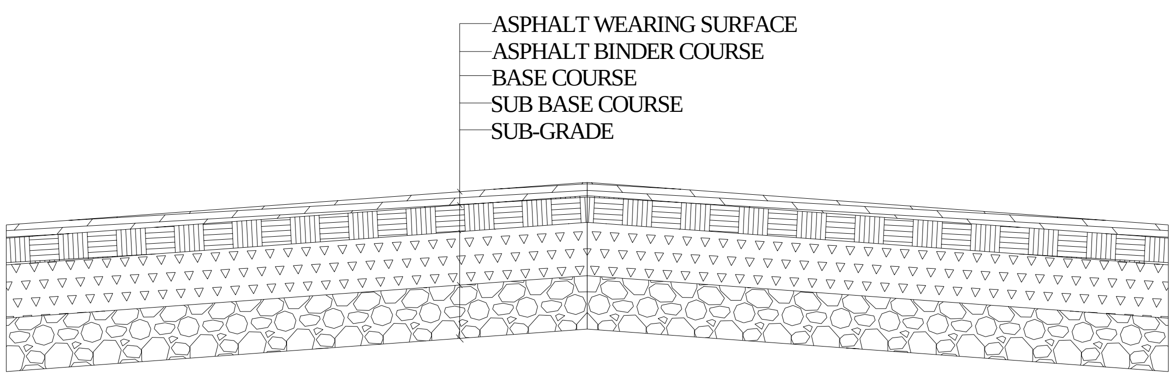


Figure 2.1 Elements of flexible pavement

Pavement deformation in the wheel path will start immediately following the passage of commercial vehicle over a flexible pavement. This permanent deformation in a well-designed pavement is fairly evenly distributed between the asphalted materials, the unbound base and sub-base, and the sub grade. In bituminous materials it may arise from additional compaction under traffic and from sideways displacement.

A pavement layers are subject to vertical compressive stresses due to superimposed wheel loads. The wearing course, the binder course, and any bituminous base material will also be subject to tensile stress as the wheel load passes. Lower bituminous layers will be subject to smaller tensile stress. Unbound granular materials used in bases and sub-base cannot accept significant tensile stress, and the structure of such layers will relax under load, so reducing the effective elastic modulus of the materials. Structural failure will generally be initiated by fatigue cracking in the wearing course, followed by similar cracking in the binder course and any other bituminous layers.

Pavements should be designed and constructed to provide, during the design life, a riding quality acceptable for both private and commercial vehicles. The assumption is often made that road pavements begin to deteriorate as soon as they are opened to traffic. However, there should be no visible premature deterioration at the early stage of the design life except due to faulty design [21].

Deterioration of flexible pavements arises from deformation under traffic loading generally associated, in the later stages, with cracking. Such deformation is associated with heavy commercial vehicles; the contribution of private cars and light commercial vehicles is negligible.

Once the permanent deformation exceeds 15mm there is an increasing probability of cracking in the wheel tracks. Water entering the cracks is likely to accelerate failure. In some countries, for flexible pavements, a maximum deformation of 25mm in the wheel tracks has been defined as the failure condition, and a maximum deformation of 15 to 20mm is regarded as the optimum condition for remedial, work such as the provision of an overlay or replacement of the surfacing. These figures relate to measurements made from the original level of the surface. In practice, measurements of rutting are more likely to be made with a 2-m straightedge.

Flexible pavements which are called upon to carry much heavier traffic loads than their design would permit often crack as a result of the large elastic deflections. This condition can cause breakup of the surface and give rise to potholing, before appreciable permanent deformation has occurred.

The American Association of State Highway Officials (AASHO) has carried out Road Test in the United States early in the sixties, and developed a rating system, known as the present serviceability index (PSI) to classify the condition of pavements. The failure condition for flexible roads, defined above, corresponds to a PSI value of between 2 and 2.5 depending on the desired level of standard of the road. The concept of pavement performance using Present Serviceability Index is as shown in Figure 2.2 [(14)].

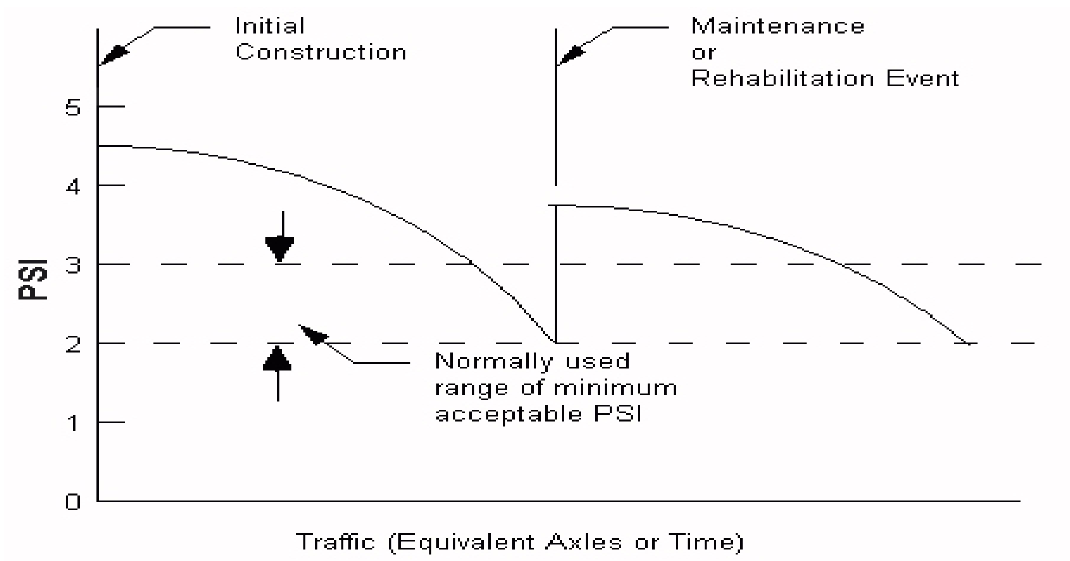


Figure 2.2 Concept of Pavement Performance Using Present Serviceability Index

2.1.1 Types of bituminous pavement distress

It is necessary to have clear understanding of type of pavements distress before discussing the different methods of evaluation, cause identification and treatment selection. There are two basic types of pavement distress. The first is structural distress and it includes damage of different pavement components of such magnitude to make the pavement incapable of sustaining the loads imposed upon its surface. The second can be classified as functional distress which may or may not progressively changed into structural distress but is such that the pavement will not carryout its intended function with out causing discomfort to users. The severity of distress for both types of distress is gradual and the range is largely a matter of opinion of the person observing the distress [19].

The types of pavement distress detailed in the following paragraphs include cracking, deformation and disintegration type of distresses caused by traffic, climate, and other reasons.

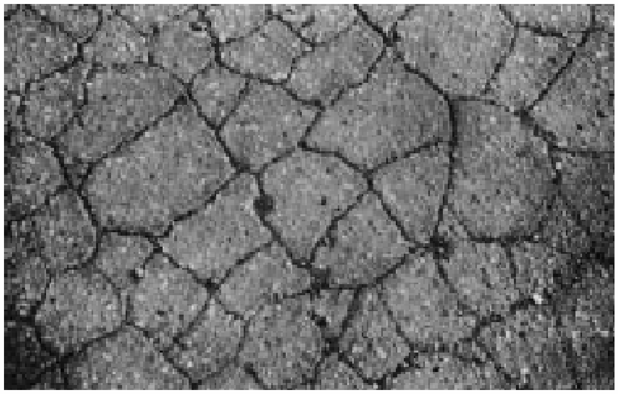
Alligator Fatigue cracks

Alligator cracks are interconnected cracks forming a series of small blocks resembling an alligator skin. The lengths of the cracked pieces are usually less than 15 cms on the longest side (Figure 2.3). In some cases, alligator cracking is caused by excessive deflection of the surface over unstable sub grade or lower courses of the structure. The unstable support is usually the result of saturation of the bases or sub grade. Although the affected areas in most cases are not large, occurring principally in traffic lanes, occasionally, will cover entire sections of pavements.

This type of failure generally occurs when the pavement has been stressed to the limit of its fatigue life by repetitive axle load applications causing accumulated tensile strain at the bottom of the bound layer. Fatigue cracking is often associated with loads that are too heavy for the pavement structure or more repetitions of a given load than provided for in design. The problem is often made worse by inadequate pavement drainage, which contributes to this distress by allowing the pavement layers to came saturated and lose strength. The asphalt layers experience high stains when the underlying layers are weekend by excess moisture and fail prematurely in fatigue.

Bleeding

Bleeding is the upward movement of the binder material in the pavement creating a film of bituminous material on the surface (Figure 2.4). This condition usually occurs during hot weather and will cause an extremely slippery surface. The most common cause of bleeding is excess asphalt binder in one or more of the pavement courses. This can result from a rich mix, variations in aggregate blending, improperly constructed seal coat, or heavy prime or tack coat. Traffic volume, tire pressure, or load in excess of design quantities can cause over compaction of bituminous layers forcing the binder to the surface particularly in a mix of very low void.



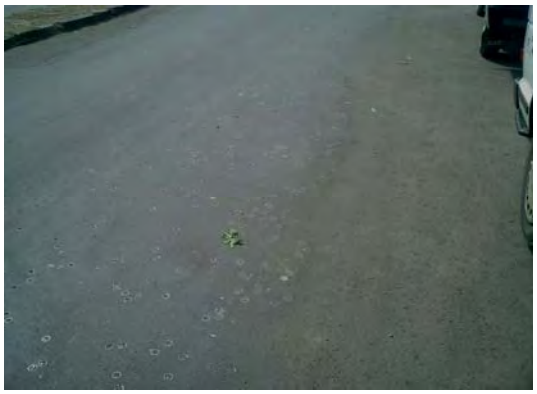


Figure 2.3 Alligator cracks *Figure 2.4 Bleeding corks imbedded*

Figure 2.5 Block cracking *Figure 2.6 Sag in asphalt pavement*

Block cracking

Block cracking is an interconnected series of cracks that divide the pavement into approximately rectangular pieces. Block cracking is differentiated from alligator cracking by size and by not being load related. The blocks usually range from 30 by 30 cm to 300 by 300 cm (Figure 2.5). The cracking is caused mainly by daily temperature cycling and by shrinkage of the asphalt concrete. This distress is not load related but is usually associated with the asphalt aging and hardening.

Block cracking can also be caused by oxidative hardening of the asphalt if mixed too long in the pug mill of asphalt batch facility, mixed too hot, or stored too long in silos. All these mechanisms make the asphalt cement especially susceptible to tensile strains, which can exceed the tensile strain capacity of the asphalt mixture and cause the block cracking.

Block cracking is more often seen in large paved areas, such as parking lots or airfield pavements, than on roads and streets. It can be very serious, especially if the cracks begin to exhibit raveling and other advanced stages of deterioration, such as development of secondary cracks. Because the cracks can be closely spaced, the underlying layers can be exposed to significant quantities of infiltrating surface water. These cracks should be sealed to prevent or minimize intrusion of water [(1)].

Bumps and sags

Bumps and sags are small, localized, upward and downward displacements of the pavement surface (Figure 2.6). Bumps can be caused by differential heave or settlement over utilities, the buildup of material in a crack in combination with loading. Sags are caused by a localized failure of the underlying material resulting in subsidence.

Corrugation

Corrugation is a form of plastic surface movement typified by ripples across the bituminous pavement surface (Figure 2.7). The cause of corrugations is usually lack of stability in the bituminous mix. Lack of stability can be caused by the mix being rich, the aggregate having excessive amounts of fines, rounded or smooth textured particles, poor bond between material layers, or the use of soft binder.

Depressions

Depressions are localized low areas of limited size which may or may not be accompanied by cracking (Figure 2.8). Depressions dip below grade and water collects in them. Depressions may be caused by traffic heavier than that for which the pavement was designed, by settlement of the underlying pavement layers, or by poor construction methods.

Edge cracking

Edge cracks are parallel to and usually within 30 to 60 cm of the edge of the pavement (Figure 2.9). This distress is accelerated by traffic loading and is caused by a weakened base or sub base at the pavement edge. Weakening of the base or sub base can normally be associated with a drainage problem causing water intrusion.

Figure 2.7 Corrugation

Figure 2.8 Depression

Figure 2.9 Edge cracking *Figure 2.10 Lane/shoulder drop-off*

Lane/shoulder drop-off

Lane/shoulder drop-off is a difference in elevation between the pavement edge and the shoulder (Figure 2.10). This distress is caused by either shoulder erosion or settlement, or by building up the roadway (i.e., overlay) without correcting the shoulder height.

Longitudinal/transverse cracking

Longitudinal cracks are those which run parallel to the pavement while transverse cracks extend perpendicularly across the pavement (Figure 2.11). This cracking may be caused by poorly constructed paving joints, temperature effects (shrinkage or expansion), hardened or oxidized asphalt, or cracks reflecting up from cracked underlying asphalt layers or stabilized base material.

Longitudinal cracks are indicial cracks that basically run parallel to the centerline of the roadway. They most often occur at the joint between adjacent lanes of asphalt mixture or at the edges of the wheel paths in a rutted pavement. These cracks allow water to penetrate into the underlying layers; possible softening of stabilized layers and accelerating the development of fatigue cracks radiating outward from the longitudinal crack. Raveling of asphalt mix material adjacent to the longitudinal crack often widens and cracks and accelerates the overall damage to the pavement structure.

Longitudinal cracks between adjacent lanes can be indicted by low temperature, since the density at the joint between paving lanes is lowest, resulting in low tensile strength. Typically the density of the asphalt mix near a longitudinal joint is at least 2 to 3 percent lower than the remaining pavement. Low tensile strength, coupled with the possibility of oxidative hardening of the asphalt due to high voids in the mixture in the joint area, makes the material particularly susceptible to cracking and subsequent raveling. Poor adhesion between the asphalt and the aggregate can aggravate the problem adjacent to longitudinal cracking and cause more rapid deterioration [(1)].

Utility cut patching

Patching and utility cut patching are areas where the original pavement was removed and replaced with new material (Figure 2.12). These areas are considered defects because the patched area or adjacent area usually does not perform as well as the original pavement.

Polished aggregate

Polished aggregate is a term applied to asphalt pavements in which the surface aggregate has been worn smooth. Polished aggregate causes a reduction in skid resistance, especially when wet (Figure 2.13). This distress is caused by low quality aggregate and repeated traffic applications.

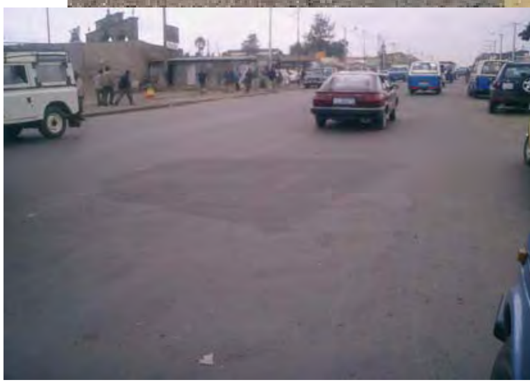


Figure 2.11 Longitudinal crack

Figure 2.12 Utility cut patching

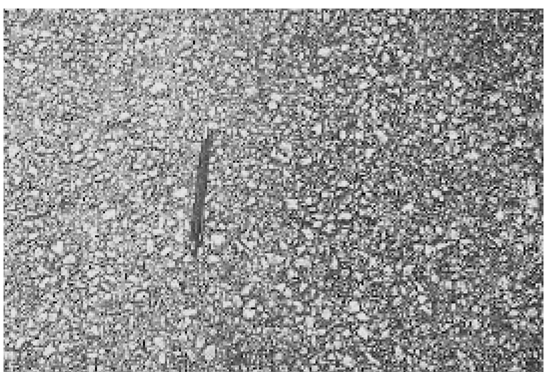


Figure 2.13 Polished aggregate

Figure 2.14 Potholes

Potholes

Potholes are usually caused by a localized weakness in the pavement resulting from a combination of such factors as too little asphalt, thin surface thickness, too many fines, too few fines, or poor drainage (Figure 2.14). Unless repaired promptly, their growth will be accelerated by traffic and moisture collected in the pothole.

The occurrence of potholes often coincides with a period of heavy rainfall during which water penetrates the asphalt layer through cracks, usually closely spaced alligator cracks, and softens the granular base course. Fine material is pumped through the cracks so that the underlying base support is weakened resulting in removal of the adjacent material by traffic. Once the first piece is dislodged, the pothole grows rapidly since all other pieces are more easily dislodged that the first piece.

Potholes can develop along any crack that occurs in a pavement for example either longitude or transverse cracks can deteriorate.

Railroad crossing

Railroad crossing distresses are depressions or bumps around and/or between the tracks (Figure 2.15).

Figure 2.15 Railroad crossing *Figure 2.16 Raveling*

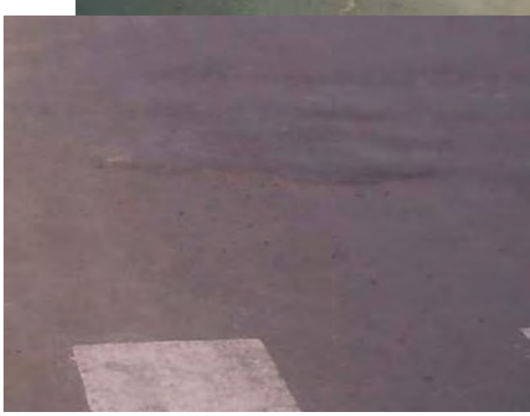


Figure 2.17 Rutting *Figure 2.18 Shoving*

Raveling

Raveling is a progressive separation of the aggregate from the binder (Figure 2.16). Raveling is the failure of bond between the aggregate and the bituminous binder. Raveling may be caused by insufficient compaction during construction, construction during wet or cold weather, dirty or disintegrating aggregate, insufficient binder in mix, or over-heating of the surface mix.

Rutting

Rutting is a depression in the wheel path (Figure 2.17). In extreme cases there may be uplift between the wheel paths in conjunction with the rutting. Rutting may be caused by a permanent deformation in the pavement layer or the sub grade due to traffic loads. Pavements constructed of low stability asphalt mix or unsatisfactory compacted asphalt mix is leading causes for the deformation in the pavement layers.

Shoving

Shoving is a localized plastic movement in the bituminous surface (Figure 2.18). Areas subjected to frequent vehicular braking action can exhibit shoving. The cause of shoving is usually lack of stability in the bituminous mix. Lack of stability can be caused by the mix being too rich, the aggregate having excessive amounts of fines or rounded or smooth textured particles, poor bond between material layers, or the use of a soft binder. Plastic flow in patching materials can also be caused by excessive moisture in the mix, contamination by oil spillage, or too much volatile material remaining when a cold-laid patch is placed.

Bus stops are often the first locations to exhibit premature distortion in the form of shoving. Shoving can be easily detected at edge lane markings where these lines bend outward in the vicinity of the shoving.

Shoving occurs when the applied forces exceed the shear strength of the asphalt mix or underlying layers. Shoving can also occur when thin asphalt layer are placed over granular bases and sub base. Shoving is primarily due to unstable asphalt layers.

Slippage cracking

Slippage cracks are usually crescent shaped cracks that normally point in the direction of the thrust of the wheels during braking (Figure 2.19). A low strength surface mix or a lack of bond between the surface layer and the course beneath causes this distress. This slippage or delaminating can cause failures on the pavement surface under traffic. The slippage can be caused by poor drainage, which could aggravate a stripping problem, or by construction.

Swell

Swell is the localized upward displacement of a pavement due to the upheaval of the sub-grade or some portion of the pavement structure (Figure 2.20). Swell or heave is commonly caused by infiltration of moisture into an expansive-type soil.

Figure 2.19Slippage cracks *Figure 2.20* Swelling

Figure 2.21 Weathering *Figure 2.22 Rave due to fuel spills*

Weathering

Weathering is a process in which the more volatile parts of the asphalt are lost which results in the hardening or aging of the asphalt binder in a pavement (Figure 2.21). Defects such as cracks or holes in the pavement or low pavement density will allow more area of the pavement to be exposed to air and water and increase the weathering process. Raveling is often associated with weathering and is often a direct result of it. Weathering can be a problem in open-graded pavement surfaces due to the increased surface area exposed to weathering conditions.

Raveling from fuel spills

Raveling from fuel spills is similar to the raveling described earlier (Figure 2.22). However, in this case the raveling is caused by fuel leaching away the asphalt binder. This distress will accelerate if more fuel is spilled on a surface that had previously started raveling. Fuel spills on pavement surface cause distress due to the void space provided in the pavement surface.

Low skid resistance

Low skid resistance can be caused by a variety of factors including excessive asphalt binder and the type of aggregate used in the mixtures. The options available to alleviate this distress are to overlay or recycle the pavement, groove the pavement, or apply a surface treatment. When the pavement is structurally sound, the first alternative is unnecessary and the grooving of asphalt pavements may be the best solution. Surface treatments include seal coats and slurry seals.

2.1.2 Failure Modes

The different types of pavement distresses discussed in section 2.1.1 above can be associated with material properties through considerations of various mechanisms and manifestation of distress as shown in Table 2.1.Failure modes can accordingly be divided into three categories: (1) rupture (2) distortion, and (3) disintegration. With the exception of safety considerations associated with the surface coefficient of friction and glare all forms of distress can be related individually or collectively to these modes [9, 14].

It is also necessary to have clear concept of pavement failure before other details are treated. Basically, the behavior of a pavement structure may be magnified in terms of output and response. Limits of response are know as distress (i.e. rupture, distortion, disintegration) and may be expressed conceptually as a function of the following:

$$\text{Distress} = f(C, S, D) \qquad (2.1)$$

Where C = weighed measure of rupture; S= Weighted measure of distortion and D = weighted measure of disintegration.

Failure of the pavement structural may then be designated as a point on the distress curve expressed in equation (2.1). At the point where the distress exceeds an acceptable level, failure of the pavement structure is said to have occurred. This point is not an absolute value, but depends upon the decision criteria and weighting functions applied.

Basically, an engineer's criteria for judging a pavement structure are how well it provides the traveling public with a safe, convenient travel way from origin to destination. In terms of the user, the "decision criteria" should include, among other things, riding quality, economics, and safety. These "decision criteria" may be expressed as a function of the following:

Decision criteria = f (R, E, S, O)…………………………………… (2.2)

Where: R= measure of riding quality; E= measure of economics; S= measure of safety; and O = other factors (reliability maintainability etc).

Failure of the pavement structure system may be expressed as a condition where the distress from the system has exceeded an acceptable level, base on the decision criteria. The desired level of ride quality and safety would vary depending upon the type of facility.

Principal arterial roads would require high levels of riding quality and safety, hence the acceptable level of output of the pavement structure, in terms of fracture, distortion, and disintegration, would be low. Therefore, a relatively small value of distress manifestations may result in a failure of such road pavement structure. On the other hand a collector road might represent other extreme, since it requires a much lower level of riding quality. Hence, the level of distress considered unsatisfactory on the principal arterial road may be adequate for these pavement structures.

The actual model of equation 2.1 would be a complicated one that required interaction terms, since these factors are not independent. Cracking will have an effect on disintegration, or change in shape may have an influence on the amount of cracking.

Table 2.1 Categories of pavement distress

Distress Manifestations	Examples of Distress Mechanism
(a) Rupture **1. Cracking**	1. Excessive load strain 2. Cumulative effects of repeated load 3. Thermal movements 4. Hygroscopic effects including volume change 5. Slippage due to horizontal stresses 6. Shrinkage
2. Spalling	1. Cumulative effects of repeated load applications 2. Other (see disintegration)
(b) Distortion **1. Plastic deformation**	1. Excessive shear stress 2. Creep
2. Rutting	1. Densification 2. Consolidation
3. Faulting	1. Volume change of underlying material 2. Lack of support for surface layer 3. Others (see plastic deformation and rutting)
4. Differential volume change	1. Swelling 2. Densification 3. Shrinkage 4. Thermal changes
(c) Disintegration **1. Stripping**	1. Loss of adhesion between aggregate and binder 2. Chemical reaction at aggregate surface
2. Raveling, sealing and loss of matrix	1. Thermal effects 2. Chemical reactivity 3. Lack of adhesion between aggregate and binder 4. Excessive stress within surface layer
3. Aggregate degradation	1. Unstable mineralogy 2. Reaction to environments 3. Excessive stress

Pavement condition involves the following four major components: (1) ride comfort (2) load carrying capacity (3) safety, and (4) aesthetics. In general, a good pavement rides well, carries traffic satisfactorily, and provides a safe tire interface for both rolling and stopping, and have pleasing appearance to the pavement manager and user as well. As there is no formula for considering all the above components in a precise manner, different people give more or less emphasis on any of the above factors depending on there particular situation [(8)]. Figure 2.23 shows a schematic representation of the variation in the major out puts which could actually be measured or predicted during pavement evaluation.

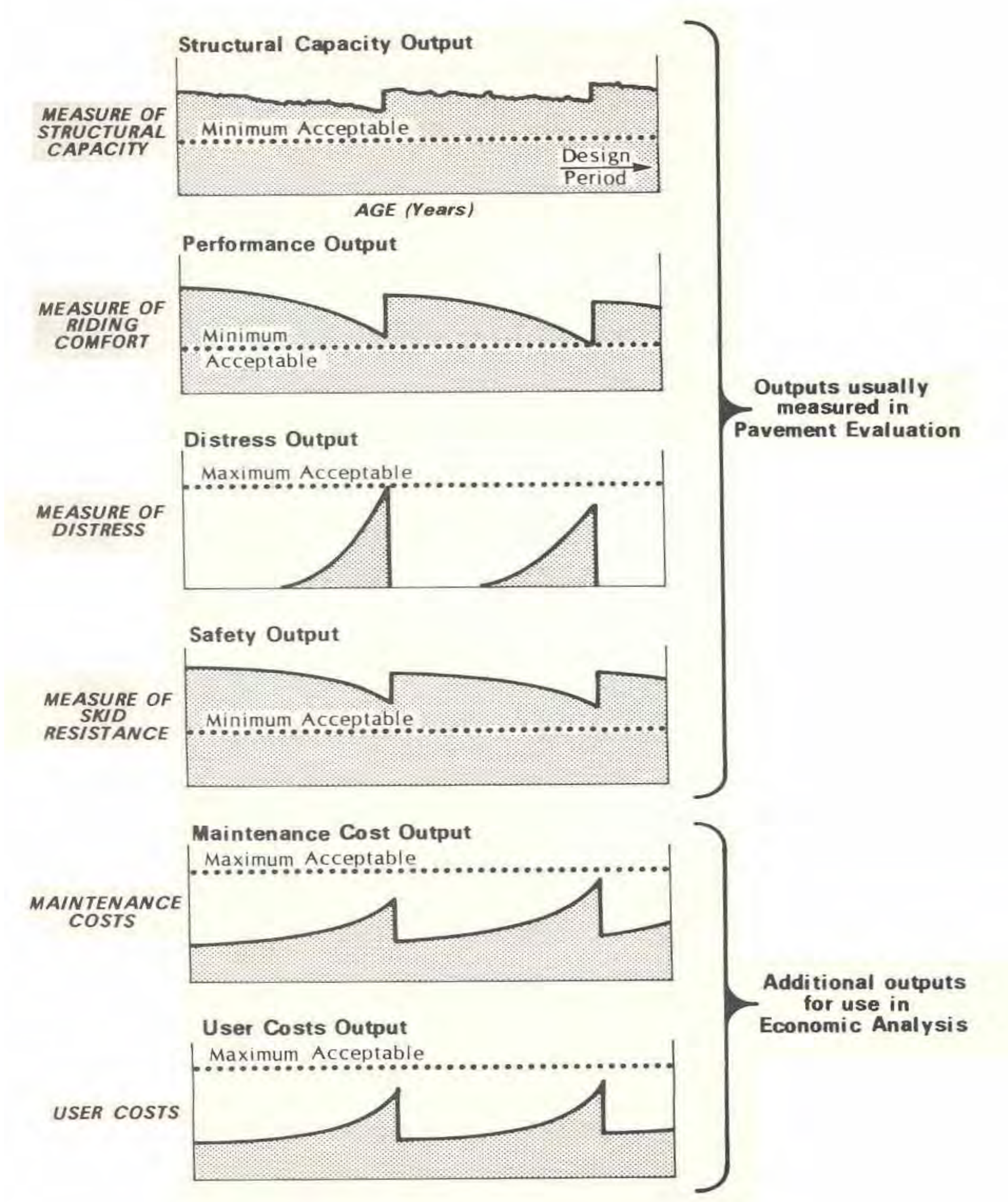


Figure 2.23 Major Types of Pavement Outputs

2.1.3 Major Causes of Pavement Distress

The major causes for the above mentioned distresses can be grouped in to three categories. The first is due to overloading that includes excessive gross loads, high repletion of loads and high tire pressure. Second climatic environmental conditions may cause surface irregularities and structural weaknesses on the pavement. For example volume change of soil due to wetting and drying resulting from improper drainage may be the prime cause of pavement distress.

A third causes may be disintegration of the paving materials due to method of construction and quality of construction material. Use of contaminated aggregate and inadequate construction supervisor are also factors that may aggravate pavement distress. Lack of maintenance will further aggravate pavement distress.

Distresses identified during condition surveys can be grouped in to three major categories of possible causes as follows:

Load Associated Distress:

1. Alligator cracking
2. Corrugation
3. (Bumps & sags) Edge cracking
4. Patching load cause distress
5. Potholes
6. Rutting
7. Slippage cracking

Climate /Durability Associated Distress

1. Bleeding
2. Block cracking
3. Joint reflection cracking
4. Line cracking (longitudinal/ transversal/
5. Patching of climate/durability swell caused distress
6. Weathering and raveling
7. Shoving

Drainage/ moisture Associated Distress

1. Bumps & sags
2. Lane/ shoulder drop off

3. Depression
4. Swell

2.2 Methods of Distress Surveys

Distress surveys can be grouped in to two broad categories; non-destructive and destructive surveys**.** The non-destructive survey includes (but not limited to) visual survey, roughness survey and deflection survey. The destructive survey includes the DCP survey and test pit excavation. Details of each type of survey are as indicated here under.

2.2.1 Visual Distress Survey

Various types and degrees or severity of distress are measured during the condition surveys. There is some degree of communality between the different factors that are usually measured. These may include the following general classes of factors:

1. Surface defects

2. Permanent deformation or distortion

3. Cracking

4. Patching

Pavement engineers have long recognized the importance of distress information in quantifying the quality of pavements. Pavement distress information can be used in a detailed manner for developing priority in maintenance program. However, in order to obtain an overall assessment of pavement conditions for a road network, it is often necessary to combine individual distress data to form the composite index called pavement condition index (PCI). PCI summarizes the condition of each pavement segment.

By definition, PCI is a subjective evaluation of pavement condition by experienced pavement engineers, based on a user-defined scale, such as 0-5, 0-10, or 0-100. It summarizes the pavement conditions in terms of individual distress, so that pavement performance may be evaluated, predicted, and improved using effective treatment [11].

This section will explain how condition survey inspection is conducted and how the pavement condition index (PCI) is determined. Pavement condition is related to several factors, including structural integrity, structural capacity, roughness, and rate of deterioration. Direct measurement of all these factors requires expensive equipment and well-trained personnel. However, observing and measuring distress in the pavement can assess these factors.

2.2.2 Deflection Survey

This comprises an evaluation of the structural adequacy and load-carrying capacity of an existing pavement and of its various components without destroying its components. For so doing, measurements have to be made at or near the surface of the pavement and the results of these measurements related in some way to the structural properties of the pavement section.

In nondestructive pavement evaluation the structure of the pavement is not altered by the external force or energy input and hence such measurements can be repeated at the same location as often as necessary. Such testing methods can be further be grouped into three.

1. Measurements of response to a static load or to a single application of a slow moving load.
2. Response to a repeated or dynamic load
3. Response to a controlled service of nuclear radiation.

The Benkelman deflection test, which is a method of response measurement to a static or slow-moving load, is applied in this research.

The Benkelman Beam was developed at the WASHO road test. It is a simple and most widely used method of measuring pavement deflection. It consists basically of a simple lever arm attached to a lightweight aluminum or wood frame that is capable of being moved by hand. A schematic of the device is shown in Figure 2.24. This equipment is versatile, simple and inexpensive to operate; however, because it is relatively static measurement method, it is quite difficult to use on heavily traveled highways carrying high speed.

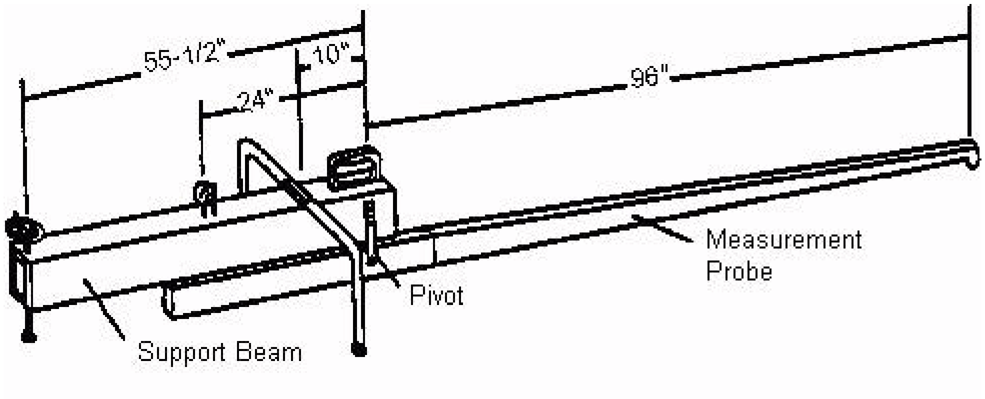


Figure 2.24 Benkelman Deflection apparatus

The general procedure for using pavement deflection for structural evaluation is [10].

1. Establish the length of pavement to be included in the structural evaluation.
2. Perform a deflection survey.
3. Calculate the representative rebound deflection (RRD).
4. Check if it is within the allowable range.

Where visual inspection or test data clearly indicate big differences in the pavement condition, it is recommendable to further divide the road into sub-sections and perform the evaluation separately. Basically the procedure involves plotting deflection data by stations, selecting adjacent areas that appear to have the same average deflection, and testing for structural significance. The magnitude of pavement deflection is an indicator of the pavement to withstand traffic loading.

This RRD value is the mean of the rebound deflections, which have been multiplied by a temperature adjustment factor for reference to 21^0c (70^0F) plus two standard deviations. The Representative Rebound Deflection (RRD) is computed as:-

$$RRD = (\overline{x} + 2s)C$$

Where

$\overline{x}$ = the arithmetic mean of the individual values that have been adjusted for temperature = $\Sigma\ x_i f_i/n$

S = standard deviation (as defined below)

f_i = temperature adjustment factor

C = critical period adjustment factor

X_i = individual deflection values

n = number of individual deflection test values

Standard deviation: -

$$S = \sqrt{\frac{\Sigma x^2 - \overline{x}\,\Sigma x}{n-1}}$$

Where S = Standard deviation

x = individual test value, corrected for temperature

$\overline{x}$ = mean adjusted test value (as defined above)

2.2.3 Roughness Survey

Pavement roughness is manifested at the pavement surface and experienced by the passenger and operator of a vehicle traveling over that surface. Pavement surface roughness is a function of the profile of the road surfaces, the characteristics of the vehicle, including tires, suspension and of the acceleration and speed sensibilities of the passenger. All of these factors undoubtedly affect the phenomenon of roughness. Longitudinal roughness is probably the major contributing factor to undesirable vehicle forces.

The serviceability of a pavement is largely a function of its roughness. Studies made at the AASHTO Road Test have shown that about 95% of the information about the serviceability of a pavement is contributed by the roughness of its surface profile (8).

Most of the road defects described in Section 2.1.2 above contribute in some way in increasing the roughness of the road pavement, although in its early stages cracking may cause little or no change. However, without proper maintenance the cracked surface deteriorates and the resulting potholes and subsequent patching may cause a rapid increase in roughness. Surface texture and variability in rut depth also have a significant effect on the roughness of a road pavement [6].

There are a variety of devices for measuring roughness that have found common use for high ways. These range from the simple to the sophisticated and can in general be classified in to the following four precision levels based on how accurately they measure the profile of the road and hence international Roughness Index (IRI) [6, 11]:

Class 1: Precision profiles

This roughness measurement method includes direct measurement of longitudinal profile using the traditional survey methods by road and level or any other efficient survey instrument at a closer interval of around 30cm.

Class 2: Other profilometric methods

This method includes direct measurement of roughness using various profilometers such as Chloe type rolling straightedge as used in the AASHTO Road Test, the surface Dynamics Profilometer (SDP) designed by the General Motors, the Siometer used by the Texas State Department of Highways, and PRORUT profilometer of FHWA.

Class 3: IRI by correlation

This method includes indirect measurement of road roughness using response-type road roughness meters (RTRRM) such as the Mays ride meter, the TRL bump integrator and other different type car road meters. The majority of road roughness measurement data currently collected throughout the world is obtained using this method. This method needs calibration of the device using MERLIN.

Class 4: Subjective Roughness Ratings

This class falls under the lowest standard of accuracy and applies methods of evaluating the ride quality using visual observations of vehicle comfort at different speeds.

The TRL bump integrator that falls under class 3 is used for this research purpose. The schematic drawing is as shown in Figure 2.25.

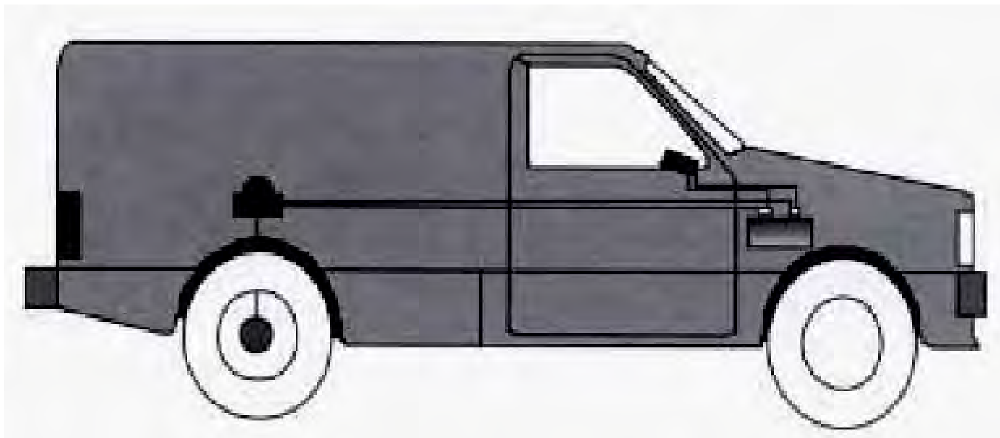


Figure 2.25 Diagrammatical representation of TRL Bump integrator

2.2.4 DCP Survey

Although pavement conditions can be evaluated to some extent by measurement of surface irregularities, or the logging of pavement defects such as cracking and deformation, it occasionally becomes necessary to remove portions of the pavement structure to ascertain just where "failures" are occurring and why. The term destructive testing is applied to these evaluation methods because the original structure of the complete pavement is destroyed with respect to future testing at that particular location. In general, such procedures are very expensive especially on existing pavements, as they require destruction of the pavement structure where the evaluation is to be made. Hence, the advantages of opening up pavements for detailed investigations below the surface must be weighed against the disadvantages of removing portions of the pavement and replacing with patches. On the other hand, too great a reliance on the appearance of defects at the surface should not be made, for many times this may give misleading results. Surface defects can be used as general guides to the underlying conditions; however, it is often necessary to determine the true position and cause of failure for a completely reliable analysis using destructive surveys [8].

The DCP apparatus, which is an instrument, designed for the rapid in-situ measurements of the road sub-grade is utilized for this research purpose. Continuous measurements can be made down to a depth of 850 mm or, when extension shafts are used to a recommended maximum depth of two meters. When the sub-grade consists of different layers with different strengths, the boundaries are identified. The thickness of boundaries is identified from the DCP plots and the thickness of the layer determined. The schematic drawing of DCP apparatus is as shown in Figure 2.26.

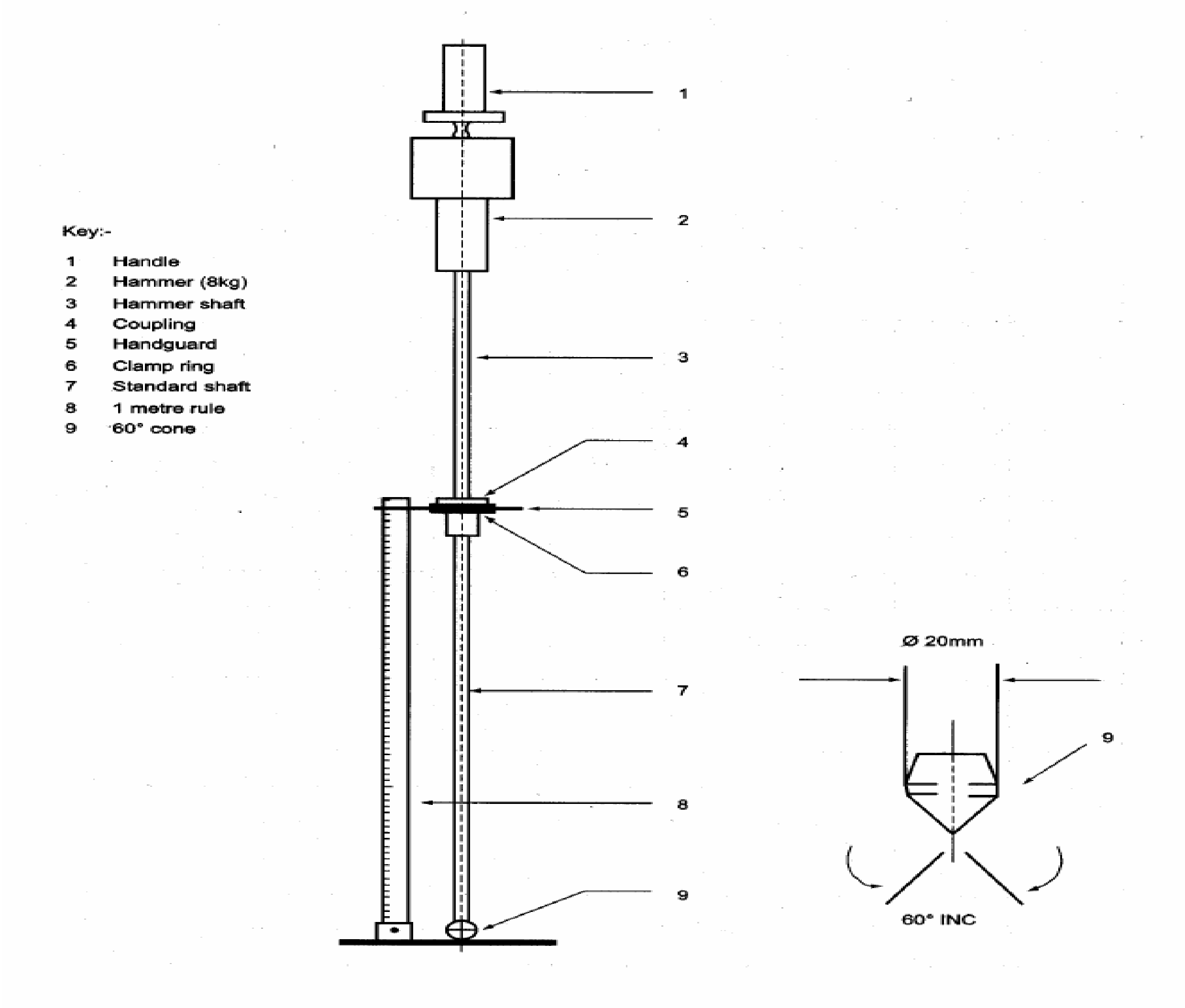


Figure 2.26 TRL DCP apparatus

2.3 Maintenance and Rehabilitation Alternatives

It should be emphasized that properly designed and constructed pavement should provide many years of maintenance free service. Anyhow pavements have finite life, as they are susceptible to wear for several reasons. Many pavement managers use the pavement condition index (PCI) to track pavement distress over time and apply maintenance treatments. Pavements are usually maintained and/or rehabilitated when the PCI drops to a level of 40-60.

Pavements are costly not only to build but also to maintain. These costs are born by the owner funding the facility. Road users also cost a lot when operating their vehicles on deteriorated and poorly maintained roads. Hence, it is advisable to develop a definite action plan in order to keep asphalt road pavements in a continuous serviceable condition.

The pavement maintenance problem is not simple. Many factors are involved that affect the performance of a pavement. Hence the type of maintenance that will be required for any particular pavement will depend on a number of conditions: the traffic system to which the pavement is subjected; Climate; the structure of the pavement; the quality of construction; the frequency and extent of inspection performed, both during construction and during maintenance; engineering talent involved, maintenance practices; discipline; and money; not necessarily in that order. In general, it is necessary to have the following in order to have the best maintenance program [(15)]:

1. Organize the maintenance crew with experienced engineering and maintenance personnel.

2. Keep records of all pavement structures that are as precise as possible. These should include records of sub grade soils, sub base and base course, wearing courses and drainage system.

3. Arrange a pavement condition survey program to check and record the pavement condition at regular intervals.

4. Reviews and analyze the condition survey reports systematically.

5. Review the current maintenance methods to make sure that they are being carried out effectively.

6. Prepare work orders for preventive maintenance and to correct distresses investigated during the condition surveys.

7. Establish suitable timetable by prioritizing the projects.

8. Prepare realistic budgets and carry out the maintenance under the most favorable weather and traffic condition.

2.3.1 Maintenance Programs

Pavement maintenance programmers are required to perform the task of preserving, repairing and restoring different damaged elements of a pavement system to its designed or accepted standard.

In general, maintenance of pavements is similar in concept to maintenance of one's home or car. If one doesn't want to repair his leaking roof, it will be further damaged and cause destruction in the house. If one does not want to timely change oil filter, he will certainly pay for the engine in a short time. The same is true to pavement maintenance. The longer one waits to maintain a pavement, the more it will cost to repair.

There is no uniform terminology with regard to definitions concerning pavement maintenances and rehabilitation. It varies from country to country and even from authority to authority as well. Maintenance programs can be categorized into routine, periodic and extraordinary maintenances. Each can be discussed in a little more detail as follows:

Routine Maintenance

A routing maintenance program comprises different activities that are to be carried out as frequently as required in order to ensure serviceability at all times [22].

Major activities include the following:

a. Clearing roadway pavement, ditches, drains, signs, and safety barriers, etc, as well as grass cutting and tree pruning,

b. Repair of minor damage to pavement, drainage system as well as any urgent repairs to restore disrupted traffic movement

c. Maintenances during rainy season such as provision of turn out ditch form storm water, clearing of mud and debris etc.

Periodic maintenance

A periodic maintenance includes operations to be carried out under a long term program within the design period of the pavement. These operations can be divided in to the following two main groups:

- Renovation of the wearing surface of the existing pavement that become worn or damaged; e.g. resealing or surface dressing of existing asphalt road.

- Restoration of drainage systems, road markings and ancillary items

Extraordinary Maintenance

Extraordinary maintenance consists of activities necessary to restore highly distressed pavements to their original design requirement. The tasks include:

- Strengthening and or/reconstruction of a pavement structure which has severely deteriorated (e.g. overlays)

- Activities to protect roads against external agents (Such as slope stabilization, retaining structures & flood control measures).

Maintenance Priorities

It is also very important to allocate the limited resources available for the maintenance purpose in such a way that it satisfies objectives and maintenance polices of the roads authority. The following basic approaches can be used to determine priorities for pavement maintenance:

i. **Urgent maintenance-** such as emergency repairs to pavements that are cut, removal of debris and other foreign objects.

ii. **Routine drainage maintenance**; ditch cleaning and deepening, cleaning bridges and culverts, backfilling scoured areas, constructing check dams and etc.

iii. **Routine maintenance of pavement**- such as patching, sealing and repairing of road furniture.

iv. **Periodic maintenance**- such as resurfacing

As indicated above the routine drainage maintenance should get more priority than the routine maintenance on pavements as repairing pavement surface defect caused by drainage problem is wastage of resource unless the drainage is first corrected [(22)].

2.3.2 Rehabilitation Concepts & selection Process

A rehabilitation work comprises activities such as major resurfacing, restoration, rehabilitation and reconstruction. It can be considered as major maintenance operation that is undertaken to considerably extend the service life of an existing pavement. Therefore, rehabilitation operations are different from routine or periodic maintenance in that the primary function of the latter activity is to preserve the existing pavement so that it may sustain the applied loading while rehabilitation is carried out to considerably prolong the functional life.

Pavement rehabilitation can be subdivided into two major categories:

1. Rehabilitation methods other than overlay.
2. Rehabilitation methods with overlays.

Even though we can categorize rehabilitation works into two as stated above, there is no definite equation, guide or a clear step by step procedure that one can use for a proper rehabilitation design. That is why some conclude that pavement rehabilitation is as much an art as a science. Hence, both theoretical analysis and engineering judgment are equally important when selecting an alternative among different rehabilitation methods. Even after selecting alternatives, there are no “right” and “wrong” solutions to pavement rehabilitation problems, but rather ‘'better”, “Optimum” or “Preferred” solution [5].

2.3.3 Selecting Alternative Rehabilitation Methods.

Selecting a preferred solution for rehabilitation is a complex engineering problem. Anyhow, a rehabilitation analysis can be made simpler by following a logical step-by-step procedure. The following fundamental steps as outlined in AASHTO Guide for Design of Pavement Structures can be followed [5] :

1. Problem definition, i.e. determining cause of distress or pavement problem.
2. Potential problem solution, to develop a candidate list of solutions that will properly address the problem.
3. Selecting preferred solution,

The pavement rehabilitation selection process is as outlined in Figure 2.27

The feasible rehabilitation solutions for a specific pavement distress can be obtained by rating different candidate solutions against identified constraints. A feasible alternative can be defined as one that addresses the cause of distress and is effective in curing the existing problem and also prevent further occurrence of it by satisfying identified constraints.

As indicated above, there is no perfect method for selecting the most “preferred” rehabilitation alternative for a given road. Rather, sound engineering judgment, creativity and flexibility are very important in the selection process. Thus, each road authority has to develop a procedure to select preferred solution for its rehabilitation projects using both monetary and no monetary evaluations.

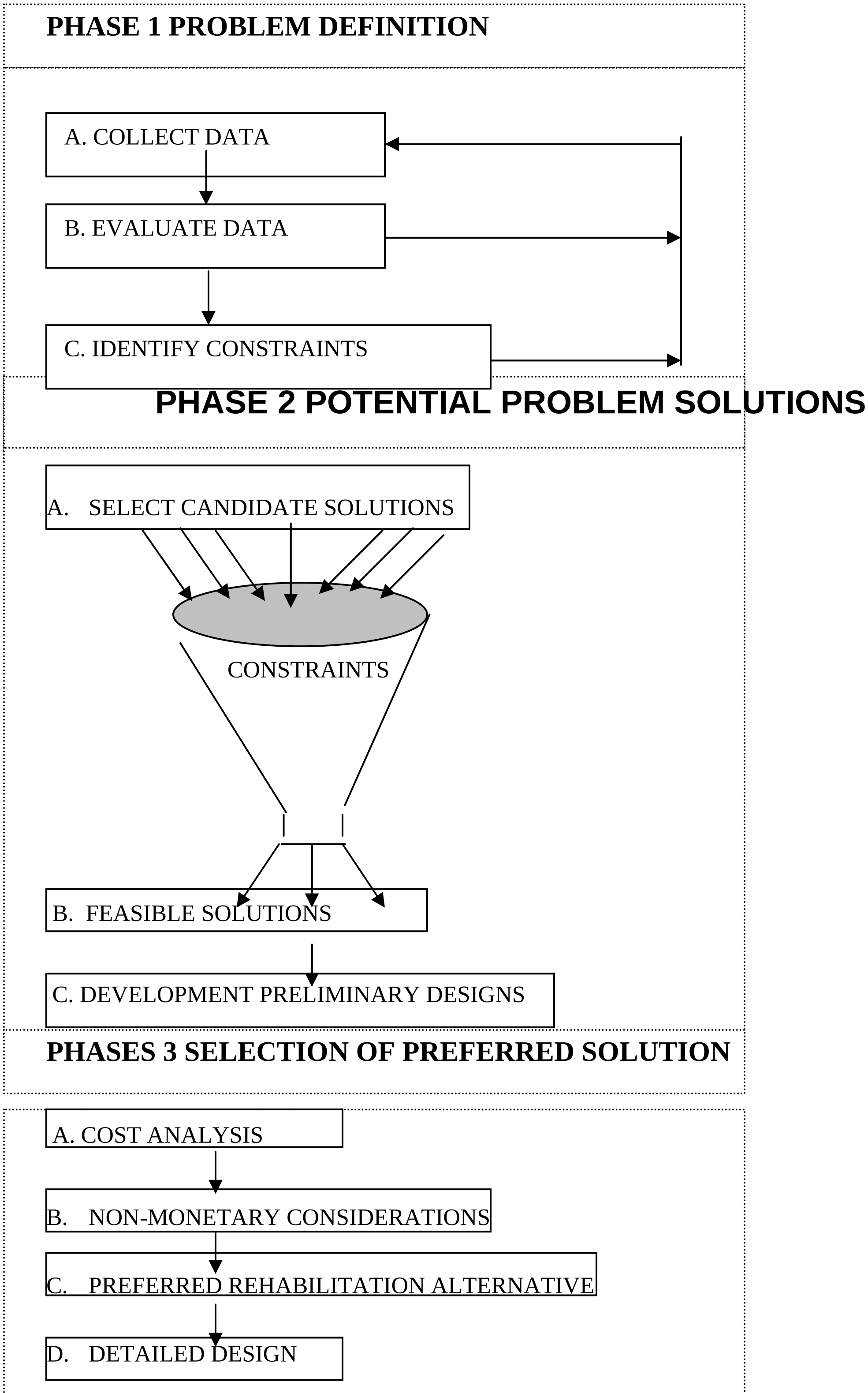


Figure 2.27 The pavement Rehabilitation Selection Process [5]

3.0 Methods for Pavement Evaluation & Treatment Selection

3.1 Introduction

This chapter provides an overview of the applied procedures in order to attain the objective of the research. It shows methods followed for the investigation, evaluation and analysis of the pavement condition to identify cause of distress and propose maintenance options.

To note it once again, the objective of this research is in general to make an initial or primary assessment for identifying major causes of Asphalt pavement distresses or defects on principal arterial roads and proposes appropriate maintenance options for the Addis Ababa City Roads.

This section describes procedures followed to establish the nature, severity and extent of pavement distress. It provides guidance on the use of non-destructive and destructive pavement tests and describes how the results of these tests can be utilized, both to identify the causes of distresses and to assess the strength of the existing pavement. It also reviews possible treatment options.

3.2 Procedure

3.2.1 Selection of Test Roads and Test sections

The Pavement evaluation under this research has concentrated on the five radial arterial roads connecting Addis Ababa with other regional states. Exact location of representative test sections within the selected roads are identified considering factors affecting potential pavement performance such as the sub-grade soil type, pavement type, pavement cross-section (layer material type & thickness) traffic loading and, pavement condition as major criteria [(8)]. Existing information from the AACRA PMS are also utilized for selecting test sections. Name of test roads and their corresponding number of test section is as shown in Table 3.1 below.

The following major criteria were considered when making the study on the five arterial roads: -

- These roads can fairly represent arterial roads in the road network.

- These roads are the most utilized sections and convey higher traffic loading and hence are prone to damage than others.

- These roads need top priority in having routine and periodic maintenance, as they are main routes for travels within and without Addis Ababa.

- These roads traverse through different geographic location of Addis Ababa and comprise different sub grade soil types.

Table 3.1 Test Roads & Test Sections

Test Road No.	Test Road Name	Number of Test Sections	Total Length (km)
1	Debrezeit Road (from St. Yosef Church to Kaliti Interchange)	13	3.9
2	Jimma Road (from Mexico sq. to Old Airport)	9	2.6
3	Arbegnoch Road (from St. Yohannis Church to Winget school)	13	3.9
4	Dej. Belay Zeleke Road (from St. Giorgis Church to Sheger Park)	9	3.0
5	Fikeremariam Aba Techan Road (from Kebena to Megenagna)	11	3.7
Total		55	17.1

The start and end chainage of the test sections are selected following a preliminary site visit. Each test section is selected in such a way that it will have certain consistent characteristics (or relative homogeneity) through out its area or length as follows:

- Similar cross sectional dimension

- Similar structural composition of the pavement material type

- Similar traffic volume
- Similar pavement

3.2.2. Visual Condition Survey

The visual Condition survey is made in order to measure various types and degrees or severity of distress. The measured components are surface defects (such as longitudinal joint cracks, potholes, raveling, bleeding and lacy edge), permanent deformation or distortion, fatigue cracking and patch deterioration.

These evaluations are also necessary for defining, and subdividing sections of road in similar condition when the uniform sections are relatively short, the detailed condition survey can be best carried out over the entire length of the section. For time and resource limitation a maximum of 2.6 – 3.9 km length of road is used for visual survey from each arterial road. These selected Test roads are further subdivided in to blocks of 50meter length.

The condition survey procedure offers a method for identifying pavement distress types and defining the levels of severity and extent associated with each distress. The visual survey is made using commonly used recording formats and guidelines for determining pavement condition that involves observing and recording the presence of specific types and severities of defects or distresses on the pavement surface.

The procedure followed for visual inspection of the road pavement is:

- Record distresses walking along the Test Road section.
- Measure distresses using proper parameters such as fatigue cracking (sq.mt), bleeding (sq.mt), corrugation (sq.mt), depression (sq.mt), longitudinal and transverse cracking (linear mt), patch deterioration

(sq.mt), potholes (number), raveling and weathering (sq.mt), rutting (sq.mt), slippage cracking (sq.mt), and swell (sq.mt)[5].

- Log the final results on the data collection form.

The following pieces of equipment are utilized to carry out visual condition survey: measuring wheel, measuring tape and camera. Figure 3.1 shows the visual condition surveys on Test Road No-2.

The identified distress is quantified and recorded using the following estimators [3, 4, 5]:

- **Distress type** - identify types of physical distress existing in the pavement. The distress types are categorized according to their casual mechanisms (i.e. functional or structural).

- **Distress severity** - estimating the distress items in three damage levels i.e. low (L), medium (M) and high (H) severity. This assessment helps to estimate degree of deterioration.

- **Distress extent** - Denote relative area (percentage of the road section) affected by each combination of distress type and severity.

Figure 3.1 Visual Surveys on Test Road N0-2

Figure 3.2 Deflection Surveys on Test Road N0-5

The Pavement Condition Index (PCI) is determined by measuring pavement distress with a numerical indicator based on a scale of 0 to 100.The following pavement condition ranking is given to PCI values: 0-10(failed); 10-25(very poor); 25-40(poor); 40-55(fair); 55-70(good); 70-85(very good); 85-100(excellent).

During the condition survey, the inspector walks over the road section, measure each data on the inspection sheet (Refer samples of filled forms in APPENDIX-A). The equipment used for this survey is hand odometer to measure distress lengths and areas, a 2mt straightedge, and ruler to measure the depth of or depressions. One form is used for each sample unit (i.e. test section).

Calculation of the PCI is done using the PAVER (which is a data management system for **PAV**ement **E**valuation and **R**ehabilitation) method which involves the following five steps [(12)]:

Step 1: Inspect each sample unit and record distress

Step 2: Determine deduct values for each distress type and severity

Step 3: Compute total deducted value by summing all individual distress Deducted values

Step 4: Compute the corrected Deduct values using correction curves

Step 5: Compute the PCI by subtracting all corrected duct values from100; i.e. PCI = 100 - CDV. If all sample units in a section are surveyed, the PCI of the section is computed by averaging the PCIs of all its sample units.

The five steps followed in calculating the PCI as used in the manual PAVER method are outlined below in Figure 3.3 for elaboration.

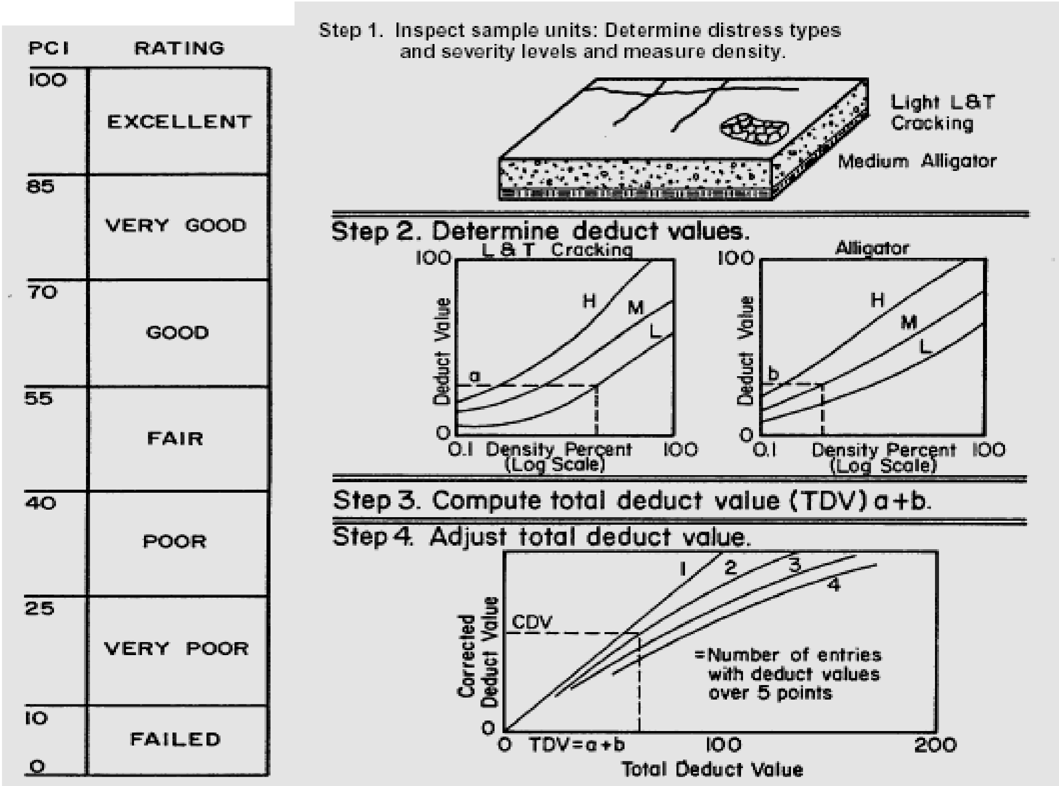


Figure 3.3 PCI Scale & Steps for calculating PCI for a Test section [12]

The elements of pavement condition rating are recorded as follows:-

- The type of defect
- The severity of the defect (low, medium, high as stated in AASHTO Guide)
- The extent to which the road surface is affected by the defect.

Drainage condition surveys were also made as part of the visual condition surveys. A five point assessment scale is used as follows:

1. **Very good:** where the shape and level of drains is as designed.
2. **Good:** where drainage functions can be easily fulfilled.
3. **Average:** where drainage condition is slightly impeded.
4. **Poor:** where drainage function is impeded due to sedimentation, vegetation or scour.
5. **Very poor:** drainage non-existent.

3.2.3. Non Distractive pavement Investigation

This investigation is carried out using the following instrument [5, 6]:

a. Roughness measurement using Bump Integrator for functional (serviceability) evaluation.

b. Deflection measurement using Benkelman Beam for structural evaluation.

An observation of serviceability (functional) evaluation below the acceptable level is one way to trigger structural evaluation.

Roughness that is a primary component of serviceability measurement is used in estimating the international roughness index (IRI). The roughness measurement is done in all test sections using Ethiopian Road Authority's Bump Integrator and following standard procedures [8, 10].

Though roughness of roads on a homogeneous pavement section is a good measure of pavement condition, it does not directly identify the nature of distresses or their causes. The IRI is obtained using correlation formulas of Bump integrator and MERLIN as given in the Overseas Road Note No. 18 [16]. Calibration of the specific vehicle used for the roughness measurement was made against MERLIN. The calibration result is as attached in APPENDIX-C.

Benkelman deflection device, which is the least expensive of all other deflection devices, is used for the non-destructive structural evaluation of the pavement. This is a mechanical device that measures the maximum deflection of a road pavement under the dual rear wheels of a slowly moving loaded truck. The transport research laboratory (TRL) recommends the uses of a 63.2 KN rear axle load. A rear axle load of 80 or 100 KN is commonly used. The maximum deflection under a slowly moving wheel load is a good indicator of the overall strength of a pavement and has been shown to correlate well with long term performance of pavement under traffic.

The deflection test for this research purpose is measured between a single axle with dual wheels of the rear axle loaded at the legal load limit of Ethiopia, which is 10 Ton. Figure 3.2shows deflection measurement on Test Road No-5.

3.2.4. Distractive Pavement investigation

This investigation consists of Test Pit Excavation and subsequent DCP test on selected road sections that require further detail investigation on the sub-grade soil and the pavement material as well [6].

This investigation is employed to collect information about the in-situ pavement structure and sub grade CBR that eventually will help to observe any potential problem or cause of distress. Refer to Fig.3.4 & Fig. 3.5.

Figure 3.4 DCP Surveys on Test Road No 1

Figure 3.5 Test pit excavation on Test Road No 1

DCP is used for rapid measurement of unbound base, sub base and the in-situ sub-grade strength. Measurement can be made down to a depth of 800mm-1200mm. Where pavement layers have different strengths, the boundaries between them can be identified and the thickness of each layer estimated.

The principle of the DCP is to drop one given weight on a shaft and to record the corresponding length of penetration in the sub grade of one known cone found at the lower end of this shaft. The measurement to be recorded give the penetration length versus the number of the weight has been dropped (number of blows).

Correlations have been established between measurements with the DCP and the in-situ CBR so that the results of DCP measurements can be interpreted in terms of in-situ CBR. The correlation depends upon the weight and the size of the cone used during the measurements. The TRRL DCP with 8kg weight and 60^o cone with a 20 mm diameter was used for this research purpose [18].

3.2.5. Inspection and material testing

As damage unrelated to structural deficiency of pavement are in some cases caused by defective material and substandard workmanship, visual Inspection is made on AACRA's on going asphalt projects for checking of their actual construction and maintenance performance.

3.2.6 Data Analysis

The analysis consists of classification and quantification of distresses so as to identify causes of distress and propose possible maintenance options. The following steps are followed:

i) Classification of distresses

Classify the type of distresses into possible causes such as load associated, climate/durability associated and moisture/drainage associated distresses based on the results of the visual condition survey [3, 6].

ii) Identify Probable Cause of Pavement distress

The last stage in the data analysis is to establish causes of pavement distress by interpreting the data collected during the visual condition survey and other field investigations and testing [5,6].

(a) Analysis of Visual Distress Survey

- Quantify the existing distresses with relation to their severity for each test section.

- Calculate the PCI value for each test section and mean PCI for test road.
- Rate the overall condition of the pavement section using PCI scale.
- Classify the quantified distresses into their probable causes such as Load associated, material durability associated and drainage associated distresses.
- Quantity the most dominate distresses in the whole test roads.

(b) Analysis of Deflection test

- Measure the rebound pavement deflection at each test section
- Calculate the representative rebound deflection (RRD) for each kilometer distance.
- Rate the pavement condition based on the computed RRD value
- The RRD values can further be used to determine the structural adequacy of the pavement layer and the type of maintenance requirement as discussed in chapter 5.

(c) Analysis of DCP test

- Measure the penetration per blow for each unbound pavement layers and the sub grade.
- Determine the in-situ CBR values for each unbound pavement layers.
- Check if any weak layer exist that can cause structural failure.
- Evaluate the in-situ CBR values for each pavement layer against required standard values and identify the pavement layer, which is the cause of distress.

(d) Test pit investigation

- Obtain thickness of different pavement layers from the test pit excavation
- Extract sub grade soil samples for laboratory tests and comment their suitability.

- Check if any strong relationship exists between sub grade material quality and other pavement evaluation variables such as deflection, roughness and distresses quantified during visual surveys.
- Identify possible cause of distress from relationships of material quality variables, loads, distresses and pavement response variables.

(e) Roughness measurement and analysis

- Measure the bump count and covert to international roughness index (IRI) through appropriate calibration formula.
- Check the actual roughness against permissible values.
- Compare the roughness results with other pavement investigation results and tests to check if any relation ship exist that can give clue for cause of distress causes.

3.2.7 Limitations in the Data Collection

The whole Pavement Evaluation Data is collected in six months time, i.e. from April to December 2004. As a result all collected pavement performance data could only give accurate information during that time. On the other hand, some portion of the analysis such as determining predominant distresses in the network, developing functional Relationship between different pavement distresses, pavement response variables and material properties require long historical data and other details as noted below:

- Total service time of each Test Road
- Total load repetitions that the Test sections sustained until the time of investigation.
- Historical data of measured distresses categorized at different seasons of the year.
- Design details of each pavement structure and the sub grade material.
- Detail information regarding maintenance history of each test section.
- Seasonal data about moisture fluctuation on each test road.

Generally speaking, collection of the above relevant data would only be much easier on experimental test sections that are carefully made in such a way to reasonably model the road network under study. In view of such remarks, one can understand that the analysis and findings of this research could only be considered as an initial assessment that may serve as a springboard to further carry out detailed assessment within the Addis Ababa road network.

5. Distress Assessment and Evaluation on Addis Ababa Arterial Roads

4.1 Visual condition survey

The visual distress surveys were made on selected test sections following the methods as discussed in Section 3.2.1 above. Detail result of the visual survey is as shown below.

4.1.1. Calculating pavement condition index (PCI) on test road No.1

- The Visual survey for this test road is carried out from Beheretsige junction to Kaliti interchange, which is 3.9Km length.
- Thirteen homogeneous test blocks ranging form 288mts to 419mts length are surveyed. The minimum and maximum block PCI values are 12 and 64 respectively.
- The weighted average PCI value (i.e. considering area of pavement) for Test Road No. 1 is 34%, which can be rated as poor pavement surface.
- The detail PCI values for each block is as shown in Table 4.1

4.1.2. Calculating pavement condition index (PCI) on test road No.2

- This test road covers the section from Mexico Square to Old Airport and the visual survey is carried out on the whole chainage of 2.9Kms length.

- Nine homogenous test blocks having different length (ranging from 164mts to 400mts) are incorporated in this test road. The minimum and maximum block PCI values recorded in this test road are 15% and 37% respectively.
- The weighted average PCI value for test Road No.2 is 22% which can be rated as very poor pavement surface.
- The detail PCI values for each block is as shown in Table 4.1:

4.1.3. Calculating pavement condition index (PCI) on test road No.3

- This Test Road covers the section from St. Yohannis Church to General Winget School. A total of 3.9Kms length visual survey is performed within this section.
- Thirteen homogeneous test blocks ranging from 159mts to 397mts length are surveyed. The minimum and maximum Block PCI values are 28 and 65 respectively. The detail PCI values for each block are as shown in Table 4.1.
- The weighted average PCI value for Test Road No.3 is 47%, which can be rated as fair to good road surface.

4.1.4. Calculating pavement condition index (PCI) on test road No.4

- It covers the section form St Giorgis Church to Sheger Park. The visual survey is carried out on a 3.00Kms length of road.
- Nine homogeneous test blocks having length from 145mts to 490mts are incorporated in the visual survey. The minimum and maximum block PCI values are 38 and 69 respectively. The detail PCI values for each test block are as shown in Table 4.1.
- The weighted average PCI value for Test Road No. 4 is 57% which can be rated as good pavement surface.

4.1.5. Calculating pavement condition index (PCI) on test road No.5

- This test road covers the road from Kebena (Aware junction) to Megenagna and the visual survey is carried out on 3.7Kms length within this stretch.
- Eleven homogeneous test blocks having length from 230mts to 443mts are surveyed and the minimum and maximum block PCI values are 13% and 47 respectively. The detail PCI values for each test block are as shown in Table 4.1.

- The weighted average PCI values for Test Road No. 5 is 24% which can be rated as very poor pavement surface.

Table 4.1 PCI values for Test Roads

Test Road No.1		Test Road No.2		Test Road No.3		Test Road No.4		Test Road No.5	
Block No	**PCI**	**Block No**	**PCI**	**Block No**	**PCI**	**Block No**	**PCI**	**Block No**	**PCI**
5	18	1	19	6	65	2	67	5*	15
6	29	2	37	7	59	3	69	6*	13
7	19	3	17	8	60	4	49	1	16
8	12	4	15	9	52	5	56	2	29
9	20	5	19	10	45	6	55	3	30
10	22	6	20	11	44	7	63	4	30
11	44	7	17	12	50	8	62	5	20
12	35	8	22	13	52	9	45	6	30
13	50	9	28	14	42	10	38	7	20
14	64			15	28			8	14
15	54			16	35			9	47
16	36			17	40				
17	35			18	42				

* These block numbers are end chainage of the preceding road number

4.1.6 Identifying Dominant Distresses

It is also tried to estimate the distribution of particular distresses in each test section and the whole test roads as well using the visual survey data. Distribution of major distresses in all test roads is as shown in Table 4.2 & Figure 4.1. Details about intensity of individual distress densities on each test section can be referred in Appendix A-2 to A-6. Accordingly it is observed that around seven types of distresses contribute more than 95% of the pavement defects in the five arterial Test Roads. They are:-

1. Weathering & Raveling : 54.29%
2. Corrugation : 12.68%
3. Bumps & Sags : 9.25%
4. Lane/Shoulder Drop-off : 7.34%
5. Patch & Utility Cut Patching : 6.1%
6. Shoving : 4.39%
7. Alligator Cracking : 3.84%

Total : 95.89%

The main reason for some distresses like alligator cracking to be ranked low is due to the fact that the Addis Ababa City Roads Authority usually patches cracked asphalt pavements immediately after the rainy seasons.

Table 4.2 Distribution of Pavement Distress in the five test Roads

Distress No	Distress Type	Total Distress Density	%age Distress Indicator
1	Alligator Cracking	69.86	3.84
2	Bleeding	15.20	0.84
4	Bumps & Sags	168.32	9.25
5	Corrugation	230.78	12.68
6	Depression	19.22	1.06
7	Edge Cracking	1.26	0.07
9	Lane/Shoulder Drop off	133.50	7.34
10	Longitudinal/Transversal Cracking	2.72	0.15
11	Patching & Utility Cut Patching	110.92	6.10
16	Shoving	79.85	4.39
19	Weathering & Raveling	987.96	54.29
Total		1819.593	100.0

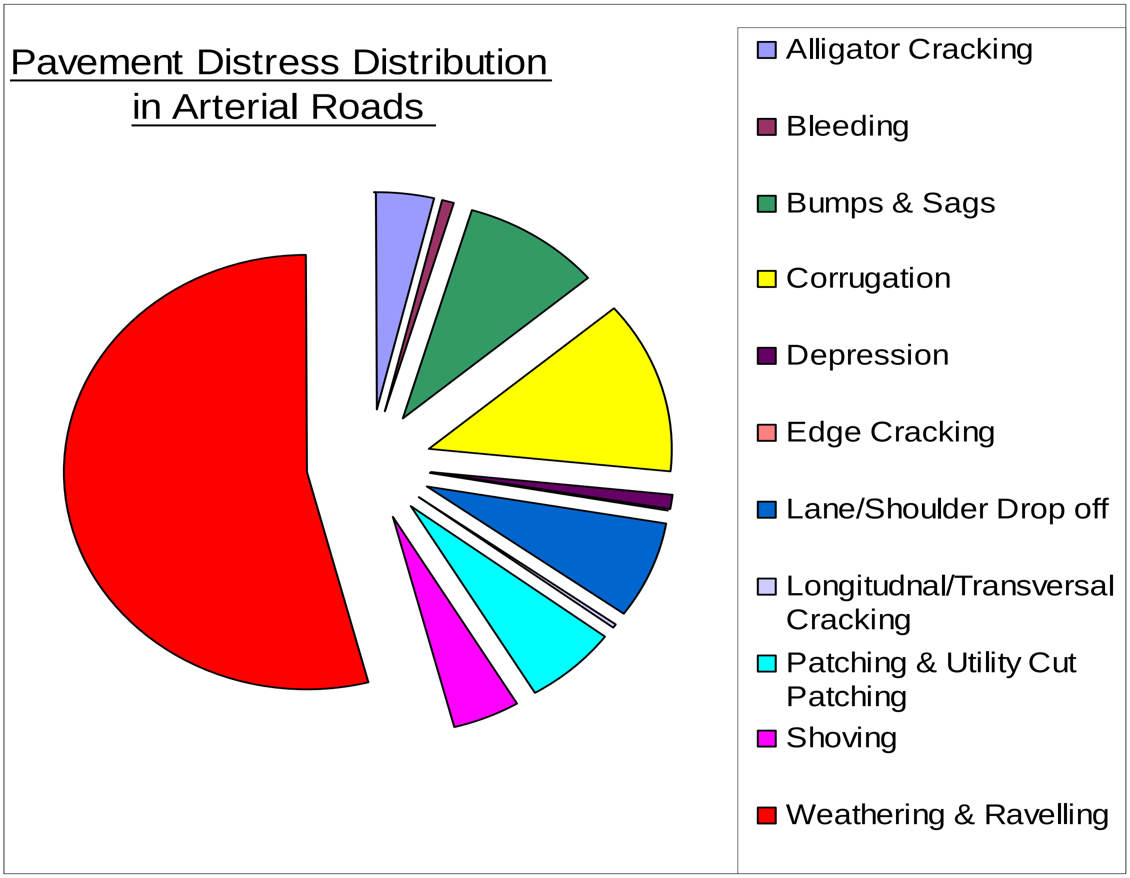


Figure 4.1 Pavement Distress Distributions in the Five Test Roads

4.1.7 Classification of Distresses by possible Causes

Distresses whose extent and severity already measured during the visual survey can further be classified in to the following three major groups as classified in Section 2.1.4:

1. Load associated distresses
2. Climate or durability associated distresses
3. Moisture or drainage associated distresses

Each recorded distress during the visual survey can be rated as follows by considering the deduct values for each test block. A sample of visual condition survey data from Test Road No1, Block No5 (refer APPENDIX A-1) is used for computing the probable causes as shown in Table 4.3 below:

Table 4.3 computing magnitude of probable causes

(Distress No)Distress type	Distress Density	Severity Level	Deduct value	Probable cause
(9) Lane/ shoulder drop off	3.87	H	16	Drainage
(1) Alligator cracking	6.80	M	40	Load
(19) Weathering & raveling	26.30	M	28	Climate/Durability
(4) Bumps & sags	1.27	M	26	Drainage
(11) Patch	11.40	M	33	Load
(16) Shoving	4.16	M	22	Climate/Durability
Total deduct value			**165**	**All causes**

The magnitude of distresses associated with each probable cause can be computed as follows:

Load associated Distress $= \frac{(40 + 33)}{165} \times 100 = 44.2\%$

Climate/durability associated distress $= \frac{(28 + 22)}{165} \times 100 = 30.3\%$

Moisture/ drainage associated distress $= \frac{(16 + 26)}{165} \times 100 = 25.5\%$

The same kind of computation is made for the remaining blocks of Test Road No.1 and others. The results for the remaining blocks are as shown in Table 4.4 below:

Table 4.4 Classification of Distress by Possible Causes

Road & Block No	***% age defects attributable to***		
Test Road No.1	**Load**	**Climate/ durability**	**Moisture /Drainage**
Block 5	44.2	30.3	25.5
Block 6	20	33.3	46.7
Block 7	49.7	12.6	37.7
Block 8	38.3	42.5	19.2
Block 9	30.8	15.7	53.5
Block 10	47.4	16	36.6
Block 11	29.3	32.8	37.9
Block 12	24	24	52
Block 13	0	24.4	75.6
Block 14	0	47.3	52.7
Block 15	41.7	22.9	35.4
Block 16	12.2	29.8	58
Block 17	0	25.5	74.5

Mean **26** **27.5** **46.5**

Road & Block No	*% age defects attributable to*		
Test Road No.2	**Load**	**Climate/ durability**	**Moisture /Drainage**
Block 1	48.9	29.8	21.3
Block 2	46.6	19.8	33.6
Block 3	48.0	28.6	23.4
Block 4	50.3	34.5	15.2
Block 5	65.8	26.3	7.9
Block 6	71.4	19.1	9.5
Block 7	4.8	50.6	44.6
Block 8	11.1	53.6	35.3
Block 9	25	28.4	46.6
Mean	**41.3**	**32.3**	**26.4**

Road & Block No	*% age defects attributable to*		
Test Road No.3	**Load**	**Climate/ durability**	**Moisture /Drainage**
Block 6	64.3	35.7	0
Block 7	72.6	27.4	0
Block 8	66.7	33.3	0
Block 9	40.8	59.20	0
Block 10	50.5	49.50	0
Block 11	0	47.7	52.3
Block 12	0	30.80	69.2
Block 13	0	29.6	70.6
Block 14	33.3	27.5	39.2
Block 15	29.1	17.3	53.6
Block 16	26.9	30.6	42.5
Block 17	16.4	41.00	42.6
Block 18	31.5	30.3	38.2
Mean	**33.2**	**35.4**	**31.4**

Road & Block No	*% age defects attributable to*		
Test Road No.4	**Load**	**Climate/ durability**	**Moisture /Drainage**
Block 2	81.1	18.9	0
Block 3	63.5	36.5	0
Block 4	62.9	37.1	0
Block 5	71.80	28.20	0
Block 6	66.70	33.33	0
Block 7	58.60	41.4	0
Block 8	56.60	43.40	0
Block 9	34.90	65.10	0
Block 10	35.00	65.00	0
Mean	**59**	**41**	**0**

Road & Block No	***% age Defects attributable to***		
Test Road No.5	**Load**	**Climate/ durability**	**Moisture /Drainage**
Block No 50:5	72.5	0	27.5
Block No 50:6	27	11.8	68.20
Block No 60:1	58.3	2.20	39.50
Block No 60:2	34.20	0.00	65.80
Block No 60:3	49.30	0	50.70
Block No 60:4	69	0	30.60
Block No 60:5	35	7.60	57.60
Block No 60:6	28	8.50	64.00
Block No 60:7	0.0	16.60	83.40
Block No 60:8	4.3	0	95.70
Block No 60:9	10	12.6	76.60
Mean	**35.0**	**5.0**	**60.0**
Mean (all test roads)	**38.9**	**28.2**	**32.9**

The visual condition survey results can be summarized identifying the probable dominant cause of distress as shown in Table 4.5 below:

Table 4.5 Mean Pavement Condition Index for Test Roads

Test road no	Description	Dominant Cause of Distress	PCI
1	St Yosef Church to Kality interchange	Moisture & Drainage	34%
2	Mexico sq.-Oldairport	Load associated	22%
3	St Yohannis Church to Winget	Climate & durability	47%
4	St Giorgis Church to Sheger Park	Load associated	57%
5	Kebena toMegenagna	Moisture & drainage	24%

The three test roads (No.1, 2 & 5) shows serious reduction in PCI value and moisture/drainage associated distresses are dominant within these test sections.

4.2 Roughness Surveys

The pavement roughness is measured using International Roughness Index (IRI) which is a standard method of measuring road roughness. Details are as shown in APPENDIX B-1 to B-5.The mean IRI values for each Test Road is as follows:

Table 4.6 Mean Roughness values for Test Roads

Test Road No.	Description	Mean IRI(m/km)
1	St Yosef Church to Kality Interchange	4.3
2	Mexico Sq.to Old airport	7.2
3	St Yohannis Church to Winget	3.9
4	St Giorgis Church to Sheger Park	3.6

5	Kebena to Meganagna	5.8

As indicated in APPENDIX B, the roughness values for all test roads are high and beyond bad limit particularly on test roads No. 2 & 5showing that these pavement sections are at a poor functional level or ride quality.

4.3 Structural Pavement Evaluation

The structural pavement evaluation is made using both destructive and non-distractive techniques as follows:

4.3.1 Non destructive Structural Evaluation

The Nondestructive Pavement deflection measurement was carried out using the Benkelman beam for each road section. When the deflection tests on each pavement section are completed, the recorded pavement rebound deflections are used to determine RRD (Representative Rebound Deflection) for a section.

The details of Benkelman deflection measurements on the five test roads are as shown in APPENDIX-D. The mean RRD values for each Test Road are asshown in Table 4.7 below:

Table 4.7 Mean Representative Rebound Deflection Values for Test Roads

Test Road No.	Description	Mean RRD (X0.01 mm)	Structural Condition
1	St Yosef Church to Kality Interchange	122	bad
2	Mexico Sq.to Oldairport	127	bad
3	St Yohannis Church to Winget	40.7	good
4	St Giorgis Church to Sheger Park	57	good
5	Kebena to Meganagna	132	bad

The results of the three Test Roads (i.e. No-1, 2 & 5) fall within the bad limit, by considering an RRD value of 80 as the maximum limit for fair pavement structure following ERA's policy.

4.3.2. Destructive Structural Evaluation

TRRL DCP with 8kg weight and 60^0 cone with a 20mm diameter are used. The DCP tests are conducted on few selected sections (of Test Roads No-1, 3 & 5) exhibiting severe functional/structural distresses and some sections that show a relatively good pavement condition. Results are as plotted in APPENDIX-E .The TRRL empirical formula is used for data interpretation and calculation of the in-situ CBR from DCP tests.

The DCP test results (mm/blow) and converted CBR values on those test sections exhibiting high deflection confirm that the unbound pavement layers underneath the bituminous surfacing have low CBR values which are below acceptable standards. Hence such layers are more susceptible to shear failure, which subsequently will be causes of pavement deterioration. In some cases there exists a layer of poor quality sandwiched between two layers of appreciable quality. This could also be cause of high deflection on the asphalt surfacing. Soil samples on selected locations are also retrieved for further soil identification in laboratory. CBR and swell tests were conducted.

The CBR values of the crushed stone base and other bottom layers are as shown in Table 4.4 below. As observed from the DCP test results, the majority of pavement sections showing low PCI values do have a base material of inferior quality with regard to bearing value. This indicates that structural inadequacy of the pavement structure has resulted in most cases due to poor base material underneath the asphalt layer. The test pit logging details also clearly confirm that there is sandwiched poor gravel material below the asphalt surface layer or otherwise between the old and new asphalt layers (refer Appendix E-7 to E-9).

Table 4.8 DCP Survey and Analysis

Test Road N0	**Test Chainage**	**Layer CBR Value**	**Remark**
1	0+300 (PCI =18%)	Layer 3 : 57%	Poor bearing base material

		Layer 4 : 111%	at layer 3
		Layer 5 : 12%	
	0+600 (PCI =29%)	Layer 2 : 157%	All layers have material of acceptable bearing value
		Layer 3 : 7%	
	2+700 (PCI =13%)	Layer 2 : 75%	There exists sandwiched poor gravel between the old and new asphalt (Refer Appendix E-2)
		Layer 3 : 42%	
		Layer 4 : 15%	
		Layer 5 : 21%	
	3+100 (PCI = 14%)	Layer 2 : 68%	Poor bearing base material at layer 2
		Layer 3 : 145%	
		Layer 4 : 31%	
		Layer 5 : 12%	
3	0+300 (PCI = 65%)	Layer 3 : 73%	All layers have material of acceptable bearing value
		Layer 4 : 9%	
	0+600 (PCI = 59%)	Layer 3 : 145%	All layers have material of acceptable bearing value
		Layer 4 : 14%	
		Layer 5 : 5%	
	3+000 (PCI = 28%)	Layer 2 : 80%	All layers have material of acceptable bearing value
		Layer 3 : 75%	
		Layer 4 : 11%	
		Layer 5 : 18%	
	3+300 (PCI =35%)	Layer 2 : 49%	poor bearing base material at layer 2
		Layer 3 : 75%	
		Layer 4 : 5%	
5	0+600 (PCI = 13%)	Layer 2 : 28%	Poor bearing base material at layer 2
		Layer 3 : 216%	
		Layer 4 : 267%	
	0+900 (PCI = 16%)	Layer 2 : 338%	All layers have material of acceptable bearing value
	1+500 (PCI = 30%)	Layer 2 : 62%	Poor bearing base material at layer 2
		Layer 3 : 133%	
		Layer 4 : 9%	
	1+800 (PCI = 30%)	Layer 1 : 72%	Poor bearing base material at layer 2
		Layer 2 : 39%	
		Layer 3 : 95%	
		layer 4 : 9%	

4.4 Relationship of Different Pavement Response Variables

Results of pavement evaluations performed on different test roads and test sections are as summarized in Table 4.9 on next pages. As already discussed in the preceding sections, each method of evaluation stands on its own merit by indicating the pavement performance and / or identifying the probable cause of distress.

In this section, a statistical analysis is made to further check whether the different performance variables within test roads are associated with each other. For instance, what is the association between sub grade CBR and PCI? Does one depend on the other, or are they unrelated? Such situations are examined by observing the relationship of each pavement response variable from the trend of least square curves.

The correlation between different pavement evaluation results were made considering major causes of pavement failure due to possible effects of:-

a) Sub grade soil type
b) Pavement structure
c) Drainage Condition
d) Traffic loading

The relationship of different distress densities with the overall pavement condition (PCI), deflection and roughness is also checked. The pavement Response Variable interaction and values of the correlation coefficient r for the whole test sections are as tabulated in Table 4.10.

It has to be clear that functional relationships between pavement responses variables at a network level could only be obtained after carrying out a number of tests at different season within a longer period as indicated in Section 3.2.7. The test sections for developing such functional relationships should also be designated in such a way that they can reasonably model the whole network. Consequently, it is only tried here to check the relationship among distresses, different pavement response variables and some pavement material properties in order to get some clues on the cause of pavement distress which can serve as a supplementary feedback for the already conducted functional and structural evaluations.

Table 4.9 Summary of Pavement Evaluation Data for Test Roads

Test Road No	TEST Chainage (Km+mt)	PCI (%)	Deflection x0.01mm	Sub grade Lab. CBR	Adjusted Roughness (IRI)	Swell (%)	Drainage condition	Equivalent single Axle Load Per Day	Weathering & Raveling Density (%)	Corrugation Density (%)	Bumps & Sags Density (%)	Lane/ shoulder drop-off	Base CBR (DCP)	Sub Base CBR (DCP)	Sub grade CBR (DCP)	Asphalt thickness in mm (DCP)
1	300	18	96	3	4.3	4.88	4	1764	26.3	0	1.27	3.87	57	100	12	18
1	600	29	94	3	3.6	5.21	4	1764	37.3	0	4.36	4.36	100		7	15
1	900	19	120	2	5.2	5.25	5	1764	0	0	3.21	3.57				
1	1200	12	140	3	6.8	5.99	5	1764	31.2	23.2	0	1.78				
1	1500	20	134	3	6.3	5.4	5	1764	31.4	8.5	3.46	4.23				
1	1800	22	124	3	5.1	5.4	4	1764	30.6	24.52	1.55	4.36				
1	2100	44	76	2	3.7	6.84	3	1764	34.3	3.64	3.8	3.95				
1	2400	35	70	4	3.6	2.2	3	1764	32.3	0	4.36	4.36				
1	2700	50	34	4	3.1	1.85	3	1764	14.3	0	4.35	4.36	75	28	21	18
1	3000	64	106	4	4.1	0.97	3	1764	15.15	0	4.07	0.56	68	88	12	15
1	3300	54	98	3	3.9	3.89	5	1764	5.08	0	5.08	2.97				
1	3600	36	70	3	4.2	4.09	5	1764	30.3	0	5.55	5.55				
1	3900	35	30	3	4.4	3.61	5	1764	26.77	0	5.08	0				
2	150	19	66	3	10.3		3	1422	0	0	1.73	0				
2	450	37	96	28	8.6		3	1422	4.43	0	4.07	0				
2	750	17	56	4	9.4		4	1422	30	0	2.43	0				
2	1050	15	88	21	8.1		4	1422	37.7	18.2	1.27	0				
2	1350	19	164	5	7.2		4	1422	32.3	14.9	0	0				
2	1650	20	52	7	6.5		5	1422	26.7	23.2	0.53	0				
2	1750	17	106	6	5.4		5	1422	42.51	0	4.07	0				
2	2250	22	114	13	5.8		5	1422	57.7	0	5.2	0.35				
2	2361	28	104		5.9		5	1422	66.7	0	5.08	0				
3	150	65	36	5	5	1.54	2	971	11.8	0	1.74	0				
3	450	59	42	7	3.9	0.49	2	971	6.02	0	0.73	0	73		9	20
3	750	59	30	7	4.2		2	971	6.02	0	0.73	0	100	14	5	15
3	1050	60	34	7	2.5		2	971	11.25	0	2.2	0				
3	1350	52	28	7	3.5		2	971	18	0	1.81	0				
3	1450	45	50	**7**	3.4		3	971	18.2	0	2.7	0.33				
3	1650	44	86	7	3.7		3	971	18.2	0	2.65	0.63				
3	1950	50	46	7	3.5		4	971	18.2	0	2.7	0				
3	2250	52	70	7	3.8		4	971	8.55	0	1.4	0.2				
3	2550	52	80	6	4.1		4	971	8.55	0	1.4	0.2				

Test Road No	TEST Chainage (Km+mt)	PCI (%)	Deflection x0.01mm	Sub grade Lab. CBR	Adjusted Roughness (IRI)	Swell (%)	Drainage condition	Equivalent single Axle Load Per Day	Weathering & Raveling Density (%)	Corrugation Density (%)	Bumps & Sags Density (%)	Lane/ shoulder drop-off	Base CBR (DCP)	Sub Base CBR (DCP)	Sub grade CBR (DCP)	Asphalt thickness in mm (DCP)
3	2850	42	80	**6**	4.4		4	971	18.32	4.12	2.03	0				
3	3050	28	**77**	6	3.5		5	971	16.17	2.03	2.43	0	80	43	18	15
3	3350	35	72	6	4		5	971	19.27	2.06	2.28	1	49	75	5	15
3	3650	40	65	6	3.9		5	971	18.22	0	2.23	0				
3	3950	42	90	6	3.9		5	971	18.2	3.6	2.33	0				
4	150	67	48	17	5.1		2	1701	2.5	0	1.8	0				
4	450	69	47	15	4		2	1701	11.3	0	1.4	0				
4	750	59	37	12	3.1		2	1701	14.14	0	0.55	0				
4	850	49	70	9	3.1		2	1701	10	0	0.76	0				
4	950	56	42	12	3.2		2	1701	5	0	0.38	0				
4	1050	56	62	12	3.1		2	1701	5	0	0.38	0				
4	1350	56	38	12	3.1		2	1701	10	0	0.85	0				
4	1650	55	57	4	3.1		2	1701	10	0	0.85	0				
4	1950	63	30	17	3.7		3	1701	20	0	1.7	0				
4	2250	62	38	8	3.7		3	1701	17.3	0	0.75	0				
4	2550	52	34	10	4.4		3	1701	9.15	0	1.25	0				
4	2650	45	28	13	3.8		3	1701	9.15	0	2.5	0				
4	2950	41	35	8	3.3		3	1701	20	0	2.2	0				
5	300	15	76	13	10	1.14	4	1909	0	34.72	2.33	7.16				
5	600	13	106	4	5.2	3.91	4	1909	0	1.61	7.38	5.9	28	100		15
5	900	16	136	13	6.7	1.79	4	1909	6.38	29.08	3.19	6.37	100	100		12
5	1200	29	124	10	8.1	1.9	5	1909	0	0	2.62	25				
5	1500	30	86	1	7.6	6.32	5	1909	0	16.2	4.94	6.14	62	100	9	10
5	1800	30	90	14	5.7	0.50	5	1909	0	12.1	1.6	4.9	72	67	9	15
5	2100	20	88	9	7.7	2.29	5	1909	2.8	0	3.05	3.35				
5	2400	20	116	2	5.6	6.93	5	1909	2.8	0	3.05	3.35				
5	2700	30	114	2	4.1	5.93	5	1909	4.1	3.3	7.8	6.7				
5	3000	20	90	11	3.6	0.85	5	1909	0	0	7.6	7.2				
5	3300	14	108	2	5.6	6.55	5	1909	0	5.8	4.7	5.9				
5	3600	47	80	2	3.9	5.06	5	1909	0	0	4.8	4.9				
5	3900				2.4				0							

Table 4.10 Relationship between Pavement Response Variables & Distresses

(Values of correlation coefficient r)

Vs	Swell	CBR	Drainage Condition	ESA	Asphalt thickness in mm (DCP)	Base CBR (DCP)	Sub grade CBR (DCP)	PCI	Deflection	Roughness	Weathering & Raveling	Corrugation	Bumps & Sags	Lane/ Shoulder Drop- off
Swell	1	-0.767	**	**	**	**	**	-0.343	+0.389	-0.063	+0.271	-0.002	+0.133	**
Sub grade Lab CBR		1	**	**	**	**	**	+0.096	-0.229	+0.361	+0.0103	+0.005	+0.062	**
Drainage Condition			1	**	**	**	**	-0.908	+0.979	+0.532	+0.712	+0.637	+0.893	+0.999
ESA				1	**	**	**	-0.319	+0.402	+0.185	-0.302	+0.509	+0.528	**
Asphalt thickness in mm (DCP)					1	**	**	+0.375	-0.52	-0.764	+0.287	-0.69	-0.34	**
Base CBR (DCP)						1	**	+0.268	-0.131	-0.093	+0.243	+0.249	-0.411	**
Sub grade CBR (DCP)							1	+0.024	-0.095	-0.334	+0.048	-0.161	+0.31	**
PCI								1	-0.684	-0.641	-0.229	-0.495	-0.327	-0.368
Deflection									1	+0.428	+0.17	+0.402	+0.301	+0.433
Roughness										1	+0.026	+0.507	+0.024	+0.287
Weathering & Raveling											1	+0.055	+0.044	-0.257
Corrugation												1	-0.159	+0.192
Bumps & Sags													1	+0.384
Lane/ Shoulder Drop- off														1

(**) Variables considered to have no significant relationship

The detail relationship is graphically shown in Figure 4.2 to 4.6

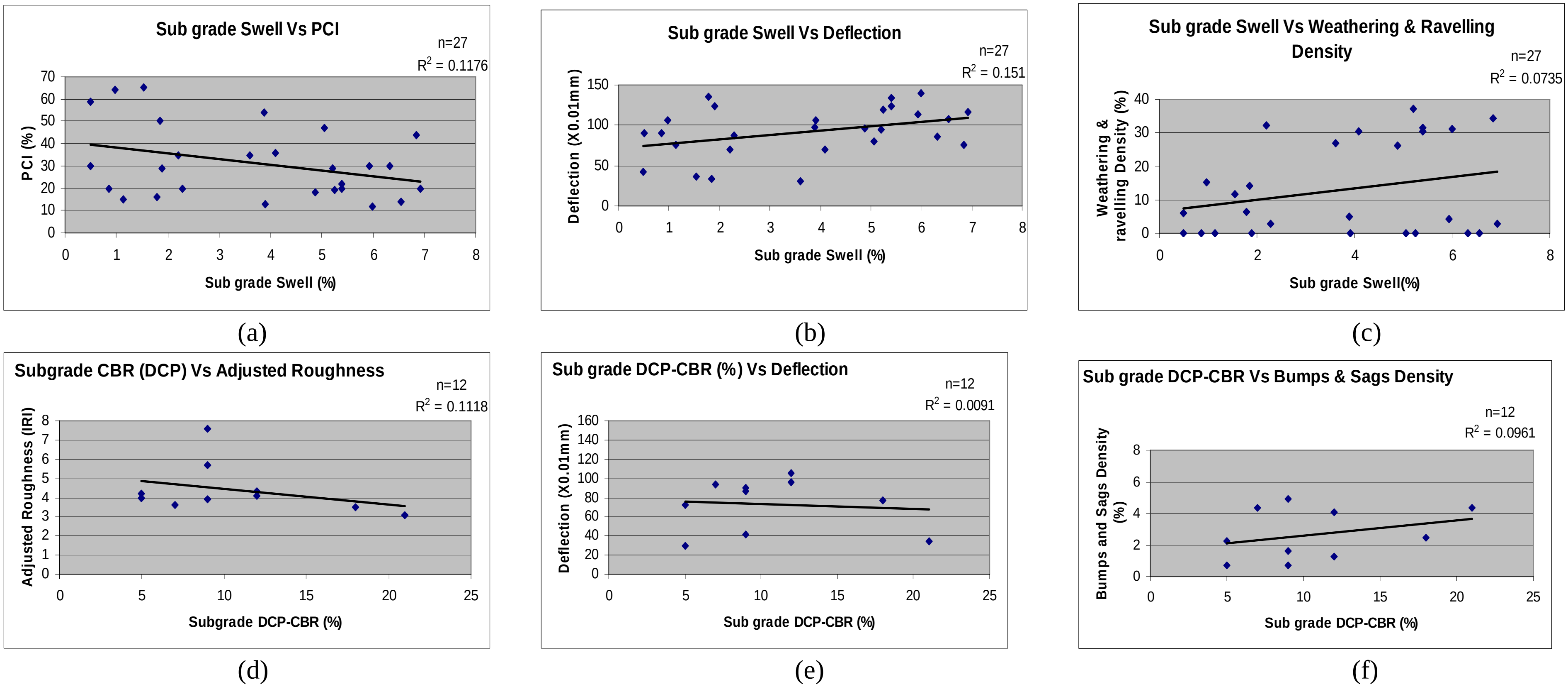


Fig 4.2 Possible effects of sub grade soil properties on Distress Densities PCI, Roughness and Deflection

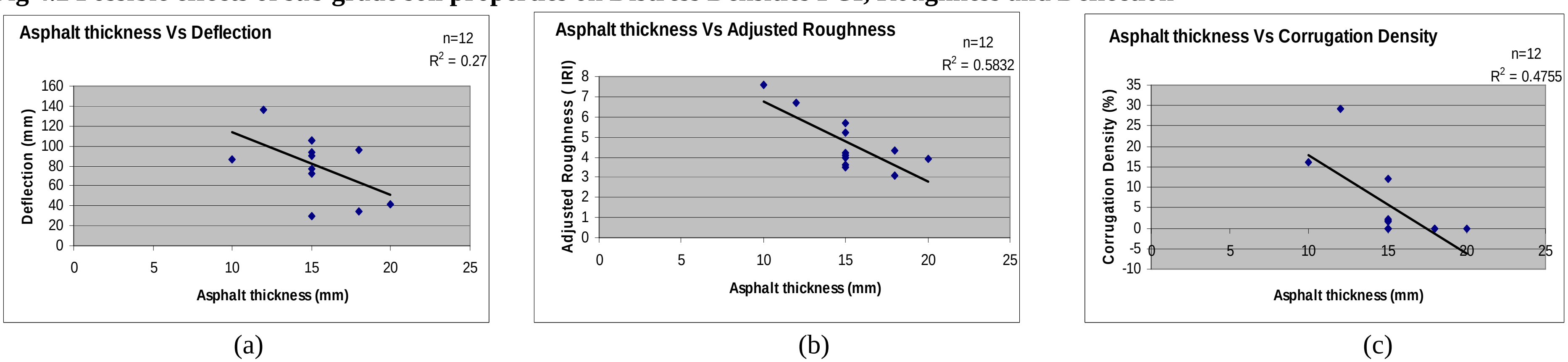
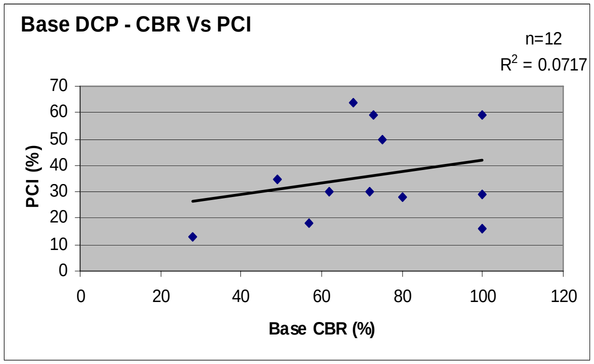
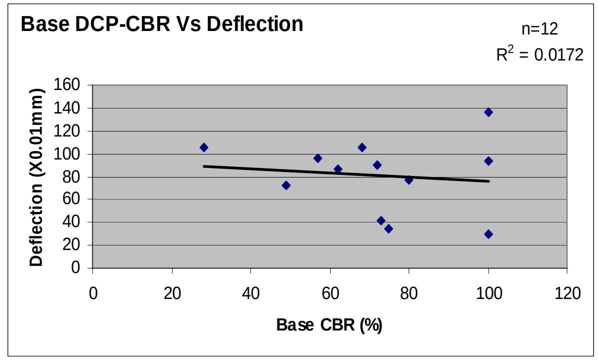


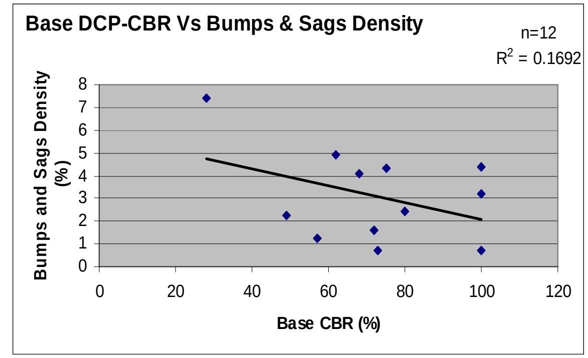
Fig 4.3 Possible effects of Pavement Structure on Distress Densities PCI, Roughness and Deflection



(d)

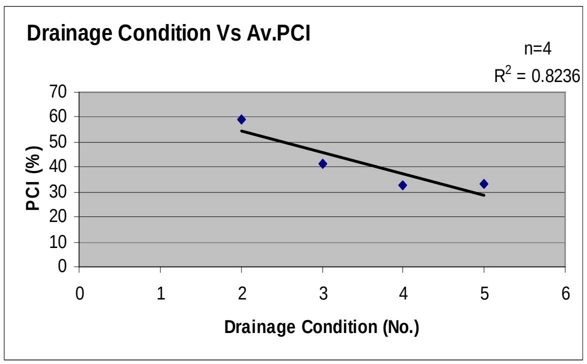


(e)

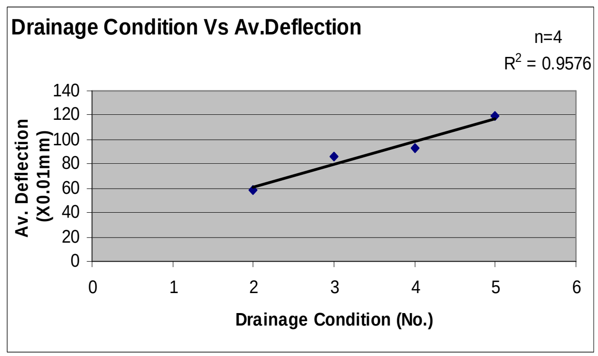


(f)

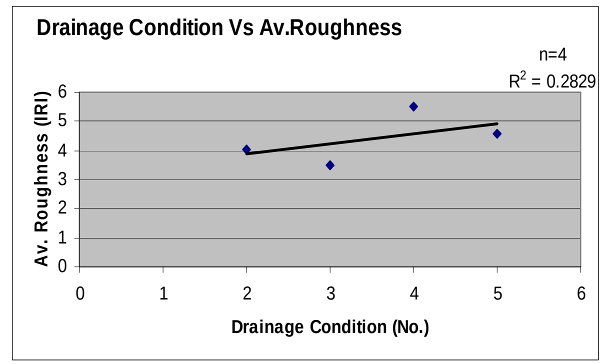
Fig 4.3 Possible effects of Pavement Structure on Distress Densities, PCI, Roughness and Deflection (continued)



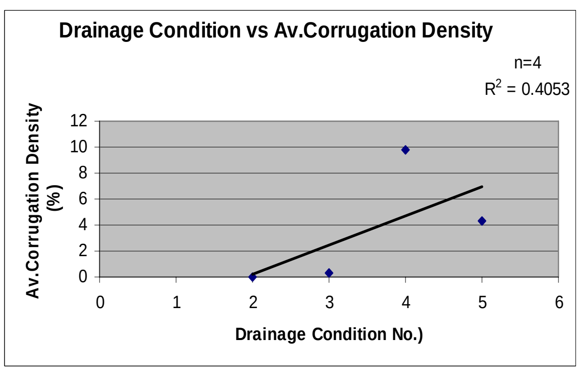
(a)



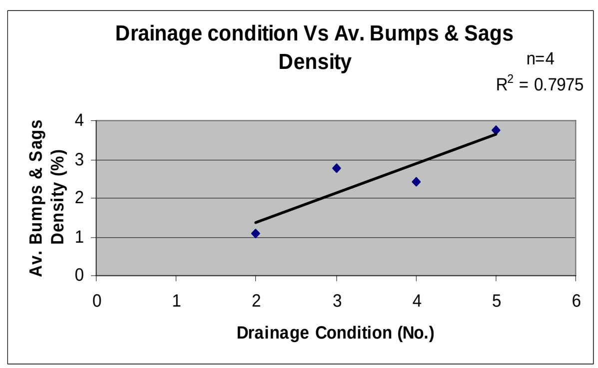
(b)



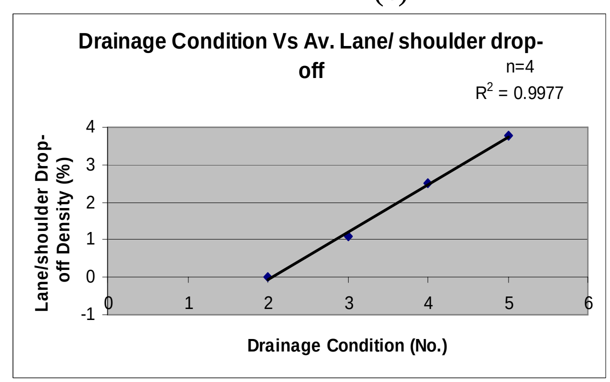
(c)



(d)

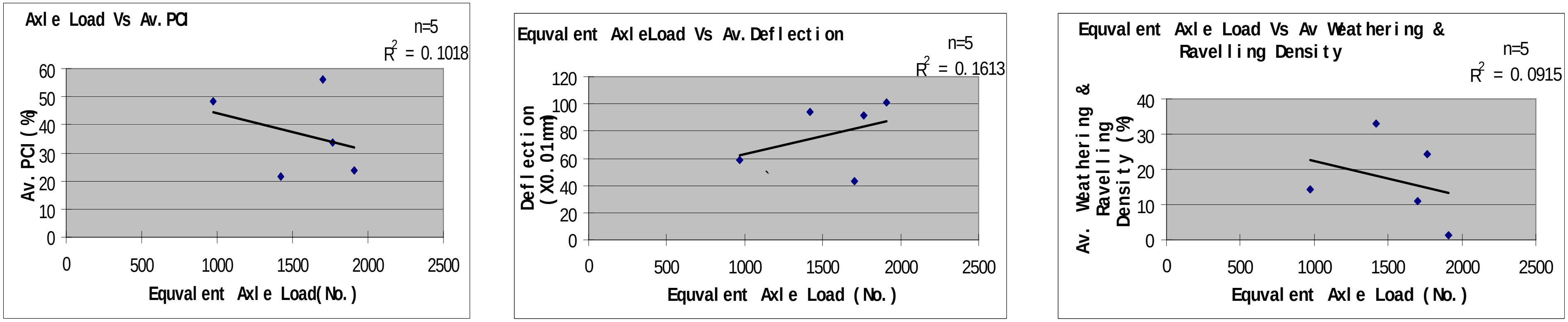


(e)



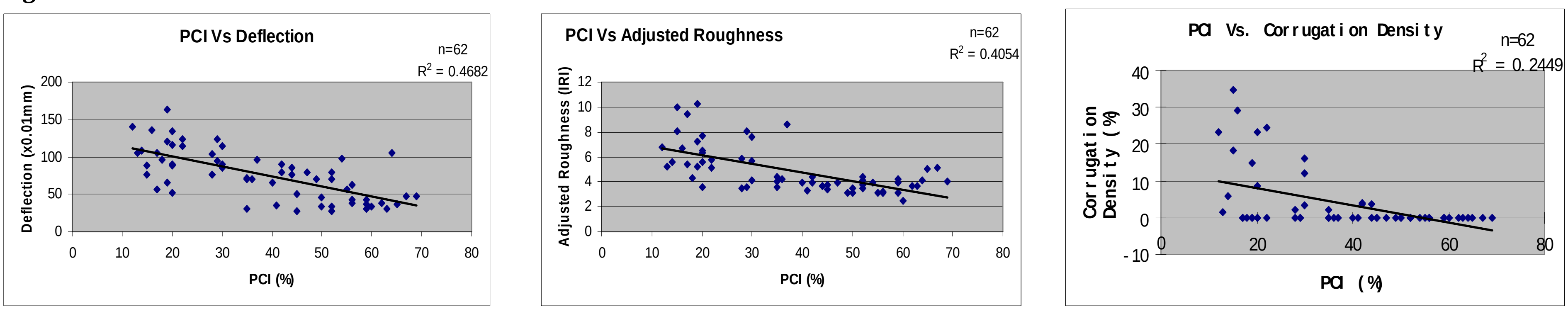
(f)

Fig 4.4 Possible effects of Drainage Condition on Distress Densities PCI, Roughness and Deflection

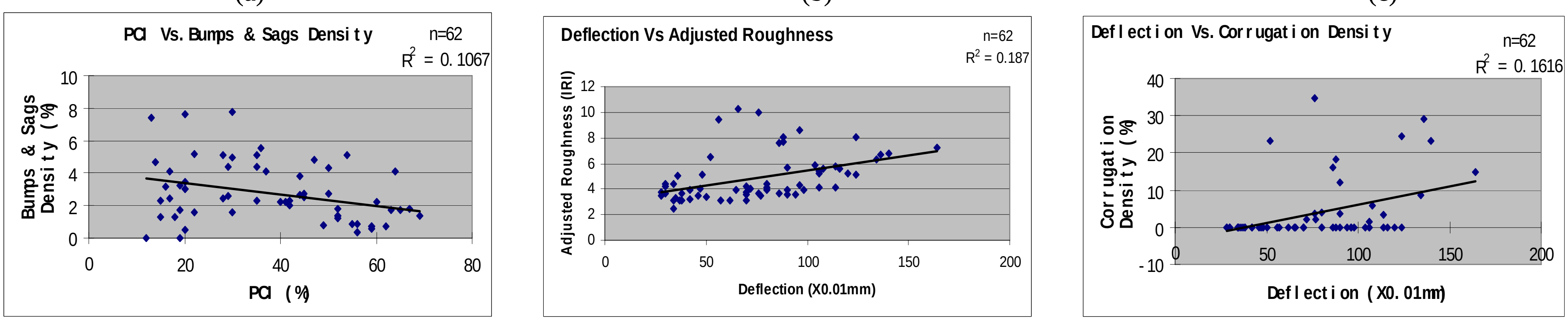


(a) (b) (c)

Fig 4.5 Possible effects of Axle Load on Distress Densities PCI and Deflection



(a) (b) (c)



(d) (e) (f)

Fig 4.6 Relationship of PCI, Deflection, Roughness and Distress Densities (continued)

The detail computational results of the correlations and the list square curves for major interaction combination are already shown in Figure 4.2 to Figure 4.6. The following observations are made from the trend of the charts and values of the correlation coefficient:

General:

- Each pavement response variable, test results and distress intensities are more or less interdependent with one another at a significant degree of confidence. As shown from the trend of the curves, the relationship of some interactions specially for those related with drainage condition; swell verses PCI and deflection; axle load verses PCI, deflection and different distresses particularly with corrugation and bumps; PCI verses Deflection; asphalt thickness verses roughness and corrugation. Strong relationship is also observed among different pavement response variables like PCI, deflection, roughness and distress densities.
- The values of the correlation coefficient would certainly be increased had a higher order polynomials or other functions been used in the regression analysis. But, it was not tried to do so as it is not the aim of this research to develop functional relationships between different pavement performance variables and test results.
- As indicated in Table 4.10, the relationship between swell verses roughness/corrugation; sub grade laboratory CBR verses roughness, raveling, corrugation and bumps; axle load verses raveling ; raveling versus shoulder drop-off; and corrugation verses bumps show a relationship which is contrary to expected theoretical concepts. This could be due to other governing factors like differences in traffic level, drainage condition, pavement structure, pavement material qualities and construction and maintenance history of each test road.

Possible effect of sub grade soil properties on pavement distress:

- The swell potential of the sub grade soil has significant impact on the pavement Condition Index (PCI) and the Deflection results. This can be observed from Figure 4.2(a) and (b). This shows that the higher the swell value the lower the PCI and the higher the deflection of the pavement structure.
- Weathering and raveling which is the most dominant distress during the time of condition survey is also observed to have significant relationship with the swell potential. It is observed that the weathering and raveling distress density increases directly proportional with the swelling value of the sub grade soil. On the other hand it is observed that the effect of swell on other distresses is comparatively lower and in some cases insignificant like for corrugation.
- The sub grade in-situ CBR value which is an indicator of the bearing strength, even though no strong relationship was also observed to have an inverse relations with the roughness IRI value and deflection values. This is depicted in Figure 4.2(d) and (e). From this one can deduce that the visually observed distresses (and the reduction in the structural adequacy of the test roads as well) are also contributed by the inadequacies in the sub grade bearing capacity. On the other hand, the sub grade in-situ CBR was observed to have no proper relationship with corrugation following theoretical aspects. This could be mainly due to the influence of other factors that can affect the in-situ CBR value like drainage conditions.

Possible effect of Pavement Structure on pavement distress:

- It can be observed from Figure 4.3 (a) and (b) that the asphalt thickness has a significant inverse relationship with deflection and roughness (IRI) values. In a similar manner, individual distresses like corrugation and bumps increase with a reduction in asphalt thickness.

- Though the relationship is not so strong, it is observed from Table 4.10 and Figure 4.3 (d) that the pavement condition (expressed in PCI) has direct relationship with in-situ base course CBR. It can also be observed from the trend of the chart that the lower the base CBR the worst is the pavement condition and the higher the intensity of distress density of bumps.

Possible effect of drainage condition on pavement distress:

- It is observed from the values of the trend of the curves of Figure 4.4 (a) to (f) that drainage condition on the test roads has strong relationship with the pavement condition (expressed as PCI),the structural adequacy of the pavement (expressed in terms of the deflection values) and on intensities of individual distresses as well . Hence, pavement drainage can be considered to have significant impact, than any other cause, to affect PCI, deflection and intensities of individual distresses particularly corrugations, bumps and shoulder drop-off values.

Possible effect of Axle loading on pavement distress:

- Even though no survey of axle load is made for this research purpose, it is tried to utilize AACRA's existing traffic data and correlate it with PCI, deflection, and dominant distresses. Figure 4.5 (a) and (b) shows that traffic load has strong direct relationship with deflection and the roughness IRI values which consequently resulted in reduction of the overall pavement condition expressed with PCI.

- As indicated in Table 4.10, the intensity of distress densities for corrugation and bumps is also observed to have direct relation with the magnitude of axle loading. Hence, this could give a clue that overstressing of the pavement structure also aggravates the visible corrugations and bumps.

- On the other hand the effect of axle loading on weathering and raveling distress density was observed to be contrary to expected theoretical concepts. This could be due to effect of causes other than loading like asphalt mix quality, oil spillage, construction deficiencies and other non-measured factors.

Relationship of PCI, Deflection, Roughness and Distress Densities:

- As indicated in the relationship of the pavement response variables with each other in Figure 4.6 (a) to (f), the PCI values are highly dependent on the structural adequacy of the pavement as expressed with the deflection measurement. This indicates that the visual distress manifestations are highly related with the structural inadequacy of the pavement structure.

5. Maintenance and Rehabilitation alternatives

5.1 General

This chapter mainly deals with the maintenance and rehabilitation for different distresses investigated earlier. As already discussed in Chapter 2, pavement distresses can be classified as being caused either by traffic loads or non load factors, including design, construction, poor-durability materials, and climate factors. Such classification helps to determine appropriate maintenance and/or rehabilitation alternative.

It is also discussed in Section 3.2.6 that distresses can be grouped by possible causes namely structural distresses and functional (non structural). This shows that the structural adequacy of the pavement can be considered as the major criteria with regard to selecting the feasible maintenance and rehabilitation alternative. Hence, the structural evaluation (particularly the deflection and DCP tests) can address whether or not the pavement can support future traffic loading within the design period.

The distress types, severity and extent are the best source of information on the impact of past traffic loadings on the pavement. If load-associated distresses are predominant in the test section, then the structural adequacy of the existing pavement must be questioned. Pertinent information gathered during the visual condition survey need to be utilized in identifying probable causes, which in turn assists for proposing the maintenance alternatives. More extensive condition surveys such as deflection and DCP tests are also essential before deciding for rehabilitation.

As indicated in the AASHTO Guide [5], the Asphalt pavement distresses and probable causes can in general be categorized as showing in Table 5.1 below. This can help for making preliminary decision on maintenance options. Hence, the existing distress types are the best source of information that indicates the impact of past traffic loading on the pavement. As already discussed in Section 2.3.2, only structurally adequate pavements are candidates for rehabilitation without overlay. In addition to identifying probable causes of distress, a properly conducted visual condition survey will document the location and severity of the distress types that eventually indicate the necessity for restoration.

As discussed in Chapter 4, all test roads exhibit several types of distresses and thus require a combination of different maintenance and/or rehabilitation. The following steps should in general be followed for proposing the appropriate maintenance and rehabilitation option:

- The maintenance options need to be decided after a thorough data analysis as indicated in Section 3.2.6 above.
- Causes of distresses were grouped into three broad categories namely load associated, climate /durability associated and drainage /moisture associated.
- Severity and extent of damage are governing criterions to choose appropriate maintenance and/or rehabilitation option.
- The maintenance option for localized surface only defects were out rightly prescribed with out any further structural investigation.

- The rehabilitation options for structural distresses were decided after carefully analyzing results of the deflection measurements.
- Preliminary pavement thickness design was made on some sections to check if those particular sections require structural strengthening or complete reconstruction.

Table 5.1 General categorization of asphalt pavement distress

	Distress Type	Primarily Traffic Load Caused	Primarily Climate/Materials Caused
1.	Alligator or Fatigue Cracking	X	
2.	Bleeding		X
3.	Block Cracking		X
4.	Corrugation		X
5.	Depression		X
6.	Joint Reflection Cracking From PCC Slab		X
7.	Lane/Shoulder Drop off or Heave		X
8.	Lane/Shoulder Separation		X
9.	Longitudinal and Transverse Cracking		X
10.	Patch Deterioration	X	
11.	Polished Aggregate	X	
12.	Potholes	X	
13.	Pumping and Water Bleeding	X(M.H)	X(L)
14.	Raveling and Weathering		X
15.	Rutting	X	
16.	Slippage Cracking		X
17.	Swell		X

L, M & H represents Low, Medium and High severity level of distress.

5.2 Methods of Maintenance

Major maintenance methods to be applied for non-load associated distresses comprises the following: crack sealing, skin patches, partial and full depth patches, pothole patching, surface sanding, surface treatments, fuel resistant seals or overlays, or porous friction course [18].

5.2.1 Maintenance of Cracking Type Distress

Maintenance methods for cracking type distresses vary depending on the type of crack, which in turn is an indicator of the cause.

i. Alligator cracks maintenance

The maintenance should include removing the wet material and installing appropriate drainage. Full depth asphalt patching is necessary for having a strong and dependable repair. When necessary, Temporary repairs can also be made by applying skin patches or aggregate seal coats to the affected areas to avoid any further damage to the pavement [18].

(ii) Edge Cracks

Poor drainage will aggravate edge cracking by causing settlement or yielding of the material underlying the cracked area. Hence improving drainage by installing under drain is necessary, in those areas where drainage facilities don't exist, before repairing the cracked surface.

(iii) Lane Joint Cracks Maintenance

Cracks bigger than 3mm in width can be filled with asphalt mixed with fine sand.

(iv) Slippage Cracks

The proper method of repairing a slippage crack is by removing the damaged surface layer and patching the area with plant mixed asphalt material after applying a light tack coat.

5.2.2 Maintenance of distortion type distresses

Distortion types distresses are characterized by a change of the pavement surface form its original shape. Lack of proper compaction, excessive fines in the mix, too much asphalt, swelling of underlying courses, or settlements are major causes of distortion. Distortion takes a number of different forms: grooves or ruts, showing corrugations, depression, and upheaval. The type of distortion and its cause must be determined before the correct remedy can be applied.

i. Ruts

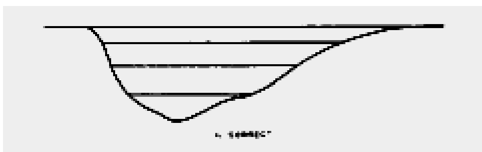
It is necessary to repair such distresses by applying light tack coat and spreading asphalt concrete in the channel since rutting can be aggravated and lead to major structural failures and hydroplaning.

ii. Corrugations and shoving

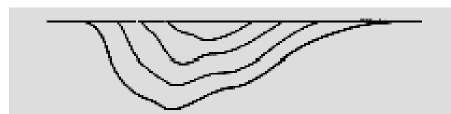
Corrugations in a thick asphalt surface can be repaired using a pavement planning machine and Shoved areas can be repaired using deep patch like for the alligator cracking.

iii. Depressions

Two or more layers of asphalt are required in the repair of deep depression. Filling the area by following the contour of depression is mostly mistakenly done. The correct way to repair a deep depression is to begin in the deepest part of the depression and place a thin layer, the surface of which, when compacted, will be parallel to the original pavement surface. Successive layers can be placed in the same manner. Figure 5.1 shows the correct and incorrect way to place asphalt backfill in a deep depression. `



Correct way



incorrect way

Figure 5.1 Back fill in deep depression

iv. Swell

Swelling can be repaired using deep patch like for the alligator cracks.

v. Utility cut depressions

The repair method is the same as for depressions.

5.2.3 Maintenance of disintegrating type distresses

Disintegration type distresses are characterized by the breaking up of a pavement into small loose fragments. This includes the dislodging of aggregate particles. If not repaired at its early stage, it can progress until the pavement requires complete reconstruction.

The two common types of early stage disintegration are potholing and raveling. Repair ranges from simple seals to deep patches.

i. Potholes

For best results, all materials for filling potholes must meet appropriate and approved standards. Proper preparation and backfilling are very important. This can be done using asphalt cutter, jackhammer, chisel and other hand tools. The sides of cut surface have to be vertical and base. The base materials should be replaced with equal or better material than that removed or with bituminous material. The hole should be primed before placing and compaction of the bituminous material. It is advisable to overfill the bituminous material by around 40% of the pavement thickness to allow for compaction. Figure 5.2 shows the steps to be followed for permanent repair of potholes [24].

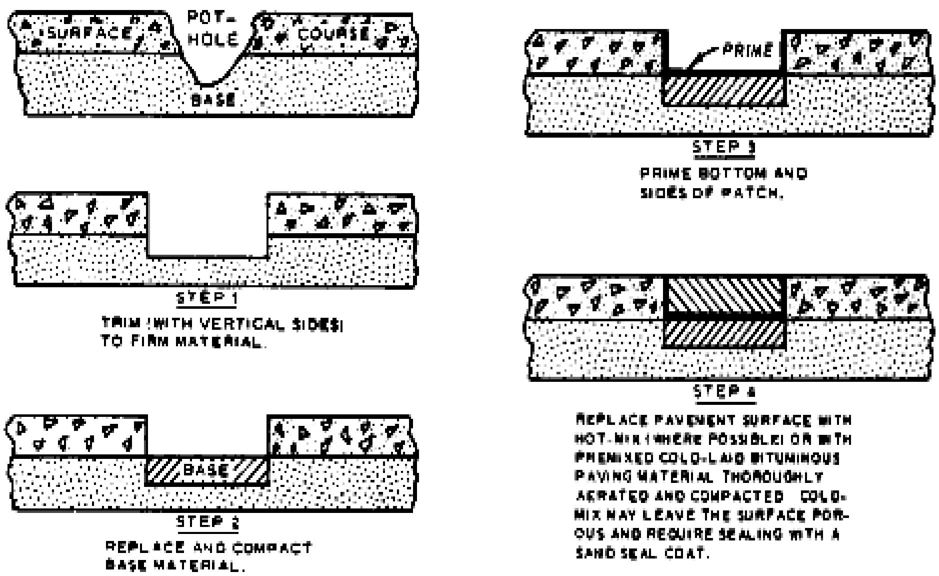


Figure5.2 Steps to be followed for permanent repair of potholes

ii. Raveling

Raveling surfaces usually require a surface treatment that can be looked upon as corrective or preventive maintenance. The type of surface treatment can be selected depending on the extent of damage and nature of traffic.

5.2.4 Summary of maintenance & repair alternatives

The pavement maintenance in general consists of all the routine repair tasks necessary to keep the pavement, under normal conditions of traffic and normal forces of nature, as nearly as possible in its as-constructed condition. All distress types and their corresponding method of maintenance and repair is as shown in Table5.2 [24].

Table 5.2 (excel)

5.3 Major Rehabilitation Methods

As already discussed in Section 2.1.3 each type of distress is the result of one or more causes, which when properly identified, provide good indication about the type of rehabilitation work that is required. Several factors such as level of surface distress, structural condition, and functional condition of the existing pavement must be considered when proposing rehabilitation methods of both overlay and non-overlay types.

Only structurally adequate pavements or pavements restored to structurally adequate condition are candidates for maintenance and rehabilitation without overlay. On the other hand, pavements having distresses of load associated type surely require overlay type rehabilitation or otherwise complete reconstruction. Hence, more attention has to be given for the structural evaluation (i.e. the deflection & DCP tests) results before deciding the most feasible and effective rehabilitation method.

Rehabilitation may range from complete pavement reconstruction to the improvement of provision of some elements such as drainage facilities. Many rehabilitation methods often provide only for the design of asphalt overlays which, in some cases are not the most suitable options. Hence, identifying the cause of distress should be made before selecting rehabilitation option [17].

The detail techniques for rehabilitation without overlay are more or less similar to methods of maintenance as discussed in Section 5.2 above. Hence, rehabilitation methods with overlay are only discussed in this Section. Preliminary pavement thickness requirement for test road showing severe structural inadequacy is also checked to propose rehabilitation alternatives for the same.

5.3.1 Rehabilitation Method with Asphalt Overlays (structural)

One of the following two approaches can be employed in order to check the rehabilitation requirement on the test roads:

a. Deflection approach

This approach applies the remaining pavement life concepts. It considers the magnitude of distress within the existing pavement versus the terminal serviceability level within overlaid pavement. Non-destructive deflection tests are used for estimating the in-situ pavement structural condition. The differences in structural capacity between what is needed for the future overlay period and what is effectively available in-situ at the time of the overlay represents the additional structural capacity required.

The following steps can be followed for determining the overlay thickness and structural adequacy evaluation [10]:

1. Determine the representative rebound deflection (RRD) as described in Section 2.2.2

2. Estimate the EAL (equivalent axle load) that the pavement will be required to support in the future after overlay. The traffic volume estimate can be done using actual counts, existing data or by estimating using traffic classifications.

3. Enter the overlay thickness chart at the RRD determined in step 1 and EAL determined in step 2 to get the overlay thickness required.

b. Effective thickness Approach

This approach applies the concepts that pavement reduces life upon exposure to traffic for extended periods of time. By the time distress conditions appear on the surface of the pavement, a certain amount of the useful life of the pavement has been utilized and this must be accounted for in the design process. This approach considers that as a pavement uses part of its total life, its effective thickness becomes less and less.

The effective thickness of an existing pavement can be determined considering composition of each pavement layer, their thickness and the nature of the sub grade.

The following steps can be followed for calculating overlay thickness on an existing asphalt concrete surface on unbound base:

1. Collect soil specimen to determine the strength values using the resilient modulus or socked CBR.

2. Estimate the design EAL.

3. Calculate effective thickness of the existing pavement layers using conversion factors for each pavement layer. The conversion factor can

directly convert each layer thickness to equivalent thickness of asphalt concrete. The total effective thickness for the existing pavement structure is the sum of the effective thickness of all layers.

4. Estimate the full depth Asphalt concrete using design charts by entering the data's obtained in steps (1) & (2) above.

5. Get the overlay thickness by deducting the effective thickness (step 3) from the full depth asphalt (Step 4)

5.3.2 Rehabilitation Requirement for the Test Roads

As indicated in the results of the visual condition surveys, test roads No-1, No-2 and No-5 are seriously damaged and have mean PCI values of 34%, 22% and 24% respectively. These values show that the Pavements are in a very poor serviceability condition. The structural evaluations (deflection tests) conducted on these test roads also confirm that these test roads exhibit the highest Rebound deflection (RRD). The mean RRD value for test roads 1, 2, and 5 is 122, 127 and 132 respectively. The high RRD values confirm that these test sections are structurally inadequate to carry the existing traffic loading.

The above clues on the structural inadequacy of the test sections (particularly on those sections showing severe functional and structural distresses) are confirmed by making preliminary pavement thickness design. The design is made following AACRA's Pavement Design Manual [16]. A design period of 20 years and traffic growth rate as indicated for each economic zone is considered. The results are as summarized in Table 5.3 below.

As observed from the laboratory test results, the sub grade soil in most of the above three test road sections (refer Table 4.5) have a swell potential of greater than 2%. This indicates that the sub grade is not suitable as a roadbed and requires soil replacement with material having swell potential less than 2 % and CBR of greater than the design CBR for each individual test road.

The above result shows that the existing pavements on those test sections are structurally inadequate and hence require complete reconstruction than performing routine maintenance and rehabilitation works. It must be emphasized that this thesis follows only one of the recommended methods of rehabilitation design. In no way should a complete Pavement rehabilitation design be followed using only such steps. Hence, further works of comparing different design methods and economic analysis on the applicable rehabilitation options and strategies are very important.

Table 5.3 Pavement thickness requirements for Test Roads No 1, 2 and 5

Test Road No.	AADT (One lane)	Growth Rate (%)	CEASA ($X10^6$)	Design sub grade CBR	Structural pavement thickness requirement
1	6,747	11.2	71.74	3	150 mm asphalt layer 240 mm cement stabilized base
2	5,435	9.1	26.86	4	150 mm Asphalt layer 220 mm cement stabilized base
5	7,320	11.1	45.4	5	150 mm asphalt layer 220 mm cement stabilized base

5.3.3 Rehabilitation using asphalt overlay

The structural evaluation using deflection test on roads no 3 and 4 shows a mean RRD, values of 74 and 57 respectively. This shows the pavement structures are from fair to good condition. In any case, the overlay thickness requirement for strengthening the existing pavement can be computed using deflection approach as described in Section 5.3.1 above. The overlay thickness requirements for a design period of ten years are computed using the Asphalt Institute Method (10) .The results are as summarized in Table 5.4.

Table 5.4 Overlay Thickness Requirements for Test Road No.3 and 4

Test Road No	AADT (one lane)	Growth Rate (%)	CESA ($X10^6$)	RRD (mm)	Overlay thickness requirement
3	3,716	7.2	6.4	0.74	50 mm asphalt layer
4	6,521	11.1	5.4	0.57	Not required

As indicated above, Test road No.3 (St Yohannis church to Winget) requires asphalt overlay of 50 mm thickness. On the other hand, no more structural overlay is required to strengthen Test Road No. 4 (St Giorgis church to Sheger Park) for the estimated design axle load. Hence, giving necessary periodic maintenances for each localized distresses following the procedure as stated in Section 5.2 above could be the best option for Test Road No.4.

5.4 Summary of Maintenance & Rehabilitation Option for Test Roads

As already discussed earlier, there are numerous pavement maintenance and rehabilitation alternatives to make good defects identified through different stages of condition surveys. It should be noted that maintenance options for localized surface defects can be directly done as prescribed earlier in Section 5.2 provided that the pavement is structurally adequate to withstand the loading, environmental and other effects it has encountered. On the other hand, it is nothing but wastage of resource to maintain those pavements, with out strengthening the structure and provision of necessary drainage facilities, where structural failures are observed during condition surveys. The maintenance and rehabilitation options already discussed can be summarized as shown in Table 5.5.

Table 5.5 Summary of maintenance and Rehabilitation options for Test Roads

	Description	Evaluation of Results	Observation	Maintenance & Rehabilit Option
	St Yosef Church to Kaliti Interchange	**Functional:** PCI = 34%……………. IRI = 4.3 m/km………... **Structural:** RRD = 1.22mm……… DCP: Poor base layer **Drainage:** No drainage facilities **Preliminary Design:** Requires complete strengthening	Poor condition Bad ride quality Poor structural capacity Bad pavement material Poor drainage	All pavement evaluation re that this road section has fa the intended functional & s purposes. Hence, it require reconstruction.
	Mexico square to Old Airport	**Functional:** PCI = 22%……………. IRI = 7.2 m/km………... **Structural:** RRD = 1.27 mm…… DCP: - **Drainage:** drainage impeded **Preliminary Design:** Requires complete strengthening	Very poor condition Very bad ride quality Poor structural capacity Poor drainage	All pavement evaluation re that this road section has fa the intended functional & s purposes. Hence, it require reconstruction.
	St Yohannis church to Winget	**Functional:** PCI = 47%……………. IRI = 3.9 m/km………... **Structural:** RRD = 0.74 mm… DCP: good base material except at one spot **Drainage:** drainage slightly impeded **Preliminary Design:** Requires complete strengthening	Fair pavement condition Good ride quality Fair structural capacity Good base material Well drained	Both functional and structu conditions revealed that th section is in a good conditi pavement strengthening us overlay can remedy the def
	St Giorgis church to Sheger Park	**Functional:** PCI = 57%……………. IRI = 3.6 m/km………... **Structural:** RRD = 0.57 mm… DCP: - **Drainage:** properly functioning **Preliminary Design:** No need for structural strengthening	Good pavement condition Moderate ride quality Good structural capacity Good drainage	Both the functional and str evaluations confirm that th section is in a good conditi adequate structural capacit and periodic maintenances to correct the existing surfa
	Kebena to Megenagna	**Functional:** PCI = 24%……………. IRI = 5.8 m/km………... **Structural:** RRD = 1.32 mm… DCP: poor base layer **Drainage:** no drainage facility **Preliminary Design:** Requires complete strengthening	Very poor condition Bad ride quality Bad structural capacity Bad base material Poorly drained	The pavement evaluation r that the road section is in a functional & structural con Complete reconstruction is improve serviceability of th

6.0 Conclusion and Recommendation

6.1 Remarks on the road maintenance practice of Addis Ababa

During previous time, the maintenance and rehabilitation works in Addis Ababa follows more of a traditional practice. No proper pavement evaluation was done in advance or during maintenance and rehabilitation. As already discussed in Section 1.2, many roads were constructed without proper design and construction supervision. Later on the same roads were simply overlaid without strengthening the bottom weak layers. Such defective works are affecting the pavement performance until now since no appropriate remedial action is taken.

The current maintenance and rehabilitation practice also depends more on visual observation and functional evaluations such as surface roughness and visual survey at network level rather than detail pavement evaluation at project level.

In general, the following major remarks can be noted regarding the road maintenance and rehabilitation practices in Addis Ababa:-

1. The road maintenance and rehabilitation works for the city of Addis Ababa, particularly until the establishment of AACRA, was being carried out with out formal policy and standards. Roads were constructed and maintained by different agencies and administrative bodies without proper coordination. This has resulted in sub standard works which are causes of subsequent damages.

2. There is still no proper material and construction quality control for the road maintenance and rehabilitation works. As a result, repeated and premature failures are observed.

3. The maintenance and rehabilitation work force is not properly organized with adequate resource such as finance,

equipment and skilled staff. This has resulted in the maintenance operation not to be efficient and effective.

4. Only around 40% of the existing asphalt roads or 12% of the whole of the existing road network have side drainage line and pedestrian walk ways. This lack of drainage system and side walks is causing damage on the asphalt pavement and affecting the proper functioning of the road respectively.

5. Different utility organizations (like water works, electric and telecommunication) are not carrying out their duties on the basis of long term plan and with coordination of one another. As a result, it is not uncommon to observe repetitive destruction on the asphalt pavements, some times even in the same year of construction. The method of patching utility trenches also lacks proper workmanship and control.

6.2 Conclusion

The pavement evaluation and analysis made on the five test roads shows that most of the pavements exhibit severe structural distress (expressed in high RRD value) and severe functional distress (expressed with high IRI and very low PCI value).The results are as shown in Table 6.1.

Table 6.1 Summary of Pavement Response Variables on the Test Roads

Test Road No.	**Description**	**Mean Pavement Response Values**		
		PCI (%)	IRI	RRD(mm)

1	St Yosef Church to Kaliti Interchange	34	4.3	1.22
2	Mexico sq - Old airport	22	7.2	1.27
3	St. Yohannis Church to Winget	47	3.9	0.74
4	St. Girogis Church to Sheger Park	57	3.6	0.57
5	Kebena to Megengna	24	5.8	1.32
Mean Value		33	5.0	1.02

The following conclusions can be made from the observations of different pavement evaluations on the five test roads:

1. The pavement sections in the test roads perform in a significant non linear fashion. However, it is observed from the trend of the least square curves that some specific distresses and pavement response variables (such as PCI, IRI and RRD), loading and other evaluations are interdependent with one another. The relationship is strong enough for some interactions particularly those related with drainage condition, axle loading and asphalt surfacing thickness. On the other hand, considerable differences in distress density were observed within a test road having similar traffic loading and sub grade soil. This could be because of the influence of other factors like variation in the pavement design, construction history, workmanship, quality of pavement materials and other environmental conditions which have significant impact on the magnitude of distresses.

2. The pavement evaluations conducted on the 55 test sections within the five radial arterial roads show that the whole of the road sections are exhibiting sever distresses which in many cases are related to causes primarily attributable to drainage and moisture related problems.

- Results of the visual survey indicate that the five radial arterial roads have mean PCI value of 33%. This mean value indicates that the majority of the pavements are at poor functional level. These values are extremely low especially on test roads No.1, 2 and 5. The structural evaluations made on the same roads also confirm that these pavements are not structurally adequate to serve the intended purpose.

- The visual survey analysis also shows that raveling, corrugation, bumps & sags and shoulder drop-off are the dominant distresses which constitute more than 80 % of the distress density in the arterial road network during the time of survey.

- Results of the non destructive structural evaluation based on deflection revealed that the majority of the pavements within the five test rods have a mean RRD value much grater than the very bad limit which is 0.80 mm. The pavements especially in test roads No.1, 2, 3 and 5 are structurally inadequate and require strengthening.

- Results of the DCP tests clearly confirm that the major cause for the structural inadequacy of pavements that exhibit severe functional and structural distresses is mainly due to the fact that existing unbound base materials (the layers below the asphalt surface) are of low bearing value. It is also observed from the DCP plots that there exists thin layer of weak unbound base material sandwiched between top and bottom gravel layers especially on those sections that exhibit low pavement condition index.

3. The following can also be concluded from the observations of relationships between different pavement evaluation parameters which can give some clues about causes of pavement distresses:

- Large deflection, low PCI values and consequently higher distress densities are observed in test sections having high swell potential. This indicates that the swell potential of the sub grade soil has significant impact on the pavement functional and structural conditions.

- The in-situ sub grade CBR value is observed to have an inverse relation with surface roughness IRI value, deflection value and corrugation distresses. This indicates that the visually observed surface defects are aggravated by inadequacies in the sub grade bearing capacity.

- Deflection, surface roughness IRI values and major distresses (except for raveling type) are observed to increase with a decrease in the asphalt surface thickness and base CBR. One can deduce from this relationship that the surface defects and structural inadequacy of the pavements are highly associated with the thickness of the asphalt surfacing and adequacy of the base course.

- The drainage condition on all test roads has a strong association with PCI, deflection, roughness and all major distresses. Such strong relationship confirms that drainage condition has significant impact, than any other cause, to affect the structural and functional condition of the pavement performance. Hence, it can be concluded that the predominant cause of distress in those pavements which failed functionally and structurally is mainly due to drainage problem (i.e. lack of both surface and subsurface drain).

- It is also observed that the axle loading has direct relationship with deflection, surface roughness IRI values and major distresses. This indicates that visible surface defects are also highly associated with overstressing of the pavement layers.

4. The deflection measurement results on test roads No. 1, 2 and 5 clearly indicates that these sections of the road network have structural inadequacy to support the existing traffic loading. Preliminary pavement design made on these test roads also confirm that the appropriate maintenance and rehabilitation measure on these road sections is structural upgrading with drainage improvements using complete reconstruction. Hence, the traditional maintenance techniques being undertaken by the Addis Ababa City Roads Authority year after year, like patching and thin overlays, is nothing but wastage of resource as such measures do simply treat the symptoms than the actual cause of distress.

5. It is observed during test pit excavation that highly permeable and open graded types of sub-base and bases are used in many of the arterial roads. However, they couldn't be considered as freely draining layers as no collector pipes and outlets are provided. Consequently, water has often been trapped at low places where severe damage to the pavements has taken place. It is also observed from the drainage surveys that the main reason of having

good PCI value with lower RRD particularly on test roads No.3 and 4 could be due to the fact that they are relatively well drained.

It should be emphasized that there is a reduction in supporting power and an increase in the rate of loss of serviceability of the pavements when the water content of bases and sub bases increase. When free water completely fills these layers and void spaces at the boundaries between layers, heavy wheel loads applied to the surfaces of these pavements produce excessive hydrostatic pressure. This impact not only cause erosion and ejection of material out of pavements, but also can strip asphalt coating. Moreover, the water weaken base courses by rearranging the internal structure of fine grained materials in aggregate mixtures, overstress sub grades where total thickness are inadequate, and cause a number of other detrimental actions.

6.3 Recommendation

1. Collection of accurate data for determining dominant distresses in a road network, identifying primary causes of distress and developing functional relationship among different pavement evaluation variables would only be easier on experimental test sections which are carefully designated in such a way to reasonably model the road network under study. To this effect one can understand that the analysis and findings of this research could only be considered as a preliminary assessment that may serve as a spring board to further carry out detailed assessment within the Addis Ababa road network. Hence, it is advisable to develop a continuous system of data collection for distresses, classified traffic counts, pavement evaluation results, and maintenance and construction records on representative test sections for a longer period of time. Such strategic data collection and analysis could certainly enable to

develop clear functional relationship among different pavement evaluation parameters.

2. No detail material test of the existing pavement structure is carried out under this research. Hence, it is also advisable to perform some destructive tests such as coring and component analysis techniques to further check the structural capacity of the pavement.

3. As observed from the visual survey, nearly 60% the Test Roads were constructed without side drain of any kind. This can easily indicate that the road design and construction traditionally adopted by the city government has fully ignored the effect of excess water in the pavement layer. According to the survey made for this thesis purpose, even some of the existing surface drains are not properly functioning. On the other hand, The Addis Ababa Roads Authority's traditional maintenance practice until now, to repair damaged pavements, is patching or providing additional thickness of asphalt without an attempt to improve the drainage conditions.

   Therefore, the pavement design and construction practice must be modified in such a way to have structural pavement layers capable of draining free water rapidly after its entry. Such rapid drainage can be achieved by providing highly permeable layers of open graded material with collector pipes to ensure constant gravity drainage. The design and construction practice adopted in the Addis Ababa Ring Road can be good example. Such kinds of surface and sub-surface drainages not only protect pavements from large surface inflow, but also from inflows of high ground water in wet periods or any unexpected inflows.

Table 4.5 Summary of Pavement Evaluation Data for All Test Roads

TEST ROAD NO	TEST Chainage (Km+mt)	PCI (%)	Deflection x0.01mm	Sub grade Lab. CBR	Adjusted Roughness (IRI)	Swell (%)	Drainage condition	Equivalent single Axle Load Per Day	Weathering & Raveling Density (%)
1	300	18	96	3	4.3	4.88	4	3912	26.3
1	600	29	94	3	3.6	5.21	4	3912	37.3
1	900	19	120	2	5.2	5.25	5	3912	0
1	1200	12	140	3	6.8	5.99	5	3912	31.2
1	1500	20	134	3	6.3	5.4	5	3912	31.4
1	1800	22	124	3	5.1	5.4	4	3912	30.6
1	2100	44	76	2	3.7	6.84	3	3912	34.3
1	2400	35	70	4	3.6	2.2	3	3912	32.3
1	2700	50	34	4	3.1	1.85	3	3912	14.3
1	3000	64	106	4	4.1	0.97	3	3912	15.15
1	3300	54	98	3	3.9	3.89	5	3912	5.08
1	3600	36	70	3	4.2	4.09	5	3912	30.3
1	3900	35	30	3	4.4	3.61	5	3912	26.77
2	150	19	66	3	10.3		3	2838	0
2	450	37	96	28	8.6		3	2838	4.43
2	750	17	56	4	9.4		4	2838	30
2	1050	15	88	21	8.1		4	2838	37.7
2	1350	19	164	5	7.2		4	2838	32.3
2	1650	20	52	7	6.5		5	2838	26.7
2	1750	17	106	6	5.4		5	2838	42.51
2	2250	22	114	13	5.8		5	2838	57.7
2	2361	28	104		5.9		5	2838	66.7
3	150	65	36	5	5	1.54	2	2105	11.8
3	450	59	42	7	3.9	0.49	2	2105	6.02
3	750	59	30	7	4.2		2	2105	6.02
3	1050	60	34	7	2.5		2	2105	11.25
3	1350	52	28	7	3.5		2	2105	18
3	1450	45	50	**7**	3.4		3	2105	18.2
3	1650	44	86	7	3.7		3	2105	18.2
3	1950	50	46	7	3.5		4	2105	18.2
3	2250	52	70	7	3.8		4	2105	8.55
3	2550	52	80	6	4.1		4	2105	8.55
TEST ROAD NO	TEST Chainage (Km+mt)	PCI (%)	Deflection x0.01mm	Sub grade Lab. CBR	Adjusted Roughness (IRI)	Swell (%)	Drainage condition	Equivalent single Axle Load Per Day	Weathering & Raveling Density (%)
3	2850	42	80	**6**	4.4		4	2105	18.32
3	3050	28	**77**	6	3.5		5	2105	16.17
3	3350	35	72	6	4		5	2105	19.27
3	3650	40	65	6	3.9		5	2105	18.22
3	3950	42	90	6	3.9		5	2105	18.2
4	150	67	48	17	5.1		2	1455	2.5
4	450	69	47	15	4		2	1455	11.3

4	750	59	37	12	3.1		2	1455	14.14
4	850	49	70	9	3.1		2	1455	10
4	950	56	42	12	3.2		2	1455	5
4	1050	56	62	12	3.1		2	1455	5
4	1350	56	38	12	3.1		2	1455	10
4	1650	55	57	4	3.1		2	1455	10
4	1950	63	30	17	3.7		3	1455	20
4	2250	62	38	8	3.7		3	1455	17.3
4	2550	52	34	10	4.4		3	1455	9.15
4	2650	45	28	13	3.8		3	1455	9.15
4	2950	41	35	8	3.3		3	1455	20
5	300	15	76	13	10	1.14	4	1910	0
5	600	13	106	4	5.2	3.91	4	1910	0
5	900	16	136	13	6.7	1.79	4	1910	6.38
5	1200	29	124	10	8.1	1.9	5	1910	0
5	1500	30	86	1	7.6	6.32	5	1910	0
5	1800	30	90	14	5.7	0.50	5	1910	0
5	2100	20	88	9	7.7	2.29	5	1910	2.8
5	2400	20	116	2	5.6	6.93	5	1910	2.8
5	2700	30	114	2	4.1	5.93	5	1910	4.1
5	3000	20	90	11	3.6	0.85	5	1910	0
5	3300	14	108	2	5.6	6.55	5	1910	0
5	3600	47	80	2	3.9	5.06	5	1910	0
5	3900				2.4				0

Table 4.6 Summary of Pavement Evaluation Data for All Test Roads

Test Road No	TEST Chainage (Km+mt)	PCI (%)	Deflection x0.01mm	Sub grade Lab. CBR	Adjusted Roughness (IRI)	Swell (%)	Drainage condition	Equivalent single Axle Load Per Day	Weathering & Raveling Density (%)	Corrugation Density (%)	Bumps & Sags Density (%)
1	300	18	96	3	4.3	4.88	4	1764	26.3	0	1.27
1	600	29	94	3	3.6	5.21	4	1764	37.3	0	4.36
1	900	19	120	2	5.2	5.25	5	1764	0	0	3.21
1	1200	12	140	3	6.8	5.99	5	1764	31.2	23.2	0
1	1500	20	134	3	6.3	5.4	5	1764	31.4	8.5	3.46
1	1800	22	124	3	5.1	5.4	4	1764	30.6	24.52	1.55
1	2100	44	76	2	3.7	6.84	3	1764	34.3	3.64	3.8
1	2400	35	70	4	3.6	2.2	3	1764	32.3	0	4.36
1	2700	50	34	4	3.1	1.85	3	1764	14.3	0	4.35
1	3000	64	106	4	4.1	0.97	3	1764	15.15	0	4.07
1	3300	54	98	3	3.9	3.89	5	1764	5.08	0	5.08
1	3600	36	70	3	4.2	4.09	5	1764	30.3	0	5.55
1	3900	35	30	3	4.4	3.61	5	1764	26.77	0	5.08
2	150	19	66	3	10.3		3	1422	0	0	1.73
2	450	37	96	28	8.6		3	1422	4.43	0	4.07
2	750	17	56	4	9.4		4	1422	30	0	2.43
2	1050	15	88	21	8.1		4	1422	37.7	18.2	1.27
2	1350	19	164	5	7.2		4	1422	32.3	14.9	0
2	1650	20	52	7	6.5		5	1422	26.7	23.2	0.53
2	1750	17	106	6	5.4		5	1422	42.51	0	4.07
2	2250	22	114	13	5.8		5	1422	57.7	0	5.2
2	2361	28	104		5.9		5	1422	66.7	0	5.08
3	150	65	36	5	5	1.54	2	971	11.8	0	1.74
3	450	59	42	7	3.9	0.49	2	971	6.02	0	0.73
3	750	59	30	7	4.2		2	971	6.02	0	0.73
3	1050	60	34	7	2.5		2	971	11.25	0	2.2
3	1350	52	28	7	3.5		2	971	18	0	1.81
3	1450	45	50	**7**	3.4		3	971	18.2	0	2.7
3	1650	44	86	7	3.7		3	971	18.2	0	2.65
3	1950	50	46	7	3.5		4	971	18.2	0	2.7
3	2250	52	70	7	3.8		4	971	8.55	0	1.4
3	2550	52	80	6	4.1		4	971	8.55	0	1.4
Test Road No	**TEST Chainage (Km+mt)**	**PCI (%)**	**Deflection x0.01mm**	**Sub grade Lab. CBR**	**Adjusted Roughness (IRI)**	**Swell (%)**	**Drainage condition**	**Equvalent single Axle Load Per Day**	**Weathering & Raveling Density (%)**	**Corrugation Density (%)**	**Bumps & Sags Density (%)**
3	2850	42	80	**6**	4.4		4	971	18.32	4.12	2.03
3	3050	28	**77**	6	3.5		5	971	16.17	2.03	2.43
3	3350	35	72	6	4		5	971	19.27	2.06	2.28
3	3650	40	65	6	3.9		5	971	18.22	0	2.23
3	3950	42	90	6	3.9		5	971	18.2	3.6	2.33
4	150	67	48	17	5.1		2	1701	2.5	0	1.8

4	450	69	47	15	4		2	1701	11.3	0	1.4
4	750	59	37	12	3.1		2	1701	14.14	0	0.55
4	850	49	70	9	3.1		2	1701	10	0	0.76
4	950	56	42	12	3.2		2	1701	5	0	0.38
4	1050	56	62	12	3.1		2	1701	5	0	0.38
4	1350	56	38	12	3.1		2	1701	10	0	0.85
4	1650	55	57	4	3.1		2	1701	10	0	0.85
4	1950	63	30	17	3.7		3	1701	20	0	1.7
4	2250	62	38	8	3.7		3	1701	17.3	0	0.75
4	2550	52	34	10	4.4		3	1701	9.15	0	1.25
4	2650	45	28	13	3.8		3	1701	9.15	0	2.5
4	2950	41	35	8	3.3		3	1701	20	0	2.2
5	300	15	76	13	10	1.14	4	1909	0	34.72	2.33
5	600	13	106	4	5.2	3.91	4	1909	0	1.61	7.38
5	900	16	136	13	6.7	1.79	4	1909	6.38	29.08	3.19
5	1200	29	124	10	8.1	1.9	5	1909	0	0	2.62
5	1500	30	86	1	7.6	6.32	5	1909	0	16.2	4.94
5	1800	30	90	14	5.7	0.50	5	1909	0	12.1	1.6
5	2100	20	88	9	7.7	2.29	5	1909	2.8	0	3.05
5	2400	20	116	2	5.6	6.93	5	1909	2.8	0	3.05
5	2700	30	114	2	4.1	5.93	5	1909	4.1	3.3	7.8
5	3000	20	90	11	3.6	0.85	5	1909	0	0	7.6
5	3300	14	108	2	5.6	6.55	5	1909	0	5.8	4.7
5	3600	47	80	2	3.9	5.06	5	1909	0	0	4.8
5	3900				2.4				0		

Table 4.6 Relationship between Pavement Evaluation Variables & Distresses

(Values of correlation coefficient r)

Vs	Swell	CBR	Drainage Condition	ESA	PCI	Deflection	Roughness	Weathering & Raveling	C
Swell	1	-0.767	**	**	-0.343	0.389	-0.063	0.271	
Sub grade Lab CBR		1	**	**	0.959	-0.229	0.389	0.0103	
Drainage Condition			1	**	-0.907	0.979	0.532	0.038	
ESA				1	-0.365	0.392	0.156	0.246	
PCI					1	-0.684	-0.637	-0.229	
Deflection						1	0.428	0.17	
Roughness							1	0.026	
Weathering & Raveling								1	
Corrugation									
Bumps & Sags									
Lane/ Shoulder Drop- off									

(**) Variables considered to have no significant relationship
The detail relationship is graphically shown in APPENDIX F

Pavement condition involves the following four major components: (1) ride comfort (2) load carrying capacity (3) safety, and (4) aesthetics. In general, a good pavement rides well, carries traffic satisfactorily, and provides a safe tire interface for both rolling and stopping, and has pleasing appearance to the pavement manager and user as well. As there is no formula for considering all the above components in a precise manner, different people give more or less emphasis on any of the above factors depending on there particular situation [8].figure 2.23 shows a schematic representation of the variation in the major out puts which could actually be measured or predicted during pavement evaluation.

Figure 2.23 Major Types of Pavement Outputs

Pavement condition involves the following four major components: (1) ride comfort (2) load carrying capacity (3) safety, and (4) aesthetics. In general, a good pavement rides well, carries traffic satisfactorily, and provides a safe tire interface for both rolling and stopping, and has pleasing appearance to the pavement manager and user as well. As there is no formula for considering all the above components in a precise manner, different people give more or less emphasis on any of the above factors depending on there particular situation [(8)].figure 2.23 shows a schematic representation of the variation in the major out puts which could actually be measured or predicted during pavement evaluation.

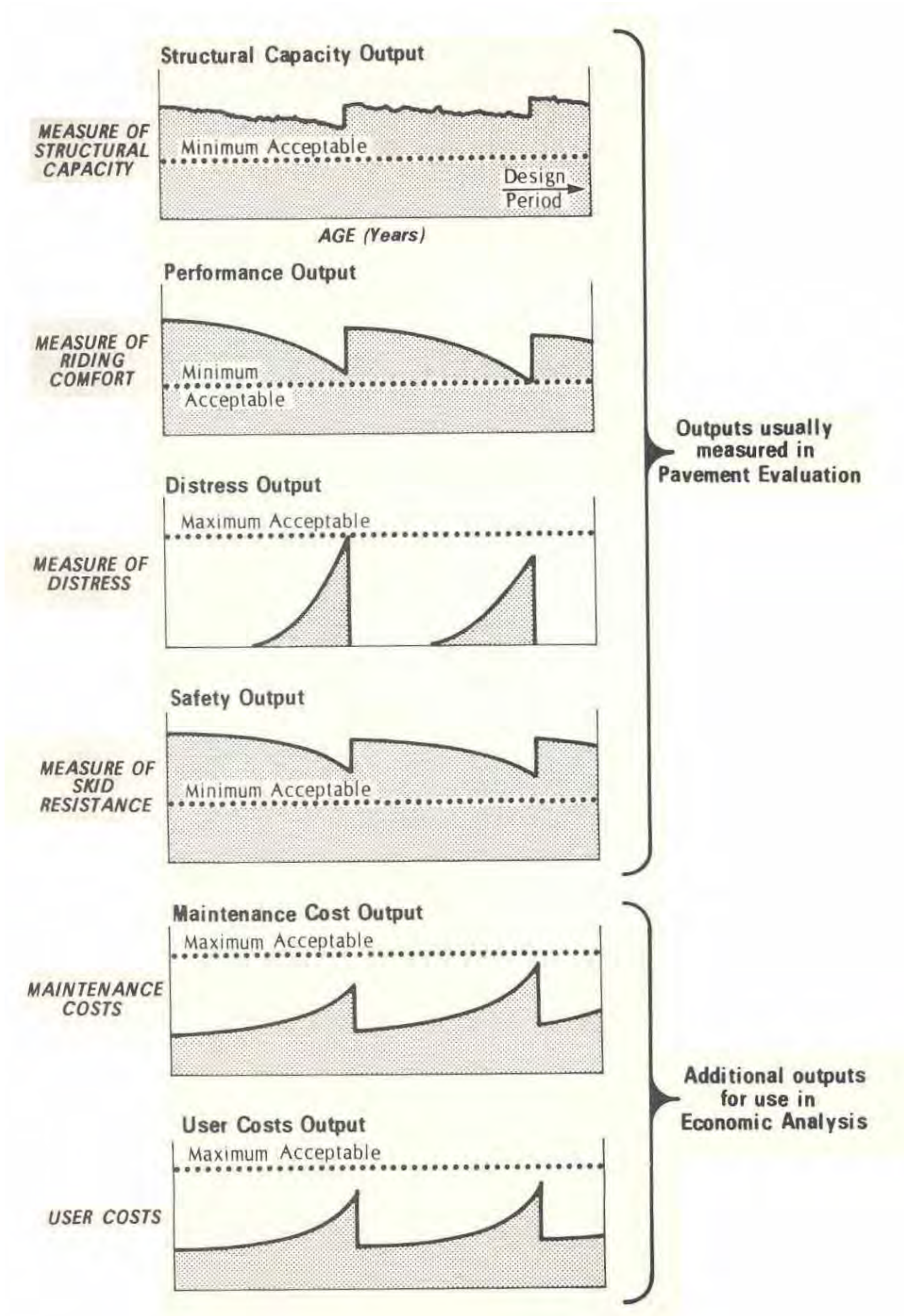


Figure 2.23 Major Types of Pavement Outputs

Table 5. Summary of maintenance options for Test Roads

	Description	Evaluation of Results	Remark	Maintenance & Rehabilit Option
	St Yosef Church to Kaliti Interchange	**Functional:** PCI = 34%……………. IRI = 4.3 m/km………... **Structural:** RRD = 1.22mm……… DCP: Poor base layer **Drainage:** No drainage facilities **Preliminary Design:** Requires complete strengthening	Poor condition Bad ride quality Poor structural capacity Bad pavement material Poor drainability	All pavement evaluation re that this road section has fa the intended functional & s purposes. Hence, it require reconstruction.
	Mexico square to Old Airport	**Functional:** PCI = 22%……………. IRI = 7.2 m/km………... **Structural:** RRD = 1.27 mm…… DCP: - **Drainage:** drainage impeded **Preliminary Design:** Requires complete strengthening	Very poor condition Very bad ride quality Poor structural capacity Poor drainability	All pavement evaluation re that this road section has fa the intended functional & s purposes. Hence, it require reconstruction.
	St Yosef church to Winget	**Functional:** PCI = 47%……………. IRI = 3.9 m/km………... **Structural:** RRD = 0.74 mm… DCP: good base material except at one spot **Drainage:** drainage slightly impeded **Preliminary Design:** Requires complete strengthening	Fair pavement condition Good ride quality Fair structural capacity Good base material Well drained	Both functional and structu conditions revealed that th section is in a good conditi pavement strengthening us overlay can remedy the de
	St Giorgis church to Sheger Park	**Functional:** PCI = 57%……………. IRI = 3.6 m/km………... **Structural:** RRD = 0.57 mm… DCP: - **Drainage:** properly functioning **Preliminary Design:** No need for structural strengthening	Very poor condition Bad ride quality Bad structural capacity Good drainage	Both the functional and str evaluations confirm that th section is in a good conditi adequate structural capacit and periodic maintenances to correct the existing surfa
	Kebena to Megenagna	**Functional:** PCI = 24%……………. IRI = 5.8 m/km………... **Structural:** RRD = 1.32 mm… DCP: poor base layer **Drainage:** no drainage facilty **Preliminary Design:** Requires complete strengthening	Very poor condition Bad ride quality Bad structural capacity Bad base material Poorly drained	The pavement evaluation r that the road section is in a functional & structural con Complete reconstruction is improve serviceability of t

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APPENDICES

Appendix A Visual Condition Survey Records (sample) & Distress Density on Test Roads

Appendix B Roughness Measurement & Analysis

Appendix C Calibration for Roughness Measurement

Appendix D Deflection Measurement & Analysis

Appendix E Dynamic cone penetration Tests & Analysis