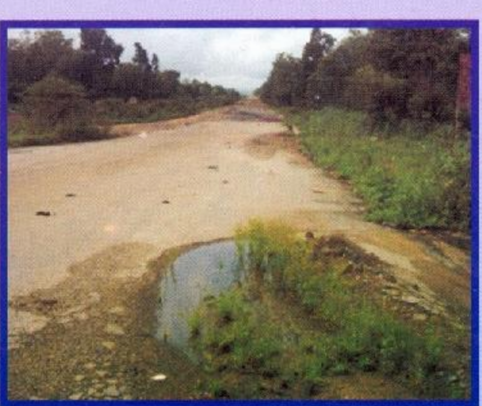
PROCEEDINGS OF NATIONAL CONFERENCE ON

ROAD PAVEMENT FAILURE IN NIGERIA



Theme

CHALLENGES OF ROAD PAVEMENT FAILURE IN NIGERIA

NBRRI
NIGERIAN BUILDING AND ROAD RESEARCH INSTITUTE
(FEDERAL MINISTRY OF SCIENCE AND TECHNOLOGY)

FMST COREN SON FMW FERMA

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HELD AT NICON LUXURY HOTEL, ABUJA, NIGERIA
7TH – 9TH MAY 2013

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EDITED BY

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JUNE 2013

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ABOUT THE CONFERENCE ON ROAD PAVEMENT FAILURE

The general state of most Nigerian roads has been a cause for concern due to the high incidences of perennial road pavement failures and the negative impact on Nigeria's socio-economic development. To address this hydra-headed phenomenon, the Nigerian Building and Road Research Institute (NBRRI) in collaboration with other Stakeholders held a National Conference on *ROAD PAVEMENT FAILURE IN NIGERIA*. The Stakeholders included ;

- Federal Ministry of Works (FMW)
- Federal Road Maintenance Agency (FERMA)
- Federal Road Safety Commission (FRSC)
- National Emergency Management Agency (NEMA)
- Standards Organisation of Nigeria (SON)
- Council for the Registration of Engineering in Nigeria (COREN)
- Nigerian Society of Engineers (NSE)

The well attended Conference was held between the 7th and 9th May 2013 at the Nicon Luxury Abuja Hotel. The theme of the Conference was **Challenges of Road Pavement Failure in Nigeria.** The four sub-themes were as follows:

- Sub Theme 1: Road Asset Management & Maintenance
- Sub Theme 2: Pavement Materials
- Sub Theme 3: Traffic and Safety
- Sub Theme 4: Contract Administration

All Papers presented were reviewed and edited before publication in this Proceeding.

This Conference is in furtherance to the resolve by the Nigerian Building and Road Research Institute to host **NBRRI Annual Conferences** on topical issues in the construction industry for the benefit of professionals, professional bodies, academia, construction-based industries, contractors, consultants, technocrats, Governments and all stakeholders in the built environment. It is expected that stakeholders in the construction industry will look forward to future Annual Conferences.

JUNE 2013

FOREWORD

Every Nation of the world desires a strong transportation infrastructure to support and sustain a strong economy. Most countries combine a comprehensive air transport with the railways and water transport to ease pressure on road network. This way, the countries would have provided the most basic infrastructure for the movement of people and goods for trade and commerce, industrial growth, tourism, etc. Nigeria's railways have collapsed, at a paltry length of less than 5,000kilometres; the air transport system is far too scanty for mention with the country lacking even a national carrier, while water transportation is almost non-existent. Therefore much is desired of Nigeria's Road transportation.

Unfortunately, when statistics of the roads are made, it is discovered that Nigeria, like many African countries, is extensively in need of more road networks and capacity expansion (lane widening, dualization, etc.) of existing roads. As example for comparison, out of the world's total road networks of about 70million kilometers, 95.5% of the entire networks are in North America, Europe, China, Japan and Brazil. USA's 6.5million kilometers of road network alone accounts for 9.3% of the entire world roads. In Africa, South Africa has a total network of 362,099 kilometers followed by Nigeria's 193,200 kilometers. The figures are more disastrous when the 35,900 kilometers of Nigeria's paved road network is compared and seen not to be even up to the over 75,238 kilometers of major highways/expressways in USA that are over 10 -lanes or 95,600 kilometers of major highways/expressways in China.

It is in the light of the above statistics that the Nigerian Building and Road Research Institute (NBRRI) considered the state of Nigerian roads and decided on this Conference as both a capacity Building Workshop as well as a forum for knowledge and technology sharing and transfer.

The Conference accorded all Stakeholders the opportunity to x-ray the Nigerian road network, analyze the problems and proffer solutions that should lead to more durable, smoother and safer roads in the country.

Indeed, the participation and zeal surpassed all expectations. The library of knowledge within the country itself proved to be inexhaustible. All Stakeholders participated comprehensively while the foreign presence from Imperial College London, UK's Transport Research Laboratory (TRL) and Dupont in South Africa is duly acknowledged. It is hoped that the numerous presentations on pavement materials (case studies and solutions, nanotechnology, etc.) would be found useful for a state-of-the-art intervention to provide many more durable roads for Nigeria. It is important to state that the papers were assessed and only those that met review comments and guidelines are published in this book of Proceedings.

The Institute (NBRRI) looks forward to hosting bigger and even more enthusiastic audience in its national Conferences which holds annually in the period of May.

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Director-General/CEO.
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June 2013

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ROAD PAVEMENT FAILURES: CLASSIFICATIONS, CAUSES AND REMEDIES

By

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Abstract

The performance of the Nigerian roads sector has not been satisfactory despite its enormous potentials for growth and development. Traditionally, the poor transport facilities and infrastructure have severely delayed economic development which weakened Transport infrastructure and contributed negatively to attempts to alleviate poverty in the country. Yet John F. Kennedy was once quoted as saying: ***"It is not strong economies that give good roads; but rather that it is good roads that give rise to strong economies!"*** *Consequently, this paper gives a clear picture of the meaning and types of road pavements, modes of failures and possible remediation processes that may be adopted for solution when there is failure. It emphasizes that Nigerian roads are not different; and must not be seen to warrant special solutions. All that our roads need is proper construction modalities that use proper materials and construction techniques. The distinction is made between general failures and pavement-specific failures. Emphasis is made of early detection of failures and the provision of prompt solutions. Indeed, the* ***Nigerian Building and Road Research Institute, NBRRI,*** *and other stake-holding Institutions need to be given enhanced research support in the form of funding, equipment, laboratory infrastructure, and training sponsorships to research peculiar solutions for the Nigerian road network failures.*

1. INTRODUCTION

The objective of this annual NBRRI conference; amongst a series of other sub-themes, is also to collate and compile an accurate set of data to give a fair statistics of the Nigerian road network. However before this is compiled, Nigeria is currently said to have the largest road network in West Africa and the second largest south of the Sahara. FRSC (2009) road safety audit sources gave the estimated road network length of 193,200km; excluding village access roads which is somewhat in contradiction with World Factbook (1999) figures of 194,394km. The paved sections constitute just 28,980km leaving unpaved sections totalling 164,220km, according to FRSC (2009) but World Factbook (1999) gives the paved network as 60068km (including 1194km of expressways). It is possible that FRSC figures may be for federal road network but Lagos and Abuja metropolis are the only places in the country that have a fairly-extensive road network.

Federal roads are divided into trunk A and trunk F: 'A' roads are those under Federal Government ownership; developed and maintained by the Federal Government while 'F' roads are those that were formerly under State Government ownership, but were taken over by the Federal Government, with a view to upgrading them to federal highway standards (Nnanna et al, 2003). State roads are classified as trunk B and they are under the ownership and management of the various State Governments. Local Government roads are classified as C under the ownership and management of the Local Governments in the country divided into urban, rural and village access roads. However, the failures of roads today can clearly partly be blamed on these road networks that have to cater for a population of 150 million people, giving an insufficient per capita facility. Malaysia, as a comparative example of a fast developing economy, today has less than 20million population; and based on reports from Mohd Rosli et.al. (2010) has concrete roads totalling 343km, asphalt roads of length 87,626km, earth and gravel roads of length 3,651km with an approximately 90,000km of paved roads. Thus, making the simple analogy to Nigeria, it can be deduced that the roads are overstressed and extensively in need of more networks as well as the effective and continuous maintenance and capacity expansion (lane widening, dualization, etc.) of existing ones. Even with the existing networks, the faults on most of Nigerian federal roads are depressions on the road surfaces, presence of pot holes and cracks, development of gullies due to erosion, washing away of the road shoulders, wearing away of surfacing and pavement markings, faulty street lights, faulty drainage systems, faulty traffic signals and wiping off of pavement markings. In the Local Governments, village roads are minor roads that provide access within the various villages.

One way to understand why roads fail in Nigeria is to take a little lesson on the makeup of the road structure; that is, to know what roads are actually for. A paved road surface provides a means for vehicles to move or commute without sinking into the surface. Vehicles concentrate a lot of weight through small surface areas provided by the tyres. Paved road surfaces allow this weight to be carried, then distributed down into the soil, until they actually dissipate through well known structural mechanics principles explained in Geotechnical engineering by the theorems of Boussinesq, Newmark and Westergard. The distribution of stresses takes place in such a way that the ground under the road supports the weight without distorting (undue settlement and bearing capacity failure). The structure of a road is actually called the "**pavement**". It is a Victorian term from the English who have bequeathed it upon the scientific community.

Figure 1: Nigerian Road Network

There are two main types of pavement (road structure) namely the **Flexible** and **Rigid** pavements. There have been arguments as to whether the use of Rigid, rather than Flexible Pavements would lead to Pothole-less and more durable roads in Nigeria. Rigid roads, in the sense of time, preparation, forming, materials and costs, are more complex to build, requiring more specialized and more sophisticated equipment. The current **global** preference within the road building industry is to use flexible pavements; and sometimes composite roads. Rigid roads consist of a thick concrete top surface and the truth is that they too can develop potholes. Where voids appear below the surface, in a flexible road, the surface will deflect permanently (sink) to fill in the space in the void. This will not (normally) happen with a rigid or composite road since there is a bridging effect by the pavement though this will depend on the size of the pothole. The danger here is that in exceptional circumstances where a large void has appeared, eventually the unsupported concrete will collapse and the catastrophe can be more devastating. Composite pavements (road structure) are where a flexible layer has been added on top of the surface of a rigid road, or where a concrete layer exists below a bitumen top surface. This can generally be classified as a rigid pavement because it has to be constructed as the main supporting layer before an overlay of flexible pavement for seepage control and smooth, less rugged driving surface.

Road failure can refer to either total collapse or the appearance of defects. A road defect can be defined as the appearance of visible evidence of an undesirable condition in the pavement affecting serviceability, structural condition or appearance. The defect includes any part of a road, highway, or its construction that does not meet the regulations for a safe road. In Nigeria, the defects that most often cause injuries to people or damage to vehicles include: inadequate road shoulders, lanes that are non-uniform, a pavement that is uneven, improper road markings and signs (if they exist at all), malfunctioning stop lights in municipal settings, construction negligence, and municipal negligence. These lead to accidents on Nigeria roads that continuously engage enforcement agencies like the police, road safety officers, even the military and Para-military, etc. Some paved roads have lost their asphalt surface and are in very poor condition or have reverted to being gravel roads. Some of the road systems are barely usable, especially in high rainfall areas; and many in the impoverished States of the northern and eastern parts of the country.

Many urban roads are tarred while some are still un-tarred. In State capitals, the advanced urban roads possess traffic facilities like street lights, drainage facilities, pavement markings and traffic signals. Rural roads are mainly earth roads; but with recent developments in the rural areas, some of them are now lightly tarred. In the developing world which includes Nigeria, road network is the most developed transport mode and the vastest in usage. The Nigerian Government over the years has tried to construct and rehabilitate the roads. Considerable interest has been shown by the Government to road investment. The issue has been the extent these interests have been driven to achieve the desired result. According to Oguara (2010), roads represent the major areas of investment in transportation and are the most dominant travel mode accounting for over 90% of passenger and goods transport in Nigeria. If a road is properly designed and built, it will remain in good condition for many years with only minimal maintenance. The positive consequence of this is keeping the traveling public satisfied, the politician's happy, and allows time for public and private officers in charge of roads to attend to other critical matters.

2 FLEXIBLE CARRIAGEWAY CONSTRUCTION

For Nigerian roads to be functional, not to be classified as failed, they should be able to possess the following characteristics:

- Give all-weather support to vehicles to bear and distribute wheel loads to within the bearing capacity of the sub-grade soil.

- Boast of adequate drainage facilities to provide free flow of water and flood along its drainage system so that water will not flow back onto the pavement to cause problems.
- Provide adequate skid resistance; thus providing enough frictional adhesion to vehicle tyres especially during acceleration, deceleration and at road geometrical curves.
- There should be conformity of geometrical features with optimal standards of design of road and lane widths, super-elevation, horizontal and vertical curves, intersections, side slopes, sight distance, etc.

There can be rigid pavements primarily made of reinforced concrete surfacing. But for the majority of cases, Nigerian roads are primarily flexible pavement type made up of several layers of different materials. The in–situ soils, called the subgrade, serve as the foundation that supports the road. When a roadway is constructed on an embankment, the imported fill material constituting the embankment becomes the subgrade. After removal of topsoil and other organic materials, the subgrade may be stabilized by compaction alone, or by compaction after mixing in asphalt emulsion, Portland cement, lime, or other proprietary stabilizing materials. On top of the subgrade, a base layer is usually constructed from good quality gravel or crusher-run aggregates. When heavy traffic is expected, the base layer is usually hot mix asphalt (HMA). In some cases, because of very poor subgrade soils, construction of a subbase layer may be necessary to serve as a construction platform to prevent the intrusion of fines into the base, improve drainage, or reduce damage from frost action. For convenience, it is mandatory on Nigerian roads that a subbase layer is provided on all roads. The subgrade or embankment fill actually bears the traffic loads. The upper pavement layers support the wheel loads and distribute them across a wider area of the subgrade, which are stressed with much lower pressures as a result of stress distribution that can be predicted using standard analytical procedures, some eloquently laid down by Matawal (2012). In the typical load application pattern, the wheel load applies a downward pressure on the road surface. The load is spread out and reduced in intensity by the various pavement layers. The pressure in the subgrade is much less than the tyre pressure on the pavement surface. The tyre deformation on the surface causes compressive stresses in the top layers of the pavement and tensile stresses in the bottom. If the deflection is large enough and occurs enough times, the tension stresses can cause a fatigue crack at the bottom of the layer. Additional loads cause this crack to migrate upwards until it reaches the surface. Surface water can then penetrate through the crack into the base and weaken it. This causes larger deflections in the adjacent pavement and more cracks will develop until pavement failure (alligator cracking) occurs. If the pavement is thick enough and/or the subgrade and base are strong enough, deflections and stresses are reduced, and load–related cracking may not occur for many years resulting in a long pavement life.

When a road is built, the surface of the ground must be excavated after general clearing to remove all organic soils as well as topsoil to the designed depth of the intended road. Organic soils and Topsoil do not support loading and even though they may appear strong in the dry OR semi-dry (partially saturated) conditions, they will actually collapse in contact with moisture leading to failure and even washouts of road pavement. On the removal/scrapping of the undesirable top layers of the soil to the designed depths, preparation is carried out on the exposed ground through a combined action of charging with soil, mixing, and compaction using appropriate construction plants such as scrapers, dumpers, excavators, dozers, caterpillars, roller compactors, etc. The road pavement itself will then be built up above the prepared surfaces and it usually consists of four (4) layers placed in the order shown in the sketch in figure 2, on the next page, which is standard all over the world.

Surface Course

Binder Course

Base Course

Sub-Base Course

Capping

Sub - Grade OR naturally existing Soils
//

Figure 2: Flexible Road Structure typical cross-section

Because the stress transmitted through the road structure from the Vehicles spreads and dissipates with depth, the stress concentration is only majorly pronounced in the upper layers and so stronger and more expensive materials are needed in the upper levels. Additionally, the nearer the surface, the flatter the profile must be to provide the ultimate geometry of the road cross-section. This is obviously because an uneven surface will be uncomfortable for vehicle occupants and will wear more quickly (each time a vehicle hits a bump, it is in effect hammering the surface). These factors are the main reasons for the layered construction of the road.

Loading or any extra weight on any "loose" (unbound) material will compact it with time, as the material is forced down to fill the gaps and voids. For this reason, during construction of each layer, artificial compaction is carried out. In fact, each of the layers of the road structure are usually laid in layers themselves, with further compaction taking place each time.

The design Life-span of Roads in the UK, and by implication in Nigeria which adopted the British standards, is 40 years, with a major reconstruction in the middle (20 years), before needing to be completely reconstructed. However, the Life-span of a road can be drastically reduced by greater than expected increase in traffic, though a certain amount of traffic growth is allowed for in projection when the road is designed. All components of Traffic, such as the **existing traffic** at the time of design, the **generated traffic** as a result of the new road, the **attracted traffic** from other roads and, of course, the **projected traffic** for the designed Life-span are usually expressed in equivalent PCU (Passenger Car Units). However, the main and frequently only factor taken into account in designing the pavement structure is the expected amount of commercial vehicles. This is because the damaging effect of an 8200kg axle load is 100 times that of a 2700kg axle load; taking cognizance that even the latter being greatly more than the axle load of a private vehicle, the single unit called PCU.

2.1 The Sub-base Course

The sub-base course is the layer immediately overlying the massive Subgrade which could be naturally existing soil OR imported soil in case of backfilled terrains. It should normally be laid as soon as possible after final stripping OR scrapping to formation level, to prevent damage from rain or sun baking which could cause surface cracks. The fact that this is required when roads are constructed emphasizes the importance of backfilling excavations quickly and properly and preventing ingress of moisture when roads have been excavated for utility works.

The most commonly used material for use in sub-bases is termed Type 1: Granular cohesionless sandy-gravelly soil. This is an unbound material made from crushed rock, crushed slag, crushed concrete, recycled aggregates or well burnt non-plastic shale. It contains particles of various sizes, the percentage of each size being within a defined range. Up to 10 percent may be natural sand. The pre-defined and calculated range of material sizes contained means that once compacted, it will resist further movement within its structure and consequently maintain stability even when there is ingress from moisture OR water. In other words, it tends not to settle, consolidate (OR sink) with time; though it will certainly settle if not properly compacted properly when laid. Other materials used for the construction of sub-bases include bituminous-bound materials and concrete and cement-bound materials, including wet-lean concrete.

2.2 Base Course Materials

Again, Type 1 is most commonly used; other materials include Type 2 and Type 3, which are Slag bound material used to be known as Wet Mix. It is a plant manufactured granular aggregate. It must be laid and compacted quickly, as this must take place within 6 hours of adding the GBS and activator components. Various other materials are less commonly used.

All materials on arrival from the plant must be protected from the weather, as drying or wetting changes the composition. They must be spread evenly. They are laid in layers of 110mm - 225mm compacted thickness, the thickness of the layers being gauged by various means including pegs and lines, sight rails and a guide wire. In initial build and reinstatement, the thickness of the layers depends on the compaction plant being used. Bituminous base materials are either dense base macadam or rolled asphalt. Various concrete and cement-bound materials are used; the specifications for these being different to those that apply to sub-base materials.

2.3 Surfacing Courses

Both the surface course and binder course are included in the part of the road structure termed the surfacing. Occasionally the surfacing is laid as a single course. Normally, it is laid as two courses of binder and surface.

The binder course helps distribute the load of traffic from above unto the base course, which is usually a weaker material. It also provides a flat surface onto which the normally thinner surface course is laid. In new construction, typical thickness is between 45mm and 105mm. Thickness may vary considerably where a new binder course is laid to an existing road structure for strengthening purposes. Stone sizes used are 20, 28 or 40mm. The thicker the binder course, the larger the stone sizes. Materials used include open graded macadam, dense coated macadam and rolled asphalt.

Surface courses are laid in a wide range of bituminous materials, ranging in thickness from 20 to 40mm. The material selected is dependent on the anticipated traffic intensity. The two most commonly used surface materials in English speaking countries are hot-rolled asphalt, HRA, and stone-mastic asphalt, SMA; the HRA being the most common in Nigeria.

Hot rolled asphalt is made with high fines and asphaltic cement content with crushed rock, slag or gravel added. Normal thickness is 40mm with 20mm coated chippings rolled into the surface providing better skid resistance.

Stone mastic asphalt is not as susceptible to rutting as other surfaces and reduces surface noise. Normal layer thickness is between 20mm and 40mm.

3 GENERAL FAILURE OF ROADWAY PAVEMENTS

There is not just one type of road failure, and there is not just one reason for each type of failure, and it is in these situations where it is very difficult to simply make passing statements that can be all encompassing OR that can replace an experienced engineer/technician with a guide that will suddenly change even limited experience in the field.

3.1 Pavement Structural Failure

This situation refers to the situation when the PAVEMENT has failed, maybe not completely, but in a major and conspicuous way. The pavement is no longer able to absorb and transmit the wheel loading through the fabric of the road without causing fairly rapid further deterioration of the road pavement. The layers making up the pavement have failed for various reasons, e.g. through age, inadequate design, poor construction techniques, poor foundation materials, or an altering in requirements of the strength of the pavement by increased traffic flow/weight, impeded drainage, decreasing subgrade strength, etc. When there is structural failure, the solution is always a form of RECONSTRUCTION.

3.2 Failure of a Road Pavement: Design-Drainage–CBR

Drainage is one very important feature that is highly and significantly responsible for road pavement failures. The water-table must be kept low to prevent the moisture content of the subgrade increasing; and hence decreasing both the shear strength and also the CBR value that was used to design the road pavement. Sub-drain systems such as French drains or even open ditches can be used to lower and lead off the water in areas of low water table; otherwise the road will weaken and fail. The water-table of naturally occurring ground will rise and fall from the wet season to dry season. This must be borne in mind when designing the road; and design for the highest water table conditions will yield best results. The road pavement itself must be constructed so that it will drain in the event of a failure of the integrity of the surfacing layers; which act as protection against surface percolation of water to the underlying sensitive layers. The internal drainage function of a road pavement can usually be performed by a drainage blanket layer, which itself must also be drained. Water table and moisture below the road pavement must be kept low and not allowed to rise up into the construction layers (because water can flow upwards, by capillary action). Water that enters the road pavement from the surface must have a drainage path out.

3.3 Road Pavement Failure - Water Damage - Poor Drainage

Once water has entered a road pavement, water damage is initially caused by hydrostatic pressure. Vehicles passing over the road pavement impart considerable sudden pressure on the water. This pressure forces the water further into the road fabric and breaks it up. This process can be very rapid once it begins. Water that has entered the road pavement and is subject to the process of freezing and thawing during the winter also brings about the swift failure of the road pavement. Eventually the water will descend to the subgrade layer below the road pavement and weaken this layer thus lowering the CBR of the subgrade which the road pavement design was based upon, and deep seated failure of the road will begin.

3.4 Premature failure of a road

The material, whatever it is, hot rolled asphalt (HRA) surface course (wearing course), surface dressing or structural concrete will fail before its predicted design life-span. This should not happen unless something was wrong at the time of construction or has gone wrong at the time of service. It is necessary to determine whether the design, specifications, supplied materials or workmanship was inadequate. Except in obvious cases of failure, this can be difficult to determine especially as financial considerations often outweighs revealing the true problem, and reputations can be at stake because client Engineers and Contractors can be very deadly in search of reputation and maximizing profits.

3.4 Workmanship as cause of Failure

Before blaming materials as the cause of failure, because it may be "convenient" to both Contractor and Engineer, it is suggested to look closely at the standard of workmanship employed in laying/using the various construction materials. There is need to bear in mind that some materials, especially hot bituminous materials, do need the right weather conditions to allow successful laying, however good the possible workmanship may be. First, it is important to determine whether the quality of workmanship available was suitable for the nature of the work to be done. Contrary to the generally operated practice and therefore opinion held in Nigeria that road maintenance and construction can be performed by any type of workmen or company, and achieve quality of work, it is to be noted that quality men and good quality plant for quality work and enough of them is required for the job in hand. A good kerb-layer (with no black-top experience) sent to lay HRA will lead to problems. It is also true with the converse that "black-top" operative is not likely to be too good at laying kerbs, etc.

4 PAVEMENT - SPECIFIC FAILURE OF ROADWAY LAYERS

Overall, if failure is in the asphalt pavement, it can be either cracking, distortion, disintegration or other surface defects.

4.1 Cracking

The selection for a maintenance and/or rehabilitation treatment is dependent upon the cause and extent of the distress. It is necessary to be able to recognize the crack type and consequently its causes. Generally, all cracks greater than 6.3mm in width should be sealed to prevent the infiltration of water and incompressible materials (rocks, sand, etc) into the crack and the underlying pavement structure. Water entering a pavement's base soils through a crack can cause significant weakening of the base and, if left untreated, will lead to the formation of additional cracks and eventually, collapse of the pavement. The types of cracks include: reflective, alligator, thermal, block, linear, edge and slippage formed as follows:

a) **Reflective cracks** form on an asphalt overlay directly over cracks in the underlying pavement. The pattern reflects the original crack pattern and can be longitudinal, transverse, diagonal or block especially prominent in asphalt overlays on rigid concrete pavements; they appear very quickly.

b)**Alligator or fatigue cracking** is a series of interconnected cracks that look like the skin of an alligator or chicken barbed wire. They are caused by repeated large deflections of asphalt pavement under heavy traffic. The bending and unbending of the pavement under these heavy loads cause the pavement to crack due to fatigue because the pavement was too thin; base or subgrade materials were of poor quality or saturated with water; traffic loads were too much for the pavement; the asphalt in the mix has become oxidized and brittle; there is high moisture content and poor drainage beneath the pavement. Generally, alligator cracked areas, due to a poor base, are not large but when associated with repeated heavy loads however, they can cover entire pavement sections. With thin asphalt pavement (<100mm), alligator cracked areas can quickly progress to potholes.

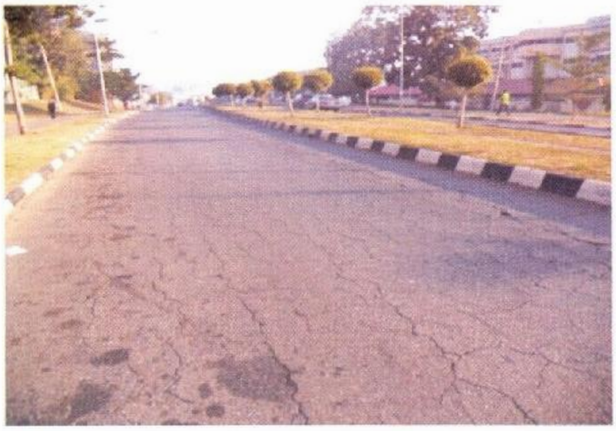

Figure 3: Alligator Cracking at initial formation stages

c) Thermal or low temperature cracks are transverse cracks perpendicular to the road centre-line and are generally equally spaced along the roadway. They result from low temperature contraction of the pavement, usually initiated at the surface, and grow downward into the pavement. As the pavement contracts with falling temperatures, the asphalt binder cannot relieve the stresses and it cracks. Temperature cycles accelerate this problem. While aggregate is the major contributor to pavement strength, the resistance to thermal cracking is almost wholly determined by the properties of the asphalt. Thermal cracking is mainly a cold weather phenomenon but will occur in Nigerian climates when harder asphalt (that will crack at higher temperatures) is typically used to combat hot weather pavement problems, such as rutting.

d) Block cracks is where the pavement divides into rectangular pieces ranging from 300mm square to 3000mm square. It is more common on low-volume roads and on large paved areas such as parking lots. Because these pavements typically are not as well compacted as major roads, higher air voids are a suspected cause and they are not load related.

e) Linear longitudinal cracks can be a paving joint phenomenon most commonly found on all classes of roads. It is caused by the inability to fully compact the unconfined edge of a paving pass. The resulting low-density mix has insufficient strength to prevent cracking and will allow the asphalt to prematurely oxidize, harden, and eventually ravel. Another longitudinal crack frequently occurs between the wheel paths when segregation will occur where the two paver slat conveyors drop the HMA in front of the paver augers. Longitudinal cracks in the wheel path are usually load related and can lead to alligator cracking. In temperate regions, frost heaves in the base or subgrade can also cause longitudinal cracks.

Figure 4: Linear longitudinal cracks

f) Edge cracks are longitudinal away from the pavement edge with or without transverse cracks branching out to the shoulder. Lack of lateral or shoulder support is the most common cause while settlement of the base soils, poor drainage and frost heaves (in temperate climate) are other causes.

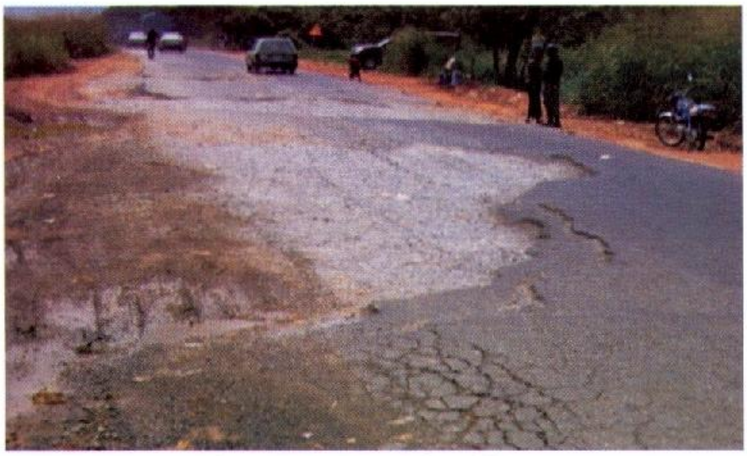

Figure 5: Edge Cracking

g) Slippage cracks are crescent shaped cracks resulting from traffic-induced horizontal forces caused by a lack of bond between the surface layer and the course below. This lack of bond may be due to dusts, dirt, oil, or the absence of a tack coat prior to placing the surface course.

Figure 6: Slippage cracks

4.2 Distortion

Pavement distortion is the result of asphalt mix instability, movement, or weakness in the granular base or subgrade. Cracking may accompany some types of distortions; and it can take many forms, but rutting and shoving are the most common.

a) Rutting from ruts are channelized depressions in the wheel tracks of a pavement surface. In severe cases, uplift on the outside of the rut may occur caused by consolidation, moisture, or movement in the subgrade or aggregate base under traffic loads. However, experience on many world roads also reveal that ruts can only be in the top layers of the pavement, caused by trucks carrying heavy loads on tyres with greatly increased inflation pressures on pavements not designed to withstand that kind of stress. Mixes which have too high asphalt content, too high fines content, round and smooth-textured aggregates, and too soft an asphalt cause rutting but improvements in mix design procedures, aggregate specifications and testing can significantly reduce rutting problems. On cold mix pavements, lack of aeration or curing of the emulsion can result in a tender mix that will rut.

b) Shoving or corrugations (or wash-boarding) are a form of plastic deformation that results in ripples across the pavement surface. They typically occur when there is severe horizontal stress where traffic starts and stops, or downgrades where vehicles break, at intersections, and on sharp horizontal curves. Corrugations are usually caused by too much asphalt or too soft asphalt in the mix.

4.3 Disintegration

This is the breakup of a pavement that begins with the loss of the fine aggregate particles from the pavement surface and progresses to the formation of potholes. Three types of pavement disintegration are raveling/weathering, de-lamination, and potholes.

a) Ravelling/weathering is the progressive loss of aggregate from the pavement surface beginning with the loss of the fine aggregate. As time progresses, larger aggregate particles come loose because of the lack of support from the surrounding lost fines. Ravelling is accelerated in the wheel paths by traffic. Weathering occurs over the entire pavement surface including the non-traffic areas; both water and traffic usually combine to cause extensive ravelling, which is caused primarily by high air voids in HMA due to poor compaction or late season paving. Too little asphalt or overheating of the asphalt in the HMA plant can also result in ravelling.

b) Delamination is the localized loss of the entire thickness of the overlay caused by the lack of bond between the overlay and the original pavement. Water is also the chief culprit when it gets between the two layers of pavement. Delamination is usually confined to the wheel-path area and takes several years after the overlay to become a serious problem but once it occurs, is very difficult to properly patch. Cleaning the old surface and applying a light asphalt emulsion tact coat will go a long way toward alleviating this problem. A tact coat is especially helpful when the overlay thickness is less or equal to 50mm.

Figure 7: Delamination

c) Potholes are well known bowl-shaped holes, of various sizes, in a pavement resulting from localized disintegration under traffic. They can start with a small crack that lets water in and weakens the road base, or a small area of ravelling that goes full depth, or a whole bunch of potholes can occur overnight in an alligator cracked area of a thin pavement. Poor soils, poor drainage, too thin an asphalt surface, poor compaction, and poor pavement maintenance can all lead to potholes.

Figure 8: Different types of Potholes

4.4 Failure as consequence of Surface Defects

Bleeding or flushing is the upward movement of asphalt to the pavement surface resulting in a smooth, black, shiny appearance that is sticky in hot sunny weather. The most common causes of bleeding are the loss of stone cover in a chip seal and the over-compaction of a tender HMA mix by heavy traffic. Overly rich asphalt mixes and application of a very heavy tack coat or excessive crack seal materials are other possible causes. A bleeding surface is very smooth and as slippery as a soap-foamed glazed tile surface. Since most bleeding occurs in the wheel-paths, it is serious safety hazard that must be dealt with immediately it occurs. On the other hand, pavement skid resistance is dependent on contact between a vehicle's tyres and the aggregates in the pavement surface. Clean dry pavements have high friction values but even a small amount of rainwater can dramatically change a vehicle's stopping distance and its ability to negotiate curves. To develop adequate friction, a tyre must squeeze the water out between its tread and the stone in the pavement surface. When soft aggregate, such as limestone, is integrated in an asphalt surface mix, it gets **polished smooth** by traffic, loses its ability to squeeze out the water, and the pavement can become slippery.

5 REHABILITATION OF ASPHALT PAVEMENTS

5.1 Detecting Road Pavement Failure

Probably the simplest question for most Nigerians to answer is the fundamental way of determining a road pavement failure. This is because most of us drive and road pavement failure is simply the appearance of deep gapping potholes on our highways. But the truth is that this represents the worst and ultimate deterioration of the roadway because the failure of the pavement should have long been detected and remedied before reaching such an appalling condition. For this purpose, Road pavement failure should be considered from the early stage when it is not even so visible and obvious to the road user. The use of **Deflectograph Survey** developed by one of the two British equivalents of the Nigerian NBRRI, the UK Transport Research Laboratory (TRL) measures the amount a road pavement will deflect when subjected to a standard load, the load being supplied by the rear wheels of the vehicle being correctly weighted. Pivoted measuring arms pass between the pairs of rear wheels and measure the deflection of the road, in one hundredths of a millimetre, when the wheel load is applied. Basically the more a road deflects, the weaker is the pavement BUT other factors have to be applied to the deflection results before assessing the road strength, e.g. the temperature at which the survey took place and the nature of the construction of the road pavement.

A **Deflectograph** usually refers to the machine i.e. the Vehicle with the specific deflectograph apparatus built into it. The deflectograph machine is used to carry out a deflectograph survey. TRL Reports 833, 834 and 835 as example, refer to specific practical TRL surveys that were carried out to determine weak areas of highway prior to actual failure and determine road strengthening measures to prevent failure, in advance.

On the whole, a solution to any failure might as well depend on the diagnosis and nature of the problem as some may involve the construction of special features to address the specific nature of failure. For this reason, there may be general and pavement-specific remedies.

5.2 General Solutions for Roadway Failure

General solutions have to be designed to address issues such as poor subgrade, gradation, permeability/drainage, capillarity, plasticity in zones outside the tropics and frost susceptibility of the soils; Slope stability, general drainage (especially storm-water and side drains and culverts/bridges), erosion control, poor CBR or weak base soils, etc. It was already noted that when there is road structural failure, the solution is always a form of Reconstruction. This is emphatic because it is not always necessary or even advisable to remove material that is still sound and will provide a good base to do new work, so it can be referred to as a major form of reconstruction. It is therefore important to conduct proper field soil investigation and analyses before making the decision. The cause of the road pavement failure can actually be determined technically using Site Investigation via employment of Trial hole method. If the Civil (Geotechnical and/or Highway) Engineers is not clear of what is in the existing road pavement, they should dig a hole and undertake a physical examination and both in-situ and laboratory testing, providing they know what they are looking for OR they should consult experts. Even simple indicators like the degree of difficulty in digging the hole will give an indication of the strength of the materials that make up its construction. There is very little substitute for experience in trial hole assessment but some things are common sense:

i. How thick is the construction, how thick are the various layers.
ii. What types of materials were used: bituminous, concrete, granular; and what condition OR state has it developed to?
iii. What the height of the water table is.
iv. What is the type of subgrade, what are the geotechnical and strength indices, like CBR, of the subgrade.
v. Is the road pavement material excavated in sound condition or disintegrating and loose?

All these questions and even more need comprehensive answers to arrive at the new road design. Trial holes are not expensive and can save a lot of money; an intimate field knowledge of the road as proposed for redesign/strengthening is never wasted.

Failure of the road pavement due to either poor external or internal drainage is important. In many roads, maintenance works on the pavement surface layers last only short periods of time because the actual problem of drainage was never addressed in the first place. Therefore, there may be need to reconstruct to provide a drainage blanket and sub-drain system or to construct side drains to lead flood and stagnant water off. Frequently, the whole road embankment may need to be completely installed to solve the problem.

The influence of moisture in soils is tremendous and is illustrated simply by the 'Effective Stress Principle' (Matawal, 1987) and so in impervious soil conditions, drainage blanket, which itself must be drained should be provided. Water table and moisture below the road pavement must be kept low and not allowed to rise up into the construction layers

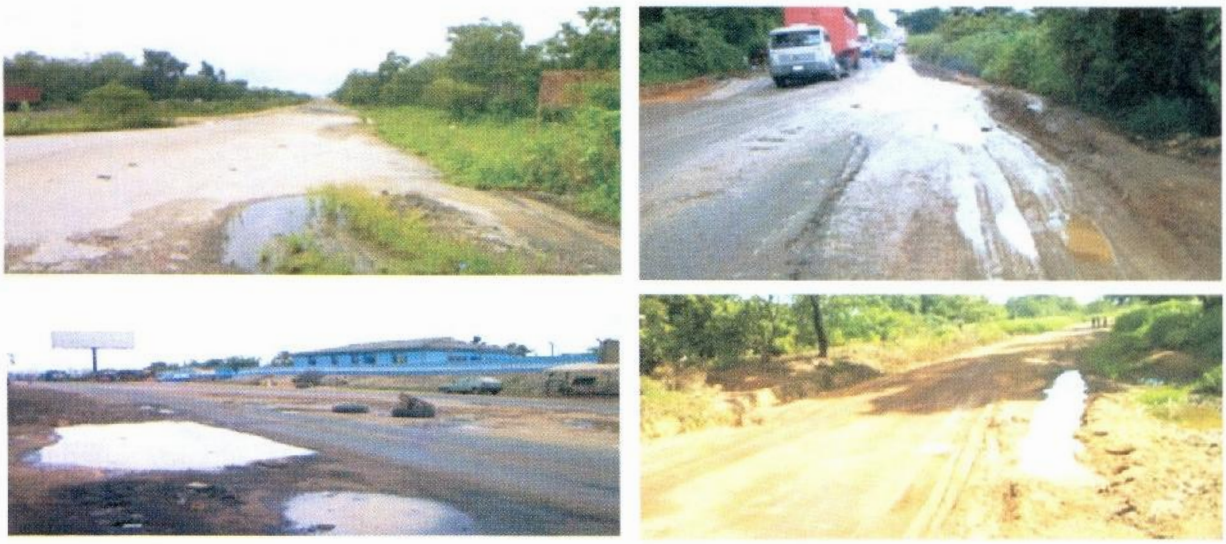

Figure 9: Failed Pavements due to Poor Drainage

Another dangerous remediation situation is erosion of side-slopes. Generally, if slope stability analyses are properly undertaken at design, this can be averted; but unfortunately, little attention is paid to this matter because of the complications of the rigorous analytical models. Consequently, designers make simple references to existing specifications which are unavailable for our own soil types since they are environment-specific. The result is usually large scale landslides, in some instances, that even sweep away the roadway and its foundation; they are confined to the hilly terrains of the Jos Plateau and the huge cuts/fills and embankments on Abuja - Lokoja road, approaches to Enugu from Ninth-Mile, etc. However, in a majority of cases in Nigeria, the problem is that of erosion due to lack of proper drainage, which must be provided as a solution.

In all circumstances of failures, unless due to normal tear and wear, the theoretical position is that reconstruction or rehabilitation should normally be at the end of life-span of the roadway. Of course, routine maintenance should be undertaken of the surface layers and some roadway feature elements, but this should be a planned event and not extensive. Therefore, the presumption always is that the workmanship employed for laying/using the various construction materials was standard.

Figure 10: Failed Roadways due to Erosion and Poor Drainage

5.3 Rehabilitation of Asphalt Pavements

There are many treatments for asphalt pavements that are showing signs of distress. Treatments can be divided into four general categories:

- **Preventive Maintenance (PM):** Preventive maintenance treatments may correct a minor defect, but are primarily intended to prevent further deterioration and extend the life of a pavement. Micro-surfacing, surface treatments, and crack sealing are examples of PM treatments. They may improve rideability but do not add structural strength to the road.
- **Corrective Maintenance:** Corrective maintenance treatments correct existing defects and deficiencies until more permanent and extensive treatments are necessary. Single course 25–37.5 mm overlays, hot in-place recycling (<25mm), and "mill and fill" overlays are examples.
- **Preventive rehabilitation:** Pavement rehabilitation treatments are intended to address serious pavements failures and restore the roadway to a condition that will ensure a service life of 10 to 20 years with normal maintenance. Pavement rehabilitation treatments include two-course overlay, hot in-place recycling with an overlay, cold in-place recycling with an overlay, and full-depth reclamation.
- **Pavement reconstruction:** Pavement reconstruction treatment is essentially "take it up, throw it away, and start rebuilding from the bottom up." The existing pavement condition is such that it can no longer serve a useful purpose, and a life cycle cost analysis would have suggested or shown that other treatments are not cost-effective.

The life of a surface dressing on a very heavily trafficked road can be relatively short. Unfortunately road surface failure is often due to poor surface dressing, i.e. fatted surfaces, or lost chippings. These can be rectified with remedial surface dressings performed with more care, but very often fatted surfaces need to be replaced with thin bitumen macadam wearing course, e.g. 10mm sized aggregates.

5.4 Road Surface Failure - Fretting – Fretting out of Road surface

This term, or the term fretting out are the terms used to describe a surface material that is beginning to lose its surface gradually, usually due to age, but it can happen when the binder has been overheated in mixing; thus prematurely ageing the binder. As already noted, fretting is not general failure or structural failure but is a surface failure. As long as overheating of the binder is not the cause of the failure, further life may be obtained from the surfacing material by the application of a suitable surface dressing. This can delay for many years the need to OVERLAY or reconstruct the road. The surface dressing will seal and hold the fretting surfacing material.

5.5 Surface Course (Wearing Course) failure

In analyzing the types of failure, it is necessary to decide whether the wearing course material has failed altogether; if so, the material will need replacing. If it is in a relatively sound condition, an OVERLAY could be used if surrounding surface "levels" permit the addition of another road pavement layer. This process will increase the strength of the road pavement. On the other hand, the situation dictated from the failure condition may indicate that the skidding surface is no longer satisfactory but the material itself is still good, example bleeding failures. The anti-skid properties of the surface may be restored with a suitable surface dressing, or even restructuring. Problems such as wheel truck rutting also have to be considered; both the material and skidding surface may be adequate but there may be ruts of such depth as to be dangerous to vehicles passing through them on overtaking movements. This will mean replacement or OVERLAY with wearing course and, on occasions, even the base course as well.

5.6 Restoring Road Surface Skid Resistance Failure by Retexturing

These situations are not common in Nigeria where road surfaces hardly survive to warrant the restoration; but they are ***physical processes that will restore texture*** to sound surfaces that have become smooth through wear. One type of retexturing machine retextures by impacting the aggregate in the road surface with numerous small hardened steel hammers to roughen the aggregate surface. Another machine impacts the road surface with free moving discs mounted on a revolving drum. Although the texture can be improved with these processes, it must be remembered that the Polished Stone Value (PSV) of the aggregate will remain the same. The improvement in the skid resistance of the road surface is caused by the creation/breaking of the exposed aggregate surfaces and once again providing "sharp" angular edges to the exposed aggregate, similar to the state of newly crushed aggregate. The duration of the improvement in skid resistance will depend upon the actual quality/characteristics of the aggregate being retextured; but with good aggregate, an improvement can be sustained for several years. An improvement is also achieved by removing the bitumen/fines matrix between larger aggregate particles and thus increasing the macro-texture of the road surface. In foreign countries, there are various contractors able to provide machinery capable of the types of RETEXTURING process, both large lorry mounted and small hand operated units; but in Nigeria, resurfacing may be better option for now

6 CONCLUSION AND RECOMMENDATIONS

The job of a road is to carry the loads under all weather conditions for a specified design life. This is achieved, where extreme conditions exist, by:

- Stabilizing (strengthening) the existing subgrade and providing stable base and subbase layers above the subgrade
- Where it is impossible to stabilize, completely backfill (replace) the deleterious layers of

subgrade before providing the stable layers above it

- Providing adequate water and stormwater drainage, because water can weaken soils and asphalt pavements
- In constructing pavements, a structure should be provided that is First, thick enough to structurally carry all expected traffic loads for a period of time; Secondly, properly compacted to develop its full strength and prevent water penetration into the pavement and its base and; Thirdly, surfaced with a wearing course that resists wear, deformation, weather and remains skid resistant

Simply put, we need to build roads to support the loads that will pass over it through a designed life-span.

Having built good roads, it is important to protect these roads through routine and emergency maintenance and interventions to ensure that they are in service through their design life spans. This can be done by considering road pavement failure from the early stage when it is even not visible or obvious to the user. This requires professionalism and the use of technical procedures has been recommended in this paper. This is because most of us drive and road pavement failure to us is simply the appearance of deep gapping potholes on our highways. But the truth is that this represents the worst and ultimate deterioration of the roadway because the failure of the pavement should have long been detected and remedied before reaching such an appalling condition.

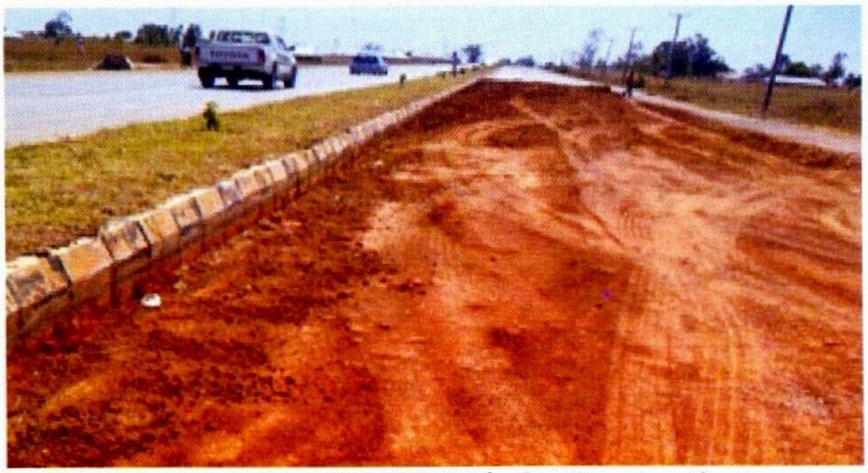

Figure 11: Pavement Failure during Construction

Also important is that before blaming materials as the cause of failure, because it may be "convenient" to both Contractor and Engineer, it is suggested to look closely at the standard of workmanship employed in laying/using the various construction materials in the field to avert errors that could lead to failure, in the first place. It is true that many roads in the country do witness pavement failure on the finished surfaces before the project is completed; even for road lengths as small as 30 kilometres. This is because of poor design and construction procedures which must be minimized. It is also necessary for regulatory agencies; particularly Police, Road Safety, the Military and Para-military to monitor the types of loads imposed upon these roads. From the analyses provided, it is clear that huge axle loads lead to the many typical failures described under cracking, distortion and disintegration.

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APPLICATION OF ROAD ASSET MANAGEMENT SYSTEM (RAMS) FOR IMPROVED ROAD MAINTENANCE AND MANAGEMENT IN NIGERIA

By

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ABSTRACT

The federal road network in Nigeria is an asset of national and strategic importance. Adequate maintenance and management of this asset is central to the overall socio-economic development of the country. A programme of work has been designed to implement an integrated road asset management system (RAMS) for an efficient and cost effective maintenance and management of Nigeria's over 37,000 km federal road network and 1,671 bridges with a total length of 177 km; thus enabling asset managers meet their overall business and operational objectives. The system is intended to assist road network managers to rationalize decision making in planning, programming, procurement and execution of works, and in the allocation of resources in order to make the best use of public funds in preserving the road network at an acceptable level of serviceability. RAMS will enhance the capabilities of asset managers by providing a source of readily accessible, relevant and valid information and data on the road as well as improved support for decision-making by providing analytical tools. The paper outlines current approach to maintenance and management of federal roads, describes the concept of an asset management system, and highlights the benefits of deploying an asset management system on Nigerian roads. It presents the different phases and work status currently being undertaken to implement an integrated road asset management system incorporating GIS-based Road Information System (RIS) & Bridge Information System (BIS), Pavement Management System (PMS), and Bridge Management System (BMS). Implementation issues including critical success factors and implications for road management and maintenance in Nigeria are discussed. The paper concludes by re-emphasizing the potential benefits of deploying an integrated road asset management system such as improvement in maintenance management and data collection, better network performance, monitoring and improved budgeting processes. Other expected benefits include human capacity development and improved communication.

1.0 INTRODUCTION

The national road network in Nigeria, currently valued at over N 5 trillion, is an asset of national and strategic importance as it plays a central role in the country's socio-economic activities. Nigeria's road density is 0.2 km per square km which is significantly more than the West and Central African average (0.06 km per square km). Nigeria has a total road network of about 200,000km owned by the Federal, State and Local Governments. Only about 39,500km of the 200,000km is paved mostly in bituminous layers. Out of this, the Federal Government owns about 29,500km representing 75% of the entire bituminous road network in Nigeria. The balance is shared between the 36 States and the 774 Local Government Areas. The road ownership structure pie chart in km is shown in Figure 1.

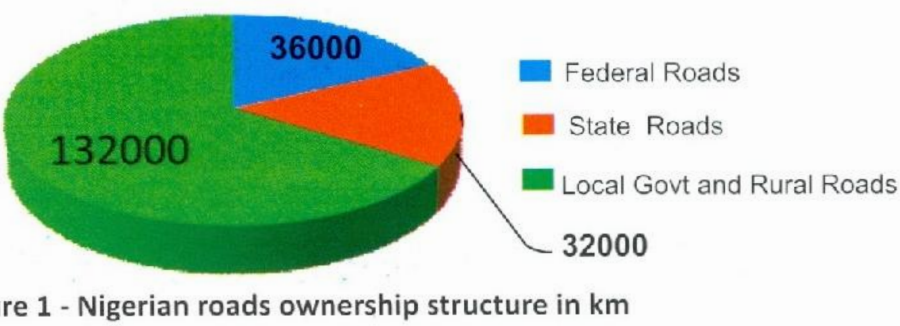


Figure 1 - Nigerian roads ownership structure in km

Currently most of the goods and passengers transportation in the country are carried by road. Although Federal roads constitute 18% of the total national road network, they carry more than 80% of the national vehicular traffic. In accordance with information from the Federal Ministry of Works (FMoW), other key statistics of the federal road network are:

- About 80% of the 35,000 km of federal roads was constructed as at 1983.
- In 1983, only about 150,000 vehicles were plying Nigerian roads.
- In 2000, about 1.3million vehicles were moving on Nigerian roads.
- In 2012, the number of vehicles on Nigerian roads rose to 9million. Yet, the total length of bituminous roads in Nigeria did not witness any appreciable increase to meet the demand.
- This has led to increased pressure on Nigerian roads, coupled with the non-availability of rail transportation for haulage these past 20 years.

Majority of the Federal roads and bridges were constructed, reconstructed, and rehabilitated during the era of the oil boom in the 1970s after the civil war. Little or no attention was given to maintenance works on the existing roads. With scant attention to other transport systems, the railways went systematically underground, waterways were not encouraged and every haulage and transport system depended mainly on the highways. All manner of loads, ranging from heavy containers from the ports, granites from quarries, petroleum products from refineries and ports and several tonnes of cement and construction materials, subjected Nigerian highways and urban roads to enormous stress and excess axle loads which remained unchecked. The roads became heavily stressed and distressed over the years.

Without strategic maintenance programme in place, these roads, under heavy stresses, exceeded their serviceability level and life spans long before their designed life span and they failed systematically; and eventually collapsed collectively, beginning from the 90s. At this time, about 30,000 km of Federal roads were in place to support the movement of commuters, goods and services from the Local Government/State roads into the various markets and different parts of the country, through the Federal highways.

A 2010 road condition survey found only 27% of the roads was in good condition with devastating consequences to the nation's economy:

- N88 bn (Eighty-eight billion Naira) loss due to increased vehicle operating costs
- N12 bn (Twelve billion Naira) loss due to delayed turn-around and increased travel time
- N75 bn (Seventy-five billion Naira) loss due to reduction in asset value
- Total annual loss to the economy in the order of N175 billion (One hundred and seventy-five billion Naira).

SOURCE: *"Roads Vision 2000" - The loss calculated at 2.5% of GDP*

From the foregoing, it is clear that a well maintained road network is expected to positively impact on the national economy, overall transport costs, safety; and associated benefits to the road user and the management agency by reducing road user costs and managing agency's whole life costs of operation and maintenance.

The paper is structured as follows:

- A background on Maintenance and Management of Nigerian Federal network
- Integrated Road Asset Management System(RAMS)
- Potential benefits in deploying a RAMS
- Critical success factors and challenges of RAMS implementation
- NIAF/World Bank support in the development of RAMS in Nigeria

2.0 MAINTENANCE AND MANAGEMENT OF NIGERIAN FEDERAL ROAD NETWORK

In Nigeria like many developing countries all over the world, great efforts have been made towards the improvement of road networks to drive national economic progress. Sadly enough however, in most cases, strategic and consistent road maintenance efforts have left a lot to be desired. It is good to ensure that the huge investment on road infrastructure does not become a waste. When roads are built and left to deteriorate and become death traps and return to tracks and gullies, it actually represents a huge waste considering the colossal initial capital investment.

2.1 Road Maintenance History in Nigeria

Pre-Independence to 2002 - The road maintenance efforts in Nigeria dates back to the pre-independence period when roads were virtually earth roads. At this time and soon after independence in 1960, roads were maintained by the Public Works Department (PWD), using workmen in gangs and road camps along road routes and managed by a headman or foreman. Years after independence, the Federal Ministry of Works took charge of the maintenance of all Federal trunk roads 'A' and 'F' using the agency arrangement of the State Ministries of Works and the Federal Ministry of Works Direct Labour Unit at Ijora in Lagos area, up to 1981. Thereafter, the maintenance of Federal roads was carried out in small contract groups across the country, supervised by Field Officers of the Federal Ministry of Works. This period up to 2002 was characterized by near complete neglect for road maintenance due to very poor or meagre funding. However, construction and rehabilitation activities boomed with the oil boom and the massive reconstruction efforts after the civil war, but with very scant attention to the maintenance of existing roads. The enactment of the Petroleum Special Trust Fund (PTF) in 1994 and the subsequent implementation of its National Highway and Urban Roads Rehabilitation programme between the years 1995 to 1999 came as a surprise rescue to the maintenance of Nigerian Federal roads network.

2002 – Date Realising the unacceptable level of near total collapse of the good road network due to postponed, delayed or total neglect of good maintenance programmes, the huge economic cost of years of neglected road maintenance and the World Bank's resolution on road maintenance in developing countries, the Federal Roads Maintenance Agency (FERMA) was established in November, 2002 by an Act of the National Assembly. The Agency effectively commenced operations in 2003. The establishment of FERMA was the first major effort of the Federal Government to institutionalise good maintenance culture on Nigerian roads and it was a stitch in time. The Agency has the statutory mandate to ensure the efficient and effective maintenance of all Federal trunk roads nationwide, make them pothole-free and serviceable all year round. This includes the provision and maintenance of road furniture and street lighting; all geared towards promoting the economic well-being of Nigerians.

2.2 FERMA Road Maintenance Activities

When the Agency commenced operations in 2003, it was faced with several challenges. They ranged from failed roads that required recovery to qualify for maintenance, additional failures as recovery commenced, funding challenges, relying mainly on annual subvention through appropriation, along with unabated excess loading and other bad habits on the roads. To brace up with the enormous challenges of several collapsed Federal Highways across the country, the Agency considered several measures in the short and medium terms which included; strategic analysis of existing problem, designing a sustainable strategy, evolving massive repair and road recovery approach; and now the Preventive Road Maintenance Strategy. The Agency has progressed with these measures.

All over the world, highway budgets continue to shrink because of competing demands for funds and attention. Therefore, the policy of Pavement Preventive Maintenance is preferred to the get-worst-first method (corrective and expensive), where roads get to highly distressed conditions before any restorative or reinstatement work is executed. Until 2011, the Agency's approaches in the past were more of corrective methods to recover the network of collapsed roads. However, while corrective repairs were in progress, additional failures developed and graduated into new challenges. Thus, the need to run the Preventive Maintenance Strategy along with the corrective efforts became imperative.

The Agency's overall approach to road maintenance and management addresses emergency works, maintenance backlogs, repairs safeguards and improvement on existing pavements. This is further illustrated as a function of pavement age as shown in Figure 2.

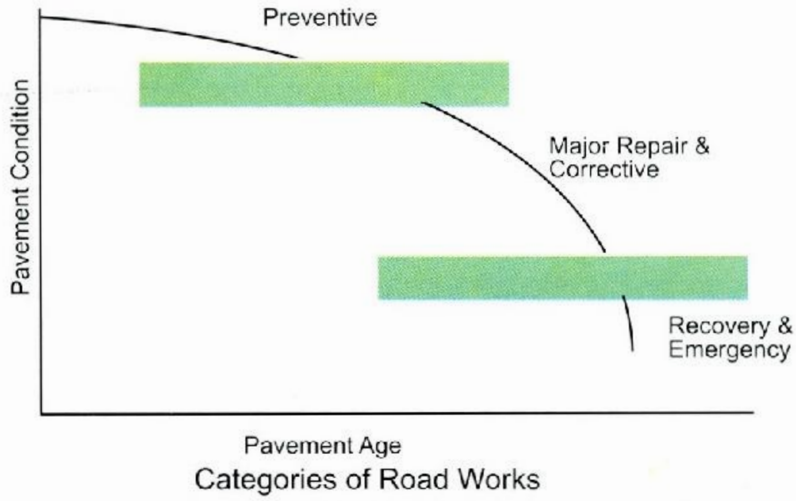


Figure 2: FERMA's Approach to Road Maintenance and Management

Preventive Maintenance Works

- Joint sealing (shoulders & carriageway joint)
- Crack sealing
- Pothole patching
- Pavement desilting
- Drainage desilting
- Provision of turn outs
- Surface milling
- Light inlay or Overlay
- Vegetation control
- Repair of markings
- Replacement of signs etc (road furniture)
- Provision of cat eyes etc.
- Street and bridge lighting maintenance

Major Repairs and Corrective Works

- Pavement strengthening along repaired/weak stretches
- Bridge repair works: Failed expansion gaps, abutment/embankment failures, bearings, transition slabs, damaged handrails, resurfacing
- Reinstatement of failed sections
- Drainage and shoulder repairs

Recovery and Emergency Works

- Recovery of collapsed roads
- Emergency interventions on roads and embankment washouts, and bridge embankment wash outs, dewatering of low lying locations etc.

The Agency and Federal Ministry of Works (FMoW) have made appreciable progress in improving the condition of the federal road network since the Agency's inception in 2003 as indicated in Table 1. However, a lot is still required to handle, effectively and on a continuous basis, the backlog of deferred maintenance and the resultant massive failure in the past.

Table 1: Conditions of Federal Roads in 2003 and 2010

	2003		2010	
Condition	Percentage	Km	Percentage	Km
Good	5%	1,706	27%	9,117
Fair	10%	3,412	29%	10,091
Bad	85%	29,002	34%	15,054

As more roads are recovered and new lengths added to the road network through upgrading such as dualization and new construction, the Agency's strategy is gradually moving away from a reactive maintenance regime to a preventive maintenance regime as illustrated in Figure 3. The latter is better suited and more amenable to structured decision support tools for cost effective and efficient maintenance and management of road assets.

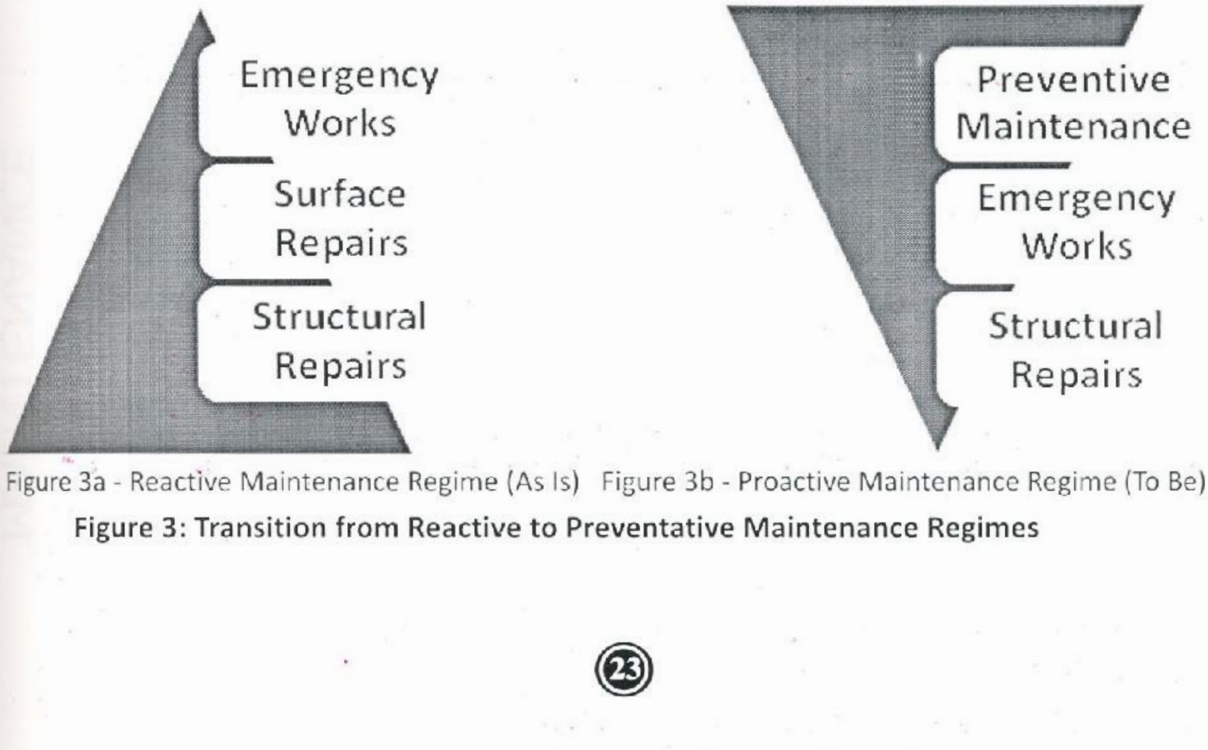


Figure 3a - Reactive Maintenance Regime (As Is) Figure 3b - Proactive Maintenance Regime (To Be)

Figure 3: Transition from Reactive to Preventative Maintenance Regimes

A typical flowchart for road maintenance programmes is shown in Figure 4. Adherence to the flow chart has been limited by paucity of quantitative data on road condition and predicted performance parameters. This is now being addressed through road condition surveys such as pavement structural strength survey using Falling Weight Deflectometer (FWD), Dynamic Cone Penetrometer test, and Road Roughness survey using ROMDAS to complement qualitative data from annual road visual inspection. However, locating historical data relating to as built records, construction age, loading history, initial cost, maintenance records, remain a challenge.

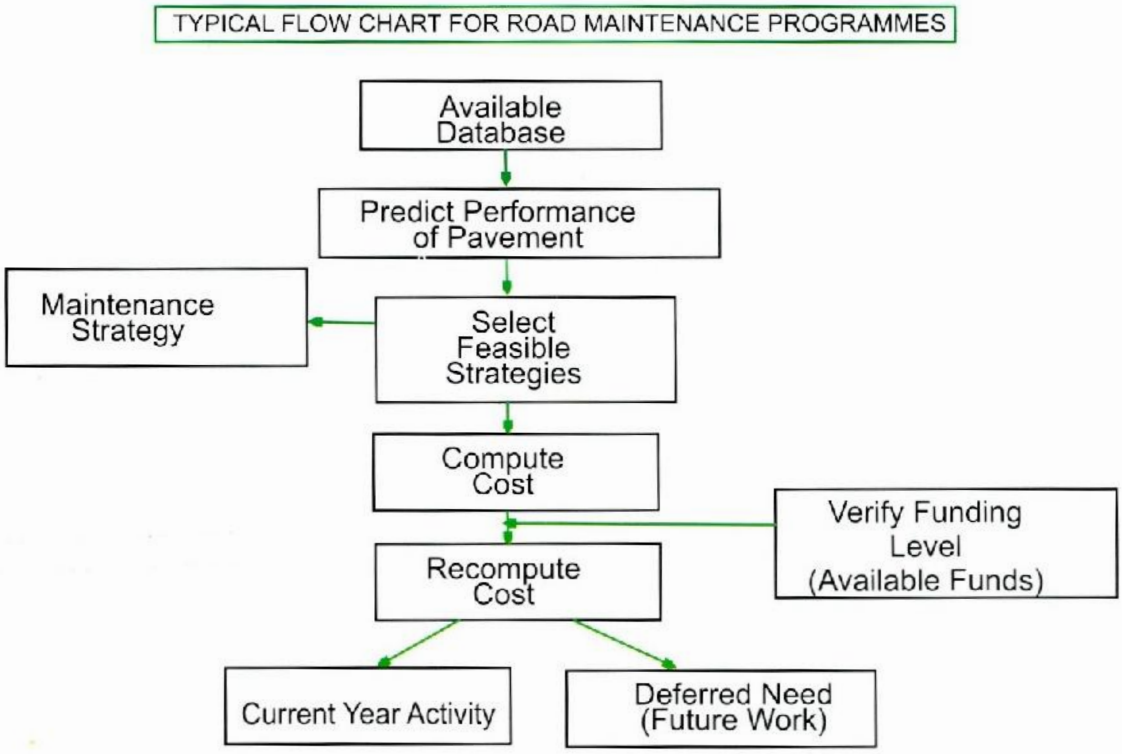


Figure 4: A typical flowchart for road maintenance programmes

Considering the need to adopt an integrated and holistic approach within the context of a good road productivity cycle as shown in Figure 5 to improve the maintenance and management of road assets in Nigeria, FERMA conceived and prepared a proposal to develop, implement and deploy a highways asset management for Nigeria's road network.

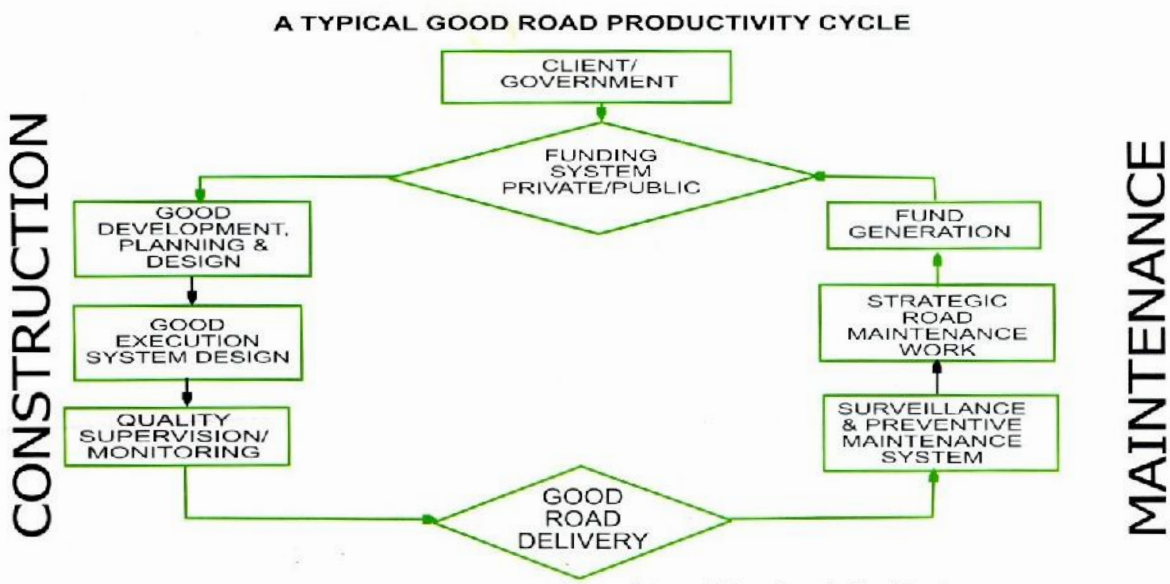
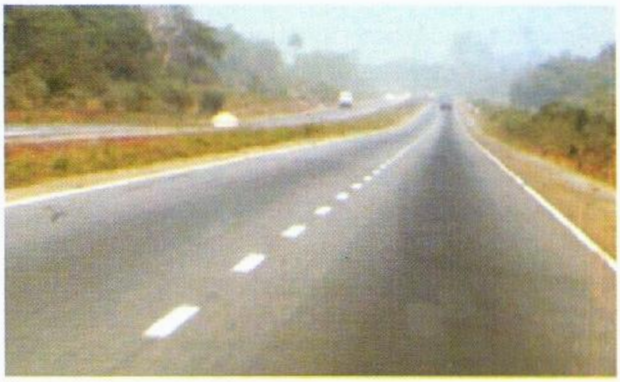


Figure 5: A typical good Road Productivity Cycle

3.0 INTEGRATED ROAD ASSET MANAGEMENT SYSTEM (RAMS)

Since the pre-Independence era, Nigeria's road network has grown and become more sophisticated. Consequently, the demand for maintenance has also increased significantly. The condition of the road infrastructure, to a large extent, determines the safety and reliability of journeys undertaken by road users. Road transport is by far the most used mode of transport in Nigeria, both with regards to passengers and goods. With an estimated length of about 200,000 km of road network and 1,700 bridges serving Nigeria's growing population of about 170 million people, an efficient, cost-effective and sustainable programme of preserving this network of asset valued at about N5 trillion is required to achieve value for money. This should be based on a sound and business-oriented approach to asset management.

Lagos –Ibadan 1910



Ibadan - Ife 2010

A 414 England, 2011

Fig: 6 - Increasing demand for Road Asset Management

The key features of a road network that need to be maintained include:

- Pavement
- Bridges
- Drainage structures
- Electrical appliances and appurtenances
- Road furniture
- Traffic control signals
- Safety barriers (vehicle restraint systems)
- Earthworks

On a global basis, good practices developed in road maintenance regimes show that road agencies have been through the stages of minimal or no maintenance to the era of maintenance management and to application of Road Asset Management Systems (RAMS). The RAMS is a computer-based tool aiding the management functions associated with road maintenance often in a business-oriented approach. The concept of *Asset Management* is being employed by road agencies the world over to preserve this all important national asset. Despite differences in understanding about the term "Asset Management" (AM), the Federal Highway Administration and the American Association of State Highway and Transportation Officials FHWA and AASHTO (Robinson, 2008) provided a definition which could be adapted to road maintenance management as follows:

"Asset Management is a systematic process of maintaining, upgrading and operating physical assets cost-effectively. It combines engineering principles with sound business practices and economic theory, and it provides tools to facilitate a more organized, logical approach to decision-making. Thus, asset management provides a framework for handling both short and long-range planning."

Road management process is usually implemented through a clear cut division of functions which includes planning, programming, preparation and operations. A systematic process of achieving the implementation of these functions could sometimes involve the use of computer to store and analyse road data to aid management decisions. Consequently,

Road Asset Management System (RAMS) can be regarded as any system capable of storing and processing road, bridge and other related infrastructure inventory, condition, associated traffic and other relevant information in order to aid the process of decision making in road management.

The types of computer-based systems that can be deployed in road management include the network information systems and decision support systems such as the Highway Development and Management Model HDM-4. While the former is an organised repository for road network data storage, the processed data from the latter, which sometimes include condition prediction models is used to aid road agencies in planning, programming, preparation and operations management functions.

Using a combination of network information system and decision support system in carrying out a specific management function can be achieved through the concept of management cycle which is represented in Figure 7.

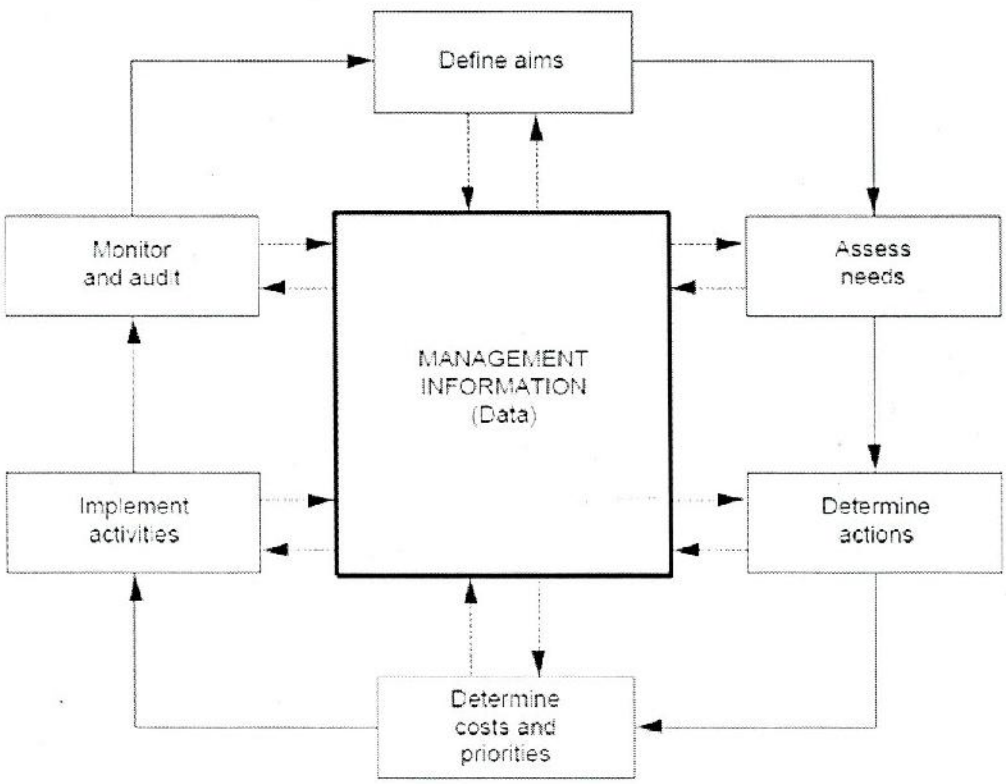


Figure 7- The Management Cycle (Source: TRL Overseas Road Note 15)

The network management Information system which is regarded as the heart of the management cycle feeds into the decision support system to support decision making in strategic planning, programming, preparation and operations.

Requirements of an Asset Management System (AMS)

To function as a holistic system, an Asset Management System shall fulfil certain requirements which can be employed in RAMS, as identified by the Organisation for Economic Co-operation and Development (OECD 2001). These requirements shall include but not limited to the following:

- To include inventory information for the asset and condition measures
- To include values of condition of the asset
- To include a performance prediction capability
- To ensure data integrity, enhance data accessibility and provide data compatibility
- To include all relevant components in life cycle cost analyses
- To enable the removal of outdated systems and unproductive assets
- To consider both system and project optimisation
- To ensure output of useful information on a periodic basis, ideally in real time
- To facilitate iterative analysis processes that can be performed on a regular basis

Furthermore, typical information groups which might be relevant to road management activities are presented in the Table 2.

Table 2: Typical information groups relevant to Road Management activities

Element	Aspects
Road inventory	Network/location
	Geometry
	Furniture/Appurtenances
	Environs
Pavement	Pavement structure
	Pavement condition
Structures	Structures inventory
	Structures condition
Traffic	Volume
	Loadings
	Accidents
Finance	Costs
	Budget
	Revenue
Activity	Projects
	Interventions
	Commitments
Resources	Personnel
	Materials
	Equipment

Source: Paterson and Scullion 1990 in TRL (1989)

4.0 APPLICATION OF RAMS - POTENTIAL BENEFITS

There are a number of potential benefits in deploying an asset management system for maintenance and management of Nigeria's road network. The optimization of service delivery can be regarded as the main aim of asset management. However some of the potential benefits associated with the implementation of a computer-based road asset management system can be grouped under data management, network performance, budgeting process, communication and staff capacity development.

4.1 Data Management

A reliable and relevant road asset data is critical in making informed decisions in asset management. With a Road Asset Management System in place, a sustainable manner of data collection, storage, analysis and retrieval could be the starting point in understanding the value of asset under consideration. Network inventory and condition status are the necessary data items which road managers routinely require to decide on maintenance needs and develop work programme backed by appropriate budget. An appropriate and functional road network information system improves ability to compare information, ensure adequate data display and reporting facilities. Output from a management information system can be further processed using decision support system integrated within the wider RAMS.

4.2 Network Performance and Monitoring

It is probably easier and consistent to assess the performance of networks for a given period of time where maintenance management decisions rely on a functional system of network information. A careful study of trends on road asset condition could assist a road agency in prioritising maintenance activities to match the existing performance of road assets. Customer-focused business approach to asset management considers the functional performance of the network and the business process employed in its management. Performance measurements consider the following:

- Road user point of view or perception
- Society's point of view
- Efficiency of the management agency to preserve the road asset
- Safety issues
- Environmental considerations in decision making

4.3 Budgeting Process

What is common to all management functions is the associated budget. Rather than rely on historical budget, road managers can utilise the prioritisation system in RAMS to simplify the budgeting process which is supported by relevant and valid data analysis achieved based on informed decisions on economic and other multi-criteria considerations.

4.4 Improved Communication

With a functional RAMS, it is easier to share information to meet both the internal and external demands of processed data and information to aid decision making process. Engineers within the agency could communicate and help other administrative staff with a language likely to be understood by non-technical/engineering personnel.

4.5 Staff Capacity Development

To sustain the operations of RAMS, it is imperative to train and improve the skills of the agency's staff. The starting point for the success of the training programme is to conduct a training needs analysis and identify the different levels of potential users of the system.

5.0 IMPLEMENTATION ISSUES – CRITICAL SUCCESS FACTORS

The guidelines for the design and operations of road asset management systems are well defined and specified in TRL (1998). In addition to funding, processes, people and technology have been identified to be the key success factors for the survival of RAMS (McPherson and Bennett, 2006).

5.1 Processes

If the main idea about RAMS is to effectively and efficiently manage and process data for decision making, it is important for the initial implementation planning to consider and put in place clear policies and sustainable procedures of data collection and quality assurance. Specific and realistic key performance indicators (KPI) could simplify the process of promoting the idea to high ranking decision-makers, leading to greater institutional support.

A regular sustainable annual budget for data collection should be backed by a sound procedure of monitoring and evaluation in order to identify gaps in the implementation process.

5.2 People

The right calibre of people is required to champion and drive the operations of the system. These identified personnel, which should include higher level managers are expected to be well motivated and trained with clear job descriptions and capacity to monitor the progress and tackle the challenges of implementation diligently.

5.3 Technology

Road agencies implementing a RAMS should be very explicit and clear about the technical and functional requirements of the proposed computer-based system in order to derive the benefit of system efficiency. Necessary arrangements for the right IT infrastructure should be in place in order to support the operation of the system in a sustainable manner. The proposed application should be user friendly and able to seamlessly integrate with decision support systems such as HDM-4.

6.0 IMPLEMENTATION ISSUES – CHALLENGES

Despite the highlighted benefits associated with the implementation of RAMS in Nigeria, it is worthwhile to consider certain potential challenges. As described in TRL Overseas Road Note 15, the "brooks pyramid" of technical, institutional and external factors represent interrelated factors that may potentially affect the smooth running of RAMS in Nigeria.

6.1 Institutional Issues

The capability of an agency to manage the technical procedures of RAMS application could depend largely on its institutional capacity. An institutional appraisal for RAMS application in Nigeria was recently conducted by the Nigerian Infrastructure Advisory Facility (NIAF). NIAF is a body established in 2007 and supported by the UK-based Department for International Development (DFID) with the aim of providing technical assistance to the Nigerian Government in order to facilitate and accelerate infrastructural reform and development. Major areas of current intervention include Roads, Power, urban development, infrastructure delivery and financing, transport and climate change.

The institutional appraisal report by NIAF has identified key areas which need to be addressed as follows:

- Public commitment from senior political and management representatives

- Support for a focused and functioning team
- Budgetary commitment
- Promotion and awareness raising
- On-going cooperation between FMoW and FERMA

Firstly, lack of maintenance culture amongst Nigerian institutions is a critical challenge. Though not limited to Nigeria, the issue of building new roads and neglecting the maintenance of existing ones seems more attractive. Secondly senior management staff needs to understand and appreciate the implications and technical challenges associated with the implementation of a computer based system.

6.2 External factors

Absence of an appropriate legal and regulatory framework, the state of national economy and consequent inadequacy of funding are major challenges which are usually beyond the technical capacity of a road agency. Sometimes, political office holders politicise project selection process and/or divert funds budgeted for maintenance to other less crucial ventures.

7.0 NIAF/WORLD BANK SUPPORT FOR THE DEVELOPMENT OF RAMS IN NIGERIA

Based on the needs identification and proposal put forward by FERMA, two international aid agencies are collaborating with FERMA/FMoW to deploy RAMS. These agencies are the DFID and the World Bank. The DFID is supporting the initiative through the Nigeria Infrastructure Advisory Facility Programme (NIAF), while the World Bank's support is through Federal Roads Development Project (FDRP) managed by the Road Sector Development Team (RSDT) of the Federal Ministry of Works. This collaborative effort is the first attempt at developing an integrated asset management system for maintaining and managing the federal road network in Nigeria.

To date the following have been accomplished since inception of the project in 2011 at the Federal Road Maintenance Agency (FERMA):

- Pavement strength surveys have been carried out using the Falling Weight Deflectometer (FWD), Dynamic Cone Penetrometer (DCP), and Road Roughness surveys using ROMDAS on federal roads.
- Needs analysis, institutional appraisal and development of database specification have been conducted.

The on-going activities include:

- The development of technical and functional specifications for the centralised database repository
- Data collection and extraction
- Network referencing, and
- Development of a GIS-based Road Information System

The integrated road asset management system will incorporate a Map-based Road Information System (RIS), an Asset inventory information system, Bridge Information and Management System (BIMS) and Routine Maintenance Management System (RMMS) among other relevant asset information. Also the multi-user system will interface with external decision support tools such as HDM4-4 road investment tool to derive prioritised work programmes. The incorporated BIMS is to be employed to rank maintenance priorities for bridges. The current programme of activities and timelines is summarised graphically in figure 8.

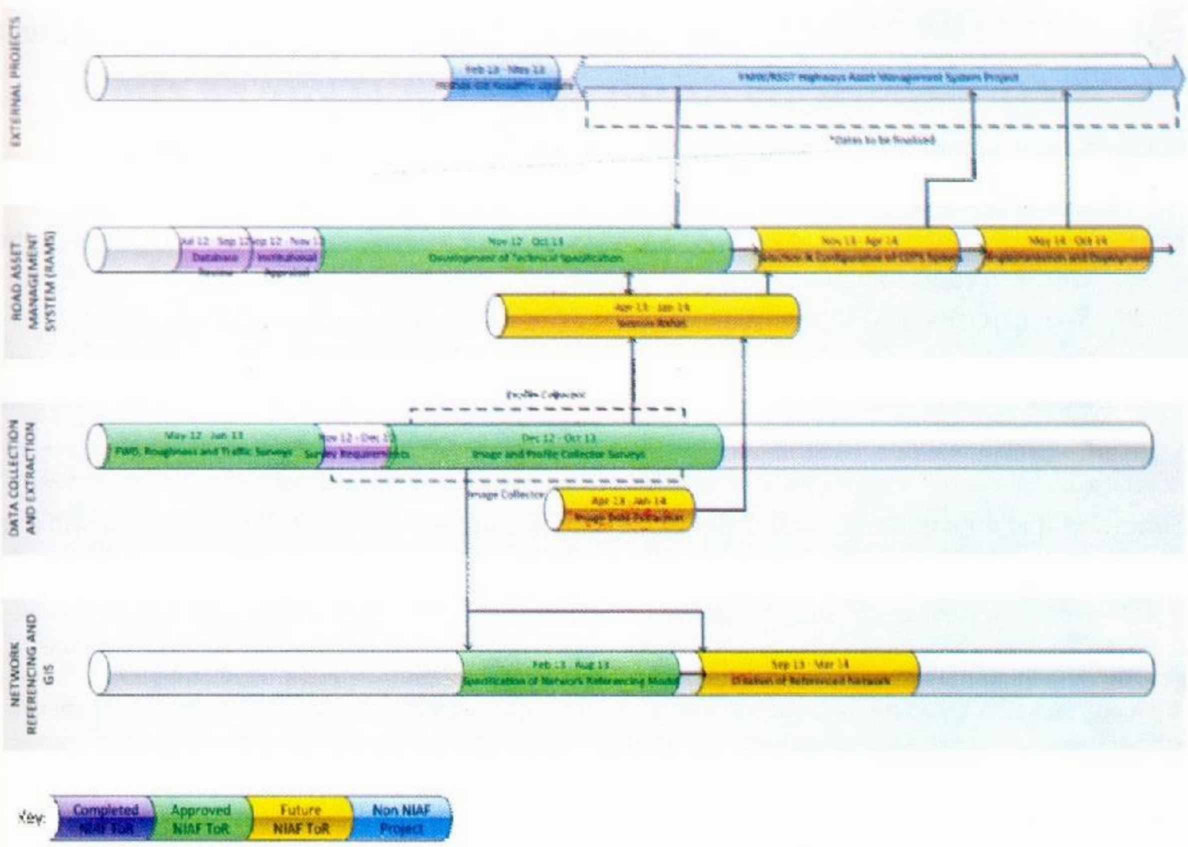


Figure 8: RAMS draft implementation Work plan

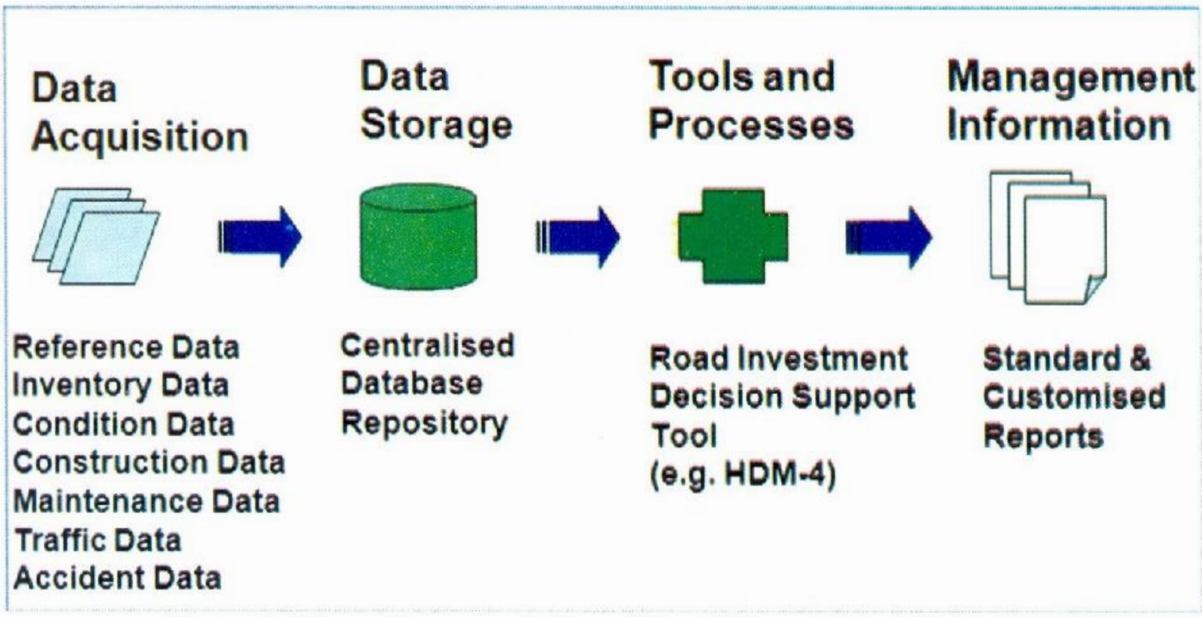


Figure 9: Schematic presentation of Asset Management System

8.0 CONCLUSION

In order to prevent a reversal on the improved road asset condition seen in the last decade in Nigeria, it is imperative that an integrated asset management system be deployed for effective and efficient maintenance and management of road transport infrastructure which has huge socio-economic importance. It is therefore expected that with an appropriate political support and institutional/technical capacity of FERMA/FMoW, the current collaborative work on developing and deploying an asset management system will have great impact on and improve road maintenance management in Nigeria. The associated benefits and value addition to the road sector particularly in ensuring continuous integrity of Nigerian roads are as follows:

- A sustainable road network data collection and Management will be in place
- A cost-effective manner of network performance monitoring will be operational
- An improved budgeting process based on project prioritisation and treatment selection will be in vogue and lead to cost-effectiveness
- Staff capacity development will be enhanced and sustained on a continuous basis
- Improved communication and information sharing both for the Agency's decision making mechanism and for external demands including other relevant stakeholder Agencies in the road sector

Generally, it is anticipated that the development and application of RAMS in Nigeria will bring the much needed improvement in maintenance management of road assets.

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QUALITY CONTROL IN ROAD CONSTRUCTION AND MAINTENANCE: PRACTICAL APPROACH

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ABSTRACT
Roads are built to provide safe passage of vehicles. They must be properly designed and constructed. After construction, roads deteriorate with age as a result of use and therefore, they need to be maintained to ensure that the objective of safety, strength and durability are met. The rate at which roads deteriorate in service depends on the quality of materials used, workmanship standard and the quality of supervision during the road construction. If roads are not maintained, functional defects will degenerate to structural defects that will require rehabilitation or reconstruction. The objective of quality control in road construction and maintenance is to achieve a well built pavement that conforms to the required horizontal and vertical profiles, design thicknesses of different courses (earthwork, sub-base, base and surface) and stipulated standards of riding quality. At each stage of construction or maintenance operations, quality control is required during the preliminary design, source acceptance, job-mix and construction. Relevant quality control tests should be carried out on construction materials. The plants and equipment must be of good quality and must be consistent with the type of job to be done. Effective supervision of construction or maintenance works as well as plants and equipment by qualified engineers is the key to the achievement of the overall objective of quality control. Engineers are to ensure that contractors comply with all the project specifications. Effective quality control leads to reduction in the cost of construction and maintenance, lowers cost of vehicles operation, transportation and maintenance. It is recommended that the option of preventive maintenance of our roads rather than reactive maintenance should be urgently embraced because preventive maintenance results in prolonged service life of roads and significant savings for the government.

1.0 INTRODUCTION

A road is a transportation medium that is built to endure and provide adequately for safe passage of vehicles. To achieve this objective, the road designs must adopt certain criteria for strength, safety and uniformity. In order to meet the requirements for strength, safety and uniformity, adequate quality control is required both at the design and construction phases of road projects and during the road maintenance operations. The general objective of the quality control of road construction and maintenance is to achieve a well built pavement conforming to the required horizontal and vertical profiles, design thicknesses of different courses and the stipulated standards of riding quality. Quality control of road construction and maintenance relates to the level of standard attained and uniformity of production that must also ensure a more economical utilisation of materials and systematic construction. Thus, effective quality control leads to reduction in the cost of construction and maintenance, lowers cost of vehicles operation, transportation and maintenance. The cost of quality control is considered to be about 1.5 to 2% of the total cost of construction; while the direct and indirect economic return from it is found to range from 5 to 10% of construction cost and atimes, it could even be more (Gupta and Gupta, 2007).

Interpreting the results of quality control for road construction and maintenance tests is a complicated one because a wide variability of the results will be produced. However, certain variations in the quality of a highway component obey the laws of probability and occur strictly by chance. Other variations are systematic and could be attributed to assignable causes such as differences in equipment, materials, construction methods, testing conditions, etc. Along with the quality control in road construction and maintenance, is that the contractor must comply with contract requirements which usually state that construction work must start within so many days of the award of the contract and end at a particular time.

2.0 PRE-REQUISITES FOR EFFECTIVE QUALITY CONTROL

The pre-requisites for effective quality control of highway construction and maintenance include:

(i) Estimates and construction specifications.
(ii) Adequately qualified personnel and proper equipment.
(iii) Periodic appraisal of quality control data for effecting possible improvements in the construction and maintenance techniques.

During construction and maintenance, two types of quality control can be considered:

(i) Process control
(ii) End result type control.

In process control type, the designer decides the type of equipment to be used, procedure of construction to be adopted, etc. in advance. He also decides the quantum of work to be done to achieve the desired results. In this method, the responsibility of the field personnel is to see that the work is executed as per specifications laid down in the schedule.

In end result type control, the contractor has a free hand to select the method of construction and equipment to achieve the desired results at the end. In this method, the responsibility of the field personnel is to perform tests on finished work at regular intervals to check whether the work has been executed as per specifications or not. The choice of control method is a matter of judgment, depending on the magnitude of the work and the availability of facilities to execute the work.

Quality control is required during the following road and maintenance activities: Preliminary design, source acceptance, job-mix control and routine construction control (The Asphalt Institute, 1969). It is also required for road alignment profile and surface evenness; longitudinal and transverse profiles.

(i) Preliminary Design Testing

The principal purpose of preliminary design testing is to determine that the local prospective sources of aggregate are of satisfactory quality that will satisfy the mix design and gradation requirements proposed for the specifications.

(ii) Source-Acceptance Testing

Source-Acceptance testing is often performed after the award of contract and after the contractor has indicated the proposed source(s) of all aggregate materials. This test is primarily a matter of materials control and inspection. This involves mix design, and the essence is to determine the most economical blend of aggregates that will satisfy both the gradation and mix design requirements of the specifications.

(iii) Job-mix Control Testing

Job-mix control testing is usually performed at the start of plant production and in conjunction with the calibration of the mixing plant for the job-mix formula which established the actual gradation and asphalt content to be obtained in the mixing plant.

(iv) Routine Construction Control Testing

This testing is performed as a routine and periodic item of inspection during the paving construction. Samples of the hot paving mixture are lifted at the mixing plant and check-tested for design properties.

3.0 ROAD CONSTRUCTION

The road construction works contain some or all of the following underlisted operations which are also shown in figure 1.

(v) Earthwork

(vi) Sub-base course

(vii) Base course

(viii) Surface course

- Bituminous surface
- Concrete surface course

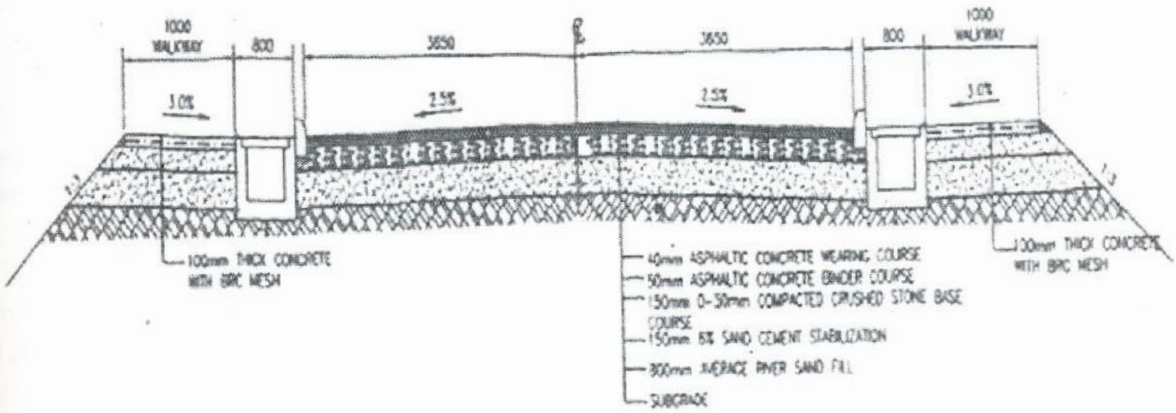

Fig. 1: Road Cross-Section (Source: Oguara, 2006)

Each stage of the above operations requires adequate quality control measures to produce durable roads. Appropriate drainage should also be provided as an integral part of road construction, otherwise it will be difficult to maintain the road quality in service because the road might be washed away by unchanneled stormwater.

3.1 EARTHWORK

The soil to be used should be free from stumps, root and rubbish and should not have clods more than 50mm in sizes. The soil may be compacted in layers varying from 150mm to 300mm depending upon the size and type of rollers that are to be used. The soil should be compacted at optimum moisture content – Six (6) to Sixteen (16) passes of the rollers are sufficient to give the Proctor's standard field density depending upon the thickness of layer and the type of soil and roller used. The underlisted tests are carried out as quality control measures on earthwork:

- Gradation/Sand Contents
- Plasticity Index
- Standard Proctor test
- C.B.R. test on a set of 3 specimens
- Presence of deleterious materials

- Natural moisture content
- Moisture content just before compaction
- Dry density of' compacted layer

3.2 SUB-BASE COURSES

The sub-base course is the portion of the flexible pavement structure between the subgrade and the base course. The sub-base usually consists of a compacted layer of granular material, either treated or untreated. The sub-base course is used to build up the pavement strength economically above that provided by the subgrade soils. If stone is to be used, it should be of good quality, that is, it should be free from laminations, unsound and weathered fragments. It should be free from dust.

Sub base courses may be of the following types:

(i) Water Bound Macadam (W.B.M) sub base
(ii) Soil, or gravel sub base
(iii) Mechanically stabilized soil base
(iv) Lime stabilized soil base
(v) Cement stabilized soil base
(vi) Sand-bitumen mix sub base

3.2.1 Water Bound Macadam Sub Base

For the water bound macadam to be used as sub base, oversized aggregates are used. The size of aggregate varies from 40 to 90 mm. The material should conform to the standard requirements.

3.2.2 Soil and Gravel Sub Base

This type of sub base is constructed of low grade materials such as soil and gravel mixture, etc. The materials to be used should be of specified quality. At the time of execution of work, the following points should be noted:

(i) Before starting compaction, the moisture content of the material should be checked and brought to the specified level.
(ii) Rolling should start at the edges and proceed gradually towards the centre parallel to the centre line of the road. At super elevations, the rolling should start from inner edge to outer edge. Rolling should be continued till the specified density is achieved.
(iii) After compaction, the surface should be free from movement under the action of compacting machinery, any waviness, ridges, cracks or loose materials.
(iv) After rolling, the sub base layer should be checked for dry density.
(v) No traffic of any kind should be allowed to ply directly over the finished sub base, unless otherwise specified.

The quality control measures required on soil and gravel are:

- Gradation
- Plasticity Index
- Natural moisture content
- Presence of deleterious materials
- Moisture content prior to compaction
- Density of compacted layer
- Control of camber, grade, thickness surface finish, etc.
- CBR Test .

3.2.3 Mechanically stabilized soil

The following types of mechanical stabilization are recommended for quality control of highway construction.

(i) Stabilization of sandy soils with admixture of clay.
(ii) Stabilization of clayey soils with admixture of sand.
(iii) Stabilization with soft aggregates.

The materials used for mechanical stabilization should be of specified quality. During the execution of the work, the following points should be noted:

(i) Stabilization should be carried out by mechanical means.
(ii) The plant used for stabilization should be capable of pulverising the soil to the specified degree and to the full thickness of layers. The mixing should be done uniformly and up to the desired degree of mixing for uniformity of stabilization.
(iii) In case of manual mixing, the mixing of various ingredients should be uniform up to the full depth.
(iv) Pulverization of soil should be ensured as per specified degree.
(v) Grading and plasticity index of the mixed material should be checked if specified.
(vi) Before starting compaction, the moisture content of the mixed material should be checked and brought to the optimum moisture content.
(vii) In case aggregates are used for stabilization, then it should be ensured that aggregates are evenly dispersed in the layer stabilized.
(viii) Rolling should start at the edges and proceeding gradually towards the centre line and parallel to it. At super elevations, rolling should start from inner edges to the outer one. Rolling should be continued till the specified density is reached.
(ix) After rolling is over, the surface should be free from compaction planes, ridges, cracks, loose material etc. and should be well closed.
(x) The rolled surface should be tested for proper compaction.
(xi) The rolled surface should be properly cured as specified.
(xii) No traffic should be allowed to ply directly over the stabilized layer unless specified.
(xiii) Finished surface should be checked for level and regularity as specified.

The underlisted tests should be carried out on mechanically stabilized soil

- Aggregate Impact Value
- Water absorption of aggregates
- Degree of pulverisation
- Plasticity index of mixed material
- Sand content of mixed material
- Moisture content prior to compaction
- Dry density of compacted layer
- Deleterious constituents
- Control of grade, camber, thickness and surface finish
- C.B.R. test on material if specified

3.2.4 Lime Stabilized Soil

Lime used for stabilization should be of specified purity and quality. The quantity of lime to be used should be specified as percentage by weight of dry soil. While executing lime stabilization, the following points should considered.

(i) Mixing should be uniform and no streak should be visible.

(ii) After mixing, the lime content of the mix should be determined.
(iii) After completion, the surface should be cured for 7 days, before second layer is laid.

The quality Control Test on Lime Stabilized Soil are
- Purity of lime and available calcium oxide
- Lime content immediately after mixing

The rest is the same as found under Mechanical Stabilization.

3.2.5 Cement-Soil Stabilization

In this method, the quantity of cement to be used should be pre-determined on the basis of laboratory tests. The soil to be stabilized with cement should not have more than 0.2% sulphate content. Quality of cement should be checked as per the required standard. The quality control tests are same as for lime stabilization.

3.2.6 Sand-Bitumen Mix Stabilization

Sand-bitumen mix can be used for sub base as well as for base courses. However their composition differs as per specifications. The sand to be used should be non-plastic and it should not contain more than 10% particles finer than 75 micron size . Preferably, this limit may vary within 5 to 10%. The binder should be of specified specifications and its quantity should be pre-determined in the laboratory. The following steps should be taken during the construction:

i. The proportion of the constituent materials in the mix should be as per specifications.
ii. The equipment and method employed for mixing should be as specified. The sand particles should be uniformly and properly coated with the binder.
iii. To check the spreading of the mix, edge confinement should be adopted.
iv. The thickness of layers should be kept as per specifications.
v. Rolling and density measurement should be adopted as stated previously.
vi. Finished surface should be checked.

The following quality control tests should be considered on Sand-Bitumen Mix.
- Sand fraction finer than 75 micron
- Plasticity index of sand
- Quality of binder
- Binder content
- Density of compaction
- Control of grade, etc.

3.3 BASE COURSES

The base course is the portion of the flexible pavement structure immediately beneath the surface course. It performs the major function of a structural portion of the pavement. The base usually consists of aggregates such as crushed stone, crushed slag or uncrushed gravel and sand or a combination of these materials (Merritt, 1976).

Specifications for base course materials are considerably more stringent than those for sub-base materials in requirement for strength, stability, hardness, aggregate types and gradation. The materials to be used should be tested before use. For highway construction generally, the following types of base courses may be used:

(i) Soil-Cement Base

(ii) Lean Concrete

(iii) Sand- Bitumen Base

3.3.1 Soil-Cement Base

This is as described under sub-base.

3.3.2 Lean Concrete

This type of construction is suitable as a base for flexible as well as for rigid pavements. Materials of specified quality should be used. The proportions of mix constituents should be decided on the basis of 28-day laboratory strength. The following sequence of operation should be followed during construction:

(i) Mix should be prepared in a power-operated mixer of approved type unless otherwise permitted.

(ii) Strict control should be exercised on the proportion of constituents and water/cement (w/c) ratio. Due allowance of bulking of sand and moisture content of aggregates should be made.

(iii) After mixing, the concrete should be immediately transported to the site of placement. During transit, care should be taken to ensure that segregation does not take place.

(iv) Concrete should be spread uniformly in the pre-determined layers to give specified thickness, camber and grade of finished surface.

(v) No joints other than construction joints should be provided.

(vi) Compaction of concrete should be done with the help of suitable device within two hours of mixing of the materials.

(vii) During compaction, camber and grade of the surface should be checked and irregularities rectified either by adding or removing material.

(viii) If concrete is to be laid in two layers, the second layer should be laid within one hour of the compaction of first layer.

(ix) At least 14 days curing should be done before opening the surface to traffic.

(x) The strength of concrete should be controlled.

The quality control tests on concrete materials are:

- Los Angles Abrasion value or Aggregate impact value
- Aggregate gradation
- Aggregate moisture content
- Wet analysis of mix
- Quality of cement
- Cube strength

3.3.3 Sand-Bitumen Base

This is as described under sub-base.

3.4 SURFACE COURSE

This is the major structural portion of the road pavement. It is also designed to resist the abrasive forces of traffic, limit the amount of surface water that penetrates into the pavement, provide a skid-resistant surface and furnish a smooth and uniform riding surface. The surface course also should be durable, able to resist fracture and raveling without becoming unstable under expected traffic and climatic conditions. Surface course may be either bituminous surface or concrete surface course.

The surface course of a flexible pavement structure consists of a mixture of mineral aggregates and bituminous materials. Surface-course of asphaltic cement is usually prepared by plant mixing of heated aggregates, mineral filler and asphalt cement. Construction specifications usually require that before a surface course is placed, liquid bituminous material be applied on untreated aggregate base courses as a prime coat and on treated base courses and between layers of the surface course as a tack coat.

Types of Bituminous surface courses include:

(i) Single and two coats bituminous surface dressing.
(ii) Surface dressing using pre-coated aggregates.
(iii) Thin bituminous pre-mix carpet.
(iv) Asphaltic concrete surfacing.

3.4.1 Bituminous Surface Dressing

During the construction phase, the following procedures should be adopted:

(i) The surface should be thoroughly cleaned with wire brush of any caked earth and other matter before applying the binder.
(ii) Specified bituminous prime coat should be applied. It should be cured before laying the surface dressing.
(iii) Under the following conditions, surface dressing should not be carried out:
  - If atmospheric temperature in shade is less than 16°C.
  - Base is damp.
  - Construction materials are damp.
  - The weather is not clear i.e. weather is dusty, rainy or foggy, etc.

(i) No traffic should be allowed on the cleaned or bitumen painted base.
(ii) Care should be taken that dust does not settle on the cleaned or bitumen painted base.
(iii) The specified quantity of the binder should be sprayed at the appropriate application temperature. The rate of spray of binder should be checked regularly. The variation should not exceed ± 2.5% of the specified rate. Excessive deposit of binder should be removed immediately. To avoid double spraying of binder, the ends of the stretch should be covered with thick paper.
(iv) Aggregate of specified quality and size should be spread uniformly at the specified rate.
(v) The aggregate should be immediately rolled with the roller of approved weight; excessive rolling resulting in the crushing of the aggregate should be avoided.
(vi) If specified, second coat should be laid immediately after the first coat.
(vii) No traffic should be allowed on finished surface for 24 hours. If traffic is allowed, its speed should be restricted to minimum e.g. 16 km per hour.
(viii) In case cut back bitumen has been used, the finished surface should be closed to traffic till it is cured adequately.

The following quality control tests measures should be ascertained:

- Quality of binder
- Los Angles Abrasion value or Aggregate impact value
- Stripping value of aggregate
- Flakiness index of aggregate

should be durable, able to resist fracture and raveling without becoming unstable under expected traffic and climatic conditions. Surface course may be either bituminous surface or concrete surface course.

The surface course of a flexible pavement structure consists of a mixture of mineral aggregates and bituminous materials. Surface-course of asphaltic cement is usually prepared by plant mixing of heated aggregates, mineral filler and asphalt cement. Construction specifications usually require that before a surface course is placed, liquid bituminous material be applied on untreated aggregate base courses as a prime coat and on treated base courses and between layers of the surface course as a tack coat.

Types of Bituminous surface courses include:

(i) Single and two coats bituminous surface dressing.
(ii) Surface dressing using pre-coated aggregates.
(iii) Thin bituminous pre-mix carpet.
(iv) Asphaltic concrete surfacing.

3.4.1 Bituminous Surface Dressing

During the construction phase, the following procedures should be adopted:

(i) The surface should be thoroughly cleaned with wire brush of any caked earth and other matter before applying the binder.
(ii) Specified bituminous prime coat should be applied. It should be cured before laying the surface dressing.
(iii) Under the following conditions, surface dressing should not be carried out:
   - If atmospheric temperature in shade is less than 16°C.
   - Base is damp.
   - Construction materials are damp.
   - The weather is not clear i.e. weather is dusty, rainy or foggy, etc.

(i) No traffic should be allowed on the cleaned or bitumen painted base.
(ii) Care should be taken that dust does not settle on the cleaned or bitumen painted base.
(iii) The specified quantity of the binder should be sprayed at the appropriate application temperature. The rate of spray of binder should be checked regularly. The variation should not exceed ± 2.5% of the specified rate. Excessive deposit of binder should be removed immediately. To avoid double spraying of binder, the ends of the stretch should be covered with thick paper.
(iv) Aggregate of specified quality and size should be spread uniformly at the specified rate.
(v) The aggregate should be immediately rolled with the roller of approved weight; excessive rolling resulting in the crushing of the aggregate should be avoided.
(vi) If specified, second coat should be laid immediately after the first coat.
(vii) No traffic should be allowed on finished surface for 24 hours. If traffic is allowed, its speed should be restricted to minimum e.g. 16 km per hour.
(viii) In case cut back bitumen has been used, the finished surface should be closed to traffic till it is cured adequately.

The following quality control tests measures should be ascertained:

- Quality of binder
- Los Angles Abrasion value or Aggregate impact value
- Stripping value of aggregate
- Flakiness index of aggregate

- Water absorption of aggregate
- Grading of aggregate
- Temperature of binder
- Rate of spread of binder
- Rate of spread of aggregate

3.4.2 Surface Dressing with Pre-Coated Aggregates

During surface dressing with Pre-Coated Aggregates, the following additional quality control measures should be ensured:

(i) At the time of mixing, the aggregate and binder should be heated up to the specified temperature.

(ii) Aggregates should be uniformly coated with binder.

(iii) After coating, the aggregates should be properly aerated and cooled before they are used. During cooling operation, aggregates should not be piled in big heaps and care should also be taken to protect them from dust.

3.4.3 Thin Bituminous Premix Carpet

During execution of the Thin Bituminous Premix Carpet work, the underlisted procedures should be followed:

(i) Mix proportions should be as specified. Binder contents should be checked regularly and variations should not exceed ± 2.5% of the specified rate.

(ii) Where necessary, tack coat should be applied uniformly over the prepared base at the specified rate.

(iii) Mixing should be done thoroughly, preferably in mechanical mixers.

(iv) Aggregates should be suitably heated prior to mixing with binder, if straight run bitumen is used. Binder should be heated to the specified temperature and mixed with aggregate until they are coated with the binder.

(v) The mixed materials should be spread evenly with spreader rakes to the specified thickness and camber.

(vi) Rolling should be started immediately after the spread of the materials. Rolling should be done as described under bituminous macadam.

(vii) If specified, a seal coat consisting of premixed sand or liquid seal and fine aggregate should be applied evenly and rolled.

(viii) Traffic may be allowed immediately after the carpet has cooled down to the surrounding temperature with a speed limit of 16 km per hour in case straight run bitumen is used. In case cut-back bitumen has been used, traffic should not be allowed till be binder is fully cured.

3.4.4 Asphaltic Concrete Surfacing

During the execution of Asphaltic Concrete Surfacing work, the following precautions should be taken:

(i) Grading of combined aggregates and binder content should be as per specifications.

(ii) Mix design should be done using the same materials as available on the site.

(iii) Tack coat, if necessary, should be applied over the prepared base at the specified rate before the laying of surfacing.

(iv) Mixing plant should be of adequate capacity. It should be able to give mix of proper and uniform quality. It should have all accessories such as aggregate feeder, dryer, weight or volume batcher, binder heater, and measuring unit, filler feeder unit and mixing unit, etc.

(v) The correct quantities of different fractions of aggregates should be fed into the mixer so as to give a mix of designed proportions.

(vi) The temperature of binder and aggregates at the time of mixing should be in the range of 150 to 177°C and 155 to 163°C respectively. The difference in temperature of binder and aggregates should not be more than 14°C.

(vii) Mixing should be done for the minimum possible time but enough to give a homogeneous mix.

(viii) The binder contents should be checked periodically. The variation should not exceed ± 0.3% by weight of the total mix.

(ix) The mix should be taken to the site in tipper trucks. The mix should be spread and compacted to obtain the thickness as specified. At the time of the laying, the temperature of the mix should be in the range of 121-163°C.

(x) Rolling should be started just after laying the mix with 8 to 10 tonnes roller with speed not exceeding 5 km per hour. Rolling should be continued till the mix is fully compacted and no roller marks are left on the surface. The density obtained should not be less than 95% of the laboratory value.

(xi) Joints and edges should be constructed as discussed under bituminous macadam.

(xii) Traffic should be allowed to ply on the surface after cooling down of the carpet to the surrounding temperature.

4.0 CONTROL OF ALIGNMENT, PROFILE AND SURFACE EVENNESS

The general objective of the above controls is to achieve a well-built pavement conforming to the required horizontal and vertical profile, design thickness of different courses and the stipulated standards of riding quality.

4.1 HORIZONTAL ALIGNMENT

The quality of horizontal alignment can be controlled by checking the geometry of the road way as well as the edges of the pavement layer with reference to the designed centre-line. It can be controlled effectively if the centre-line of the road has been marked in the field by means of reference pillars on both sides of the centre line located at frequent intervals along the straights and at all changes of horizontal curvature. Except for hilly regions, the following tolerances in respect of horizontal alignment are recommended:

(i) Carriageway edges	± 25 mm
(ii) Edges of roadway and lower layers of pavement	± 40 mm

4.2 SURFACE LEVELS OF PAVEMENT COURSES

Surface levels of pavement courses calculated with respect to the longitudinal and cross profiles shown on the drawings should be checked by spot levelling or through grid levelling, etc. from the sub-grade upwards for each successive layer. The following tolerances have been recommended:

(I) Sub grade	± 25 mm
(ii) Sub base	± 20 mm
(iii) Base course	± 15 mm
(iv) Bituminous wearing course and cement concrete	± 10 mm

4.3 SURFACE EVENNESS

The surface evenness of the road results in enormous economic gains due to decreased cost of vehicles operation due to less maintenance of the vehicle and maintaining safe running speed during travel.

5.0 ROAD MAINTENANCE

Perennial early failures of road sections soon after maintenance/rehabilitation activities in the country have become a source of concern. Unfortunately, Nigeria has not yet embraced the art of preventive maintenance of her pavements but still practices reactive type of maintenance.

The basic road pavement reactive maintenance procedures practiced in the country include rehabilitation by overlay, limited rehabilitation, pavement reconstruction and potholes repair. Some of the lapses that can be observed in the construction/maintenance activities include lack of adequate quality control and assurance in bituminous materials production, construction equipments and construction procedures.

6.0 MAINTENANCE AND REHABILITATION (M&R) PROCEDURES

Maintenance and rehabilitation of bituminous pavements in Nigeria are usually carried out by Federal/State Road Maintenance Agencies as direct labour initiatives or contracted out to road contractors. The Agency responsible for the maintenance of federal roads is the Federal Roads Maintenance Agency (FERMA) while those for individual states are usually indicated by the name e.g. Ogun State Roads Maintenance Agency (OGROMA) and Kwara State Roads Maintenance Agency (KWARMA), etc.

In Lagos State however, there seems to be two agencies carrying out road maintenance and rehabilitation, namely Lagos State Public Works Corporation (LAPWC) and Lagos Metropolitan Area Transportation Agency (LAMATA). LAPWC has been in existence for decades and was traditionally saddled with the responsibility of maintaining the road network in Lagos State. LAMATA was created as an independent agency utilizing foreign loans to also maintain and rehabilitate roads in Lagos.

The contractors employed to execute Federal/State Roads Maintenance and Rehabilitation works in the country largely fall into large- or medium-scale categories. Among the large-scale contractors will be Julius Berger Nigeria Plc, while there are numerous medium scale contractors. This categorization is basically based on the machinery and capital base capacities. The large-scale contractors will usually own their own quarries, asphalt plant and boast of a large array of all the required equipment and machines needed to carry out road works. The medium-scale contractors source their construction materials (e.g. granite fines, coarse aggregates, binder/wearing course, and tack/sealing coats) from the large-scale contractors. In addition, the medium-scale contractors can only boast of owning some of the required roads equipment/machinery, but having to hire the remaining whenever they have projects.

7.0 TYPES OF MAINTENANCE/REHABILITATION ACTIVITIES

The different types of maintenance/rehabilitation activities carried out on State and Federal roads in Nigeria can generally be categorized as follows:

(i) Rehabilitation by Overlay
(ii) Limited Rehabilitation
(iii) Pavement Reconstruction
(iv) Potholes Repair

These activities are briefly described in the following sections.

7.1 REHABILITATION BY OVERLAY

In this method, badly deteriorated sections of the road are overlaid with a single coat of asphalt concrete – usually a wearing course of 50mm thickness. It is usually a major work and always causes traffic disruption when carried out within urban areas (see Photos 1 - 2).

Photo 1 – Traffic hold-up at Obanikoro along Ikorodu road (in Lagos) due to road maintenance activities (June, 2007)

Photo 2 – Traffic hold-up at Jibowu fly-over bridge along Ikorodu road (in Lagos) due to road maintenance activities (August, 2005)

The procedure for this rehabilitation method is usually as follows:

(i) Mobilize equipment and materials to site
(ii) Blend tack coat
(iii) Spray the tack coat
(iv) Lay the asphaltic concrete, and
(v) Compact the laid asphalt wearing course.

7.1.1 Mobilize Equipment and Materials to Site

Equipment to be used for the work is first brought to the site. Equipment commonly utilized in pavement overlay work includes but not limited to the following:

- Asphalt Paver, Bitumen heater/Sprayer, 10, 15, 20 or 30 tonnes Trailer Tippers
- Steel Wheel Vibratory Roller(s), Pneumatic-tyre Rollers, Water Tanker
- Brooms, Mechanical Sweeper, Digger, Shovels, Rakes, Pavement Cutter

The first batch of asphalt concrete to be laid will usually have been brought to the site in haulage trucks – usually of between 15 to 30 tonnes capacities. Photo 3 shows a 20-tonne tipper loading asphalt from Lagos State Asphalt Plant at Isheri (Ogun State border) en-route to a site, some distance away. Asphalt used for roadworks have to be transported from asphalt plants which may sometimes be located hundreds of kilometres away. LOPEK Construction Ltd (a road contractor for LAMATA) transports the asphalt for its roadworks in Lagos from KOPEK Asphalt Plant located at Ogunmakin Village, Ibadan and also from FISCO Asphalt Plant located at Ogba Village in Ijebu-Ode.

Photo 3 – A 20-tonne trailer tipper freshly loaded with asphalt and leaving the Lagos State Asphalt Plant

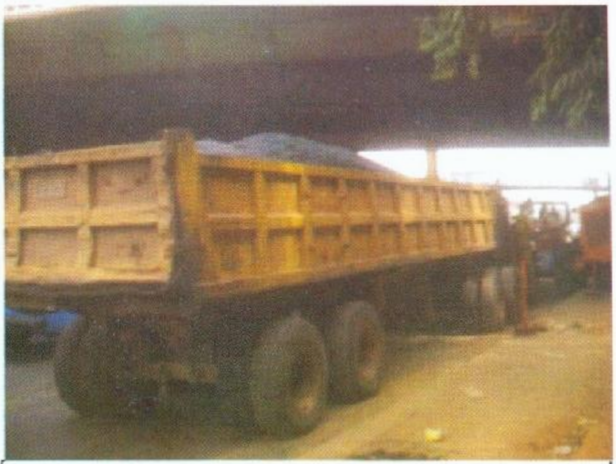

Photo 4 – A 30-tonne trailer tipper loaded with asphalt concrete, waiting at road repair site location

In addition to being transported for some hours from plant to site, asphalt concrete used for roadworks is usually also kept waiting in the trucks for more hours before being laid (see Photo 4). In some situations, asphalt has been known to be kept waiting in trucks for a whole day before being laid and rolled. The implication of this is that there would have been considerable loss of heat from the asphalt by the time of laying and compaction.

LOPEK Construction Ltd claims that asphalt is loaded from the asphalt plant at 140°C temperature and it is laid at 130°C temperature. At the Lagos State Asphalt Plant, asphalt is said to be produced at 110 – 130°C temperature range, and rolled at 90°C. Very few road contractors/road maintenance agencies bother to measure the temperature of the asphalt before it is laid and before rolling operations. Though, a company such as LOPEK LTD claims to have gauge to measure asphalt temperature on site, only Julius Berger has been found to always consistently check for temperature (see Photos 5 & 6)

Photo 5 – A Thermometer for measuring temperature of laid asphalt

Photo 6 – Close-up shot of thermometer used to measure as-laid asphalt temperature (Courtesy: Julius Berger Nig.)

The surface of the pavement to be rehabilitated is cleaned with the aid of brooms (see Photos 7 & 8). The commonest tools used for this activity are shovels and long brooms. However, large-scale contractors like Julius Berger Plc has been known to employ mechanical sweeper to perform this operation (see Photos 9 & 10)

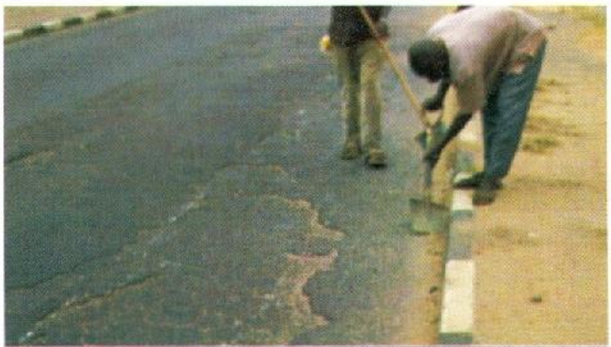

Photo 7 – Cleaning surface of pavement with shovel before overlay activities

Photo 8 – Cleaning surface of pavement with long broom before overlay activities

Photo 9 – A mechanical sweeper for cleaning pavement surface prior to tack coat application

Photo 10 – Close-up view of the iron strands of the mechanical sweeper (Courtesy: Julius Berger Nig. Ltd.)

7.1.2 Blending of Tack Coat

The blending of tack coat will usually be on-going in the bitumen heater (see Photos 11 & 12) while the surface cleaning process of the pavement is on-going. Medium to large-scale contractors have been known to use tack coat S125 to prime existing bituminous pavement surface before laying the wearing course. However, from investigation of a FERMA maintenance work group (rehabilitation of a stretch of federal road in Lagos) and at Lagos State Asphalt Plant, the engineers could not precisely distinguish whether it was MC1 or tack coat they use to prime.

The following mix proportions are used by a LAMATA contractor (LOPEK Construction Ltd) for the production of its tack and prime coats:

- For bitumen grade of 80/100 Pen: 12 litres of kerosene is blended with 182 litres of bitumen.
- For tack coat S125: 25 litres of kerosene is blended with 175 litres of bitumen.
- For prime coat MC1: 50 litres of kerosene is blended with 50 litres of bitumen.

LOPEK LTD produces its tack coat S125 and MC1 at temperatures of 120°C and 100-110°C respectively. MC1, as a prime coat, is used only to prime the surface of a compacted base course when reconstructing an existing road. Thereafter, the binder course is laid, and this is a standard procedure.

At Lagos State Asphalt plant, the MC1/Tack coat (the engineer in charge could not be certain) is produced from bitumen and kerosene at a proportion of 62.5: 37.5%.

7.1.3 Spraying the Tack Coat

Having achieved the desired blend at the appropriate temperature, the bitumen heater is positioned at the beginning of the stretch of road (see photos 11 &12). The bitumen heater moves at a very fast speed and sprays the tack coat over the existing bituminous surfacing through the spray nozzles at the back (Photo 13). Inadvertently, the dilapidated state of many bitumen heaters in use does not allow for uniform application of the tack coat through the spray nozzles. Subsequently, uniformity has to be achieved by manually using mop as illustrated in Photo 14.

Photo 11 – A typical bitumen heater at a road rehabilitation site, getting set to produce Mc1

Photo 12 – Heating bitumen and kerosene to the required temperature to produce tack coat or MC1

Photo 13 – Bitumen heater spraying tack coat on existing pavement. Notice the many gaps

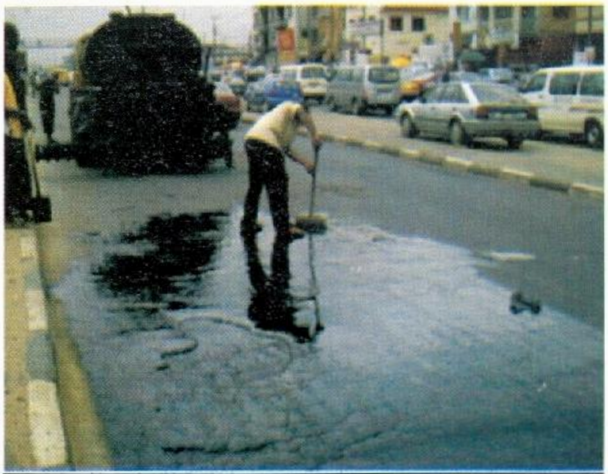

Photo 14 – Manually using mop to uniformly spread tack coat

Quantities of the tack coat are also poured into spray cans and manually applied to portions of the pavement surface that are not covered by the mechanical spraying operation. This manual method of tack coat application is also employed for surface portions where the bitumen heater's nozzles cannot extend to such as junctions (see Photo 15). The application is done rather sparingly and the effectiveness is definitely in doubt. This would lead to early manifestation of distress (such as slippage cracking) in such areas due to non-bonding between the old and newly-laid asphalt.

Photo 15 – Applying tack coat to a junction pavement surface using spray can

Photo 16 – Spraying tack coat using an extended pressure nozzle

Interestingly, Julius Berger Nig. Plc was observed to utilize a method of spraying tack coat through an extended pressure nozzle from the bitumen heater (see Photo 16). The bitumen heater moves at a walking speed, thus allowing uniform coverage of the whole pavement surface. It would seem this is the most ideal method of achieving uniform spread of tack coat for short road stretches.

7.1.4 Laying the Asphalt

It is customary to carry out small-scale patch of defects such as potholes, prior to spraying the tack coat and laying the wearing course. Quantities of the asphalt are taken directly from the truck, placed in the affected areas, raked to level and then compacted with the aid of the vibratory roller (see Photos 17-20).

Photo 17 – Applying tack coat over localized distressed areas to be patched

Photo 18 – Taking asphalt from paver to fill localized distressed areas

Photo 19 – Filling up localized distressed area with asphalt and raking to level

Photo 20 – Compacting patches with vibratory roller

Immediately after spraying the tack coat over the pavement stretch, the paver is positioned to receive asphalt from the tipper lorry and commence laying the asphalt (see Photos 21 & 22). Conventionally, a pavement overlay of 40-50mm thick HMA (after compaction) is used for major roads in the country. To achieve the 50mm thickness, the paver's screws are adjusted to lay 75mm of loose lift thickness of asphalt.

Photo 21 – Tipping stockpiled asphalt into the paver bucket

Photo 22 – An asphalt paver laying fresh asphalt wearing course

The truck tips the asphalt into the paver's bucket at regulated quantities. While still in this tipping position, the truck and the paver move simultaneously over the tack coated pavement as the asphalt is being laid. Care has to be taken, during paving, not to cover up access to central sewage systems and manhole covers. The screws of the paver must also be adjusted to cater for adequate road camber to ensure proper drainage of storm water off the pavement surface.

The laid asphalt is then raked smooth prior to commencement of compaction process (see Photos 23 & 24)

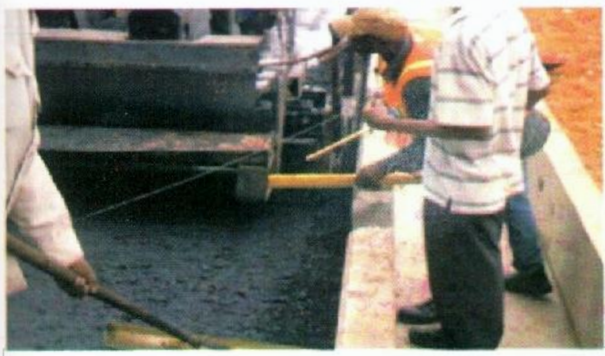

Photo 23 – Using flat-batten to smooth-level the laid asphalt

Photo 24 – Using shovels to rake freshly-laid asphalt to level

7.1.5 Compact the Laid Asphalt Wearing Course

The final step in this rehabilitation process is to compact the laid asphalt wearing course to the required density. This is commonly achieved using steel drum vibratory rollers (see Photos 25 & 26). The required density is expected to be achieved after five passes of the roller. The roller makes two passes initially while the asphalt is still hot and makes the remaining three passes after the asphalt has cooled sufficiently.

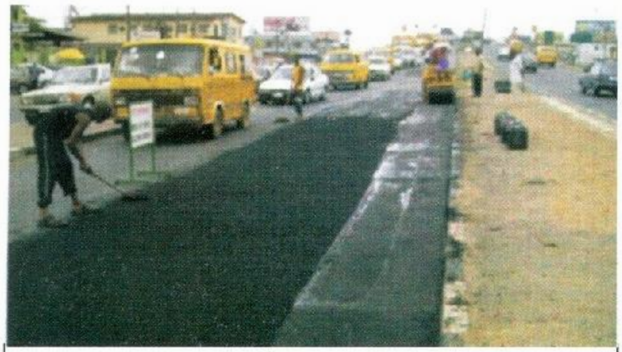

Photo 25 – Commencement of compaction of freshly-laid asphalt concrete

Photo 26 – Compacting freshly-laid asphalt using vibratory steel drum roller

A pneumatic-tyre roller (see Photo 27) should then be used to finish the compaction process, principally to achieve smoothness. It has been observed that most contractors and road maintenance agencies do not carry out this aspect of the work. However, large-scale companies like Julius Berger Construction Ltd., has been observed to finish their compaction process with pneumatic rollers.

Photo 27 – Finish-compaction of freshly-laid asphalt using pneumatic-tyre roller

7.2 LIMITED REHABILITATION

With this method, only apparently defective portions of the road section are slated for maintenance works. The remaining portions of such roads are usually left as it is. This type of maintenance is usually carried out where the defects are deemed not widespread enough to necessitate a complete rehabilitation (overlay or reconstruction) of the entire road stretch. It is also invoked in frequent situations where fund is in short supply. The most common distresses that fall into this maintenance category are usually alligator cracking, potholes, and failed patches. This rehabilitation method is similar to the Full Depth Permanent Patching and shall be compared with it accordingly.

7.2.1 Limited Rehabilitation Procedure as Practiced in Nigeria (Photos 28-35)

(i) The localized distressed areas are first marked out.

(ii) A pavement cutter is then employed to cut through pavement to expose the binder course or base course, depending on the severity of the distress. In most cases, the pavement is only scarified down to a depth of about 50mm to remove the wearing course.

(iii) The cut areas are then dug out with the aid of diggers.

(iv) If the binder course is not affected by the distress, the dug exposed area is then tack-coated. This is commonly done using spray cans.

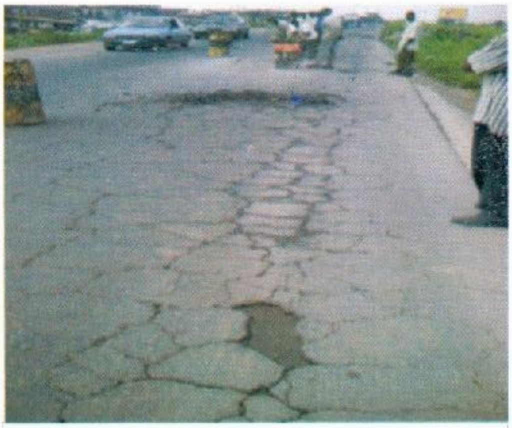

Photo 28 – Bird's eye view of alligator-cracked road section to be rehabilitated.

Photo 29 – Close-up view of alligator-cracked road section to be rehabilitated.

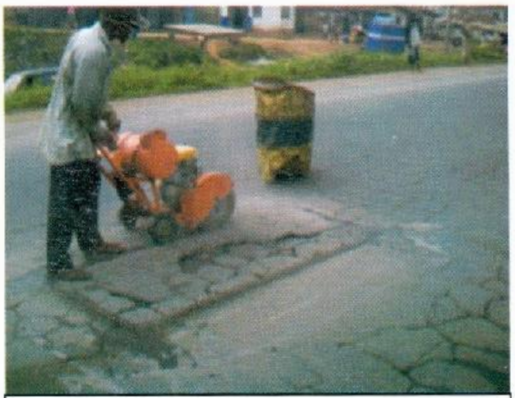

Photo 30 – Using pavement cutter to cut pavement surfacing to a depth of about 50 mm.

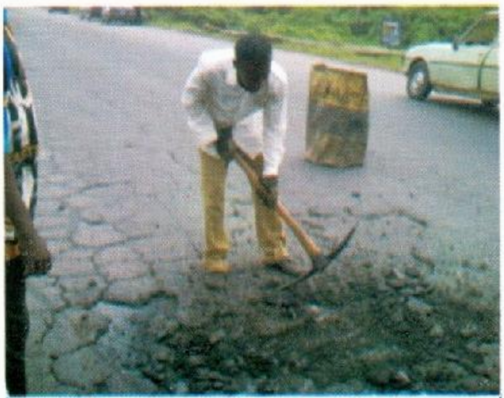

Photo 31 – Using digger to dig out cracked portions of road.

(v) The dug area is filled with wearing course asphalt from stockpile and raked smooth.
(vi) Thereafter, the area is compacted with vibratory roller, which in most cases will likely be small hand propelled types.
(vii) If the distress manifests down to the binder course, then the binder course will also be dug out to expose the base course. The base course is replaced with 150mm thick ¾" stone base materials which will be compacted and primed with MC1 prime coat.

7.2.2 Standard Full Depth Patching (Permanent Repair) Procedure

Full-depth permanent patching removes the material in the failed area and replaces it with fresh asphalt mixture. From the standard procedure for good permanent repair as enumerated in Asphalt Institute [1983], the following steps are noticed either not practiced at all by our road contractors or not adequately done:

(i) Proper identification of distress type and the appropriate excavation. For example, for a distress such as slippage cracking, milling of the asphalt surface layer may be the only excavation necessary.
(ii) Installation of drainage where water has been identified as the cause of failure.
(iii) Patching mixture should be shovelled directly from the truck, and placed against the edges first. Mix should be carefully spread to avoid segregation. Operator should avoid pulling material from the centre of the patch to the edges.
(iv) Compaction should be done with equipment most suited for the size of the job. A vibratory plate compactor is excellent for small patches.

Photo 32 – Close-up view of scarified pavement down to binder course level only.

Photo 33 – Selective scarification of pavement sections. Areas not scarified will not be repaired.

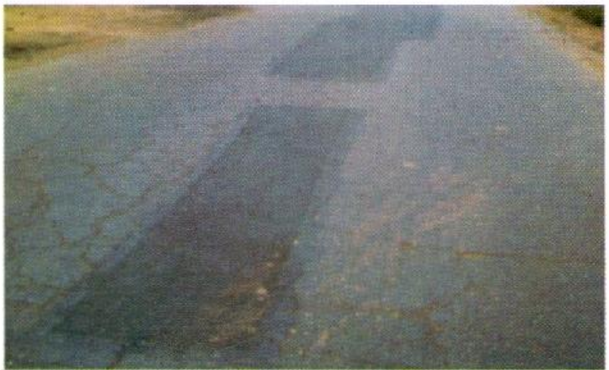

Photo 34 – Bird's eye view of rehabilitated road section. Note the existence of medium severity alligator cracks around rehabilitated area

Photo 35 – Close-up view of rehabilitated road section.

(v) Use of a straightedge or a string line to check the riding quality and the alignment of the patch.

7.3 PAVEMENT RECONSTRUCTION

Reconstruction consists of the total removal of the existing pavement structure, reworking or improving the subgrade soil, re-compacting the subgrade soil, and placement of a pavement structure with new and/or recycled materials. In Nigeria, reconstruction, as maintenance activity, takes place on road sections that have deteriorated to a state of impassability for vehicles. Under such conditions, the pavement surfacing would have been washed away to expose the underlying base/sub-base courses. The integrity of these underlying foundation courses would undoubtedly have been compromised having been exposed to moisture saturation from rainfall.

In carrying out the reconstruction, the top layer of the pavement is usually scarified up to sub-base level. A fresh base course is brought to the site, spread and compacted to a minimum depth of 150mm. Depending on the contract specification and the volume of traffic expected to be carried by the road section, the base course material could be either laterite soil or stone base. Though the use of stone base significantly increases the cost of the reconstruction, it is usually recommended and preferred when the road section carries high volume of traffic.

7.3.1 Procedure in Pavement Reconstruction (Photos 36 - 43)

(i) The entire road surface, up to about 150mm depth, is scarified with the aid of a scraper or bulldozer.

(ii) Lateritic soil or ¾"-size stone base is now placed to replace the scarified base course. Lateritic soil (when used) is hardly tested to determine its CBR percentage, nor is the soil ever stabilized. However, if stone base material is used for the base course, the CBR is expected to be a minimum of 80%. The newly-placed base course is then compacted with soil vibratory rollers, up to 150mm depth.

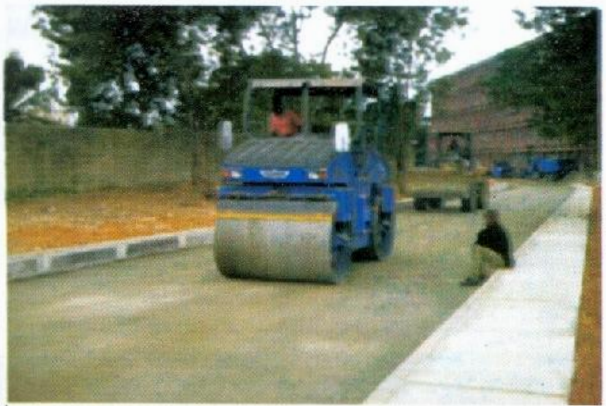

Photo 36 – Compacting stone base with vibratory roller (Courtesy: Julius Berger Nig. Ltd.)

Photo 37 – Compacting stone base using sheep's foot vibratory roller (Courtesy: Julius Berger Nig. Ltd.)

Photo 38 – A typical bulldozer used to scarify road pavement

Photo 39 – A grader that is also typically used to scarify and grade road pavement

(iii) Thereafter, the freshly-laid base course is then primed with MC1, preparatory to receiving the surfacing course.

(iv) For most reconstruction works, the surfacing course is usually a 50mm thick combined binder/wearing course. As was confirmed at the Lagos State Asphalt plant, this is the only type of asphalt produced and used for all ranges of maintenance/rehabilitation works. However, large construction companies such as Julius Berger produce and lay 40-50mm thick binder course on the primed base course, first. The binder course is compacted using both vibratory steel drum and pneumatic-tyre rollers. The binder course is thereafter tack-coated and a wearing course is placed and compacted to a minimum thickness of 40mm. LOPEK Construction Co. claims they place 50mm thick binder course and 50mm thick wearing course for their reconstruction work.

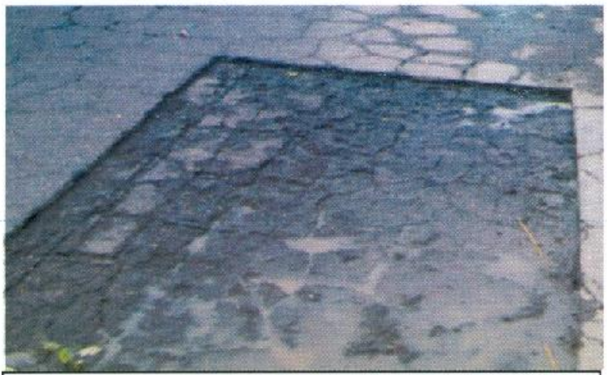

Photo 32 – Close-up view of scarified pavement down to binder course level only.

Photo 33 – Selective scarification of pavement sections. Areas not scarified will not be repaired.

Photo 34 – Bird's eye view of rehabilitated road section. Note the existence of medium severity alligator cracks around rehabilitated area

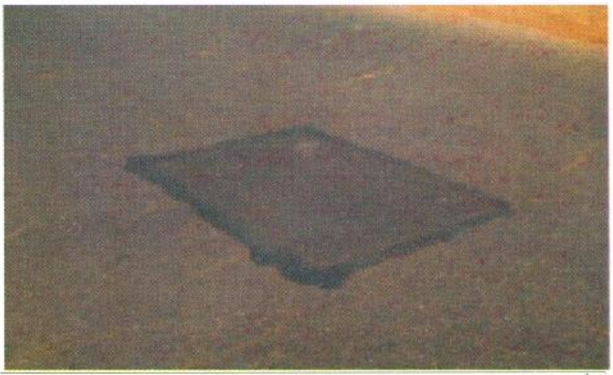

Photo 35 – Close-up view of rehabilitated road section.

(v) Use of a straightedge or a string line to check the riding quality and the alignment of the patch.

7.3 PAVEMENT RECONSTRUCTION

Reconstruction consists of the total removal of the existing pavement structure, reworking or improving the subgrade soil, re-compacting the subgrade soil, and placement of a pavement structure with new and/or recycled materials. In Nigeria, reconstruction, as maintenance activity, takes place on road sections that have deteriorated to a state of impassability for vehicles. Under such conditions, the pavement surfacing would have been washed away to expose the underlying base/sub-base courses. The integrity of these underlying foundation courses would undoubtedly have been compromised having been exposed to moisture saturation from rainfall.

In carrying out the reconstruction, the top layer of the pavement is usually scarified up to sub-base level. A fresh base course is brought to the site, spread and compacted to a minimum depth of 150mm. Depending on the contract specification and the volume of traffic expected to be carried by the road section, the base course material could be either laterite soil or stone base. Though the use of stone base significantly increases the cost of the reconstruction, it is usually recommended and preferred when the road section carries high volume of traffic.

7.3.1 Procedure in Pavement Reconstruction (Photos 36 - 43)

(i) The entire road surface, up to about 150mm depth, is scarified with the aid of a scraper or bulldozer.

(ii) Lateritic soil or ¾"-size stone base is now placed to replace the scarified base course. Lateritic soil (when used) is hardly tested to determine its CBR percentage, nor is the soil ever stabilized. However, if stone base material is used for the base course, the CBR is expected to be a minimum of 80%. The newly-placed base course is then compacted with soil vibratory rollers, up to 150mm depth.

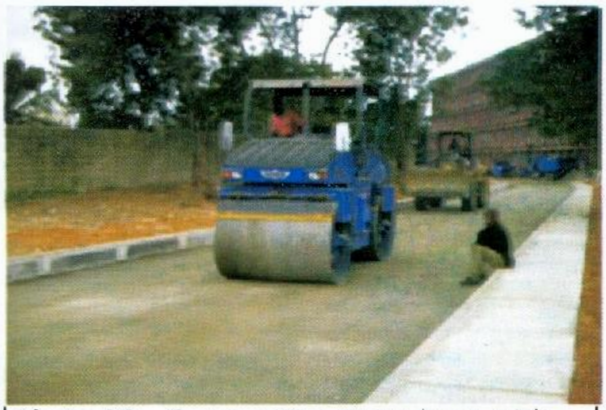

Photo 36 – Compacting stone base with vibratory roller (Courtesy: Julius Berger Nig. Ltd.)

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Photo 39 – A grader that is also typically used to scarify and grade road pavement

(iii) Thereafter, the freshly-laid base course is then primed with MC1, preparatory to receiving the surfacing course.

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Photo 40 – A steel drum roller and a smaller hand-operated vibratory compactor

Photo 41 – Soil Vibratory Roller, though in a dilapidated condition

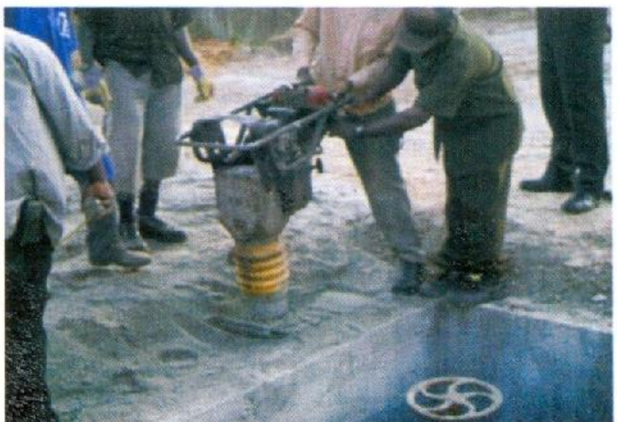

Photo 42 – A vibratory plate compactor used to compact small area (Courtesy: Julius Berger Nig. Ltd)

Photo 43 – Using hand rammer to compact tight area not easily accessible to roller (Courtesy: Julius Berger Nig. Ltd.)

7.4 POTHOLE REPAIRS

Pothole as a pavement distress could easily be said to be the most dominant of all distresses that manifest on Nigerian roads. Potholes are bowl-shaped depressions in the pavement surface in which a significant thickness of the pavement surface has been dislodged [LTPPP, 2003]. Potholes in various degree of deterioration abound on almost all the State and Federal roads in the country. However, pothole repair is hardly carried out as stand-alone pavement maintenance activity for State and Federal roads. The trend in the country is for Governments to 'allow' a road section to deteriorate to a sufficient level at which its rehabilitation can be awarded out as a contract.

Thus, pothole repairs for State and Federal roads take place mostly during overlay operation, when potholes would be patched prior to commencement of the overlay operations. Pothole repairs also take place during limited rehabilitation. The type of pothole repair commonly practiced is similar to the Pothole Emergency Repair.

7.4.1 Standard Pothole Emergency Repair

Temporary repair usually involves cleaning out the hole and filling it with a pre-mixed asphalt patching material. The recommended procedure for temporary repair is as follow [The Asphalt Institute, 1983]:

(i) Clean hole of loose materials and as much water as possible.
(ii) Use infra-red heater to heat and soften asphalt surface surrounding hole.
(iii) Fill hole with asphalt emulsion stockpile mixture and rake smooth.
(iv) Compact with vibratory plate compactor or roller.
(v) Dry compacted patch with infra-red heater.

8.0 CONCLUSIONS

From the foregoing work, the following conclusions are made:

(i) In cases where there would have been significant temperature loss within asphalt concrete before being laid, it is important to heat the asphalt concrete using the paver. Such cases would include when the waiting period of the asphalt is longer than anticipated and when asphalt is being laid during wet season.
(ii) The use of tack coat/MC1 that are not properly blended will always contribute significantly to early failure of rehabilitated road sections as adequate bonding of new layer of asphalt concrete to the old will not be achieved.
(iii) The lack of strict adherence to quality control such as recommended temperature of asphalt concrete during laying and compaction, spray rate of tack coat, inadequate compaction, etc will continue to contribute to early failure of road.
(iv) Equipment to be used for roadworks should be assessed and confirmed to satisfy the minimum recommended requirements. Bitumen sprayer must be able to spray at recommended rate, paver must have ability to heat asphalt concrete, etc.
(v) Proper evaluation of defects on urban highways through the use of non-destructive testing should be embraced as this will help to determine the appropriate type of rehabilitation to be carried out.
(vi) There is the need to encourage the use of emulsified asphalt as tack coat for asphalt overlay operation in contrast to cutback asphalt which is generally poorly blended by contractors.
(vii) The option of preventive maintenance of our roads rather than reactive maintenance should be urgently embraced. Preventive maintenance results in prolonged service life of the roads and significant savings for the Governments.

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QUALITY CONTROL IN ROAD CONSTRUCTION AND MAINTENANCE: *GENERAL PRINCIPLE*

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ABSTRACT

Quality control in Nigeria as well as in road construction and maintenance is yet to reach its excellent or highest peak (or) stage. This is as a result of many factors ranging from lack of good management, equipments, fund, down to insincerity, blurred transparency and corruption. This paper therefore, presents some opinions on quality assurance and control in road construction and maintenance. It pointed out that quality control in road construction and maintenance can only be achieved by controlling all features and characteristics that will impact desired quality on the road; quality should be built-in and inspected-in, having a unified document called ***quality manual or quality handbook*** *and using the continuous construction method in road construction and maintenance construction and re-construction. Good quality tested materials cannot be overemphasized during construction and maintenance.*

1.0 INTRODUCTION

Quality control in road construction and maintenance is very important in Nigeria as a result of perennial road pavement failures in Nigerian roads leading to big pot-holes. The big pot-holes are as a result of neglect and quality of materials and method of construction and maintenance employed.

The quality of a product may be defined as the measure of the ability of the product to fulfill or satisfy the customers implicit expectation or the explicit required/01/. Thus the quality of a product has two distinct and inter-related features which is the quality of design and quality of conformance. The quality of design is a measure of how well the product is designed to achieve its stated purpose; whereas quality of conformance refers to the degree or extent to which the product achieves the quality of design. For example, a road designed for fifteen years should never have its shoulders pealing off or cracking after one year leading to removal of the shoulder; assuming all loading criteria in design are obeyed. Others look at quality as ***high*** or ***low*** quality in terms of definition. Thus, the term quality is a subjective term and may mean different things to different people. The definition is therefore rather elusive and difficult to easily grasp. Yet others define quality as the totality of features and characteristics of a product or service that bears on its ability to satisfy a given need of a customer/01/. One can therefore conclude that quality can only be achieved by controlling all the features and characteristics which will impact the designed quality on the product. For example, all materials used in road construction and even for maintaining road must be of good quality and the method of construction and maintenance must be of good procedural quality to obtain a good road quality.

Construction of road can be defined as an act of clearing, levelling, building, compacting the various layers of sub-grade, sub-base, base and pavements to form multiple lanes or lane of road for passages of vehicles, people and commodities. The road is specifically designed as a surfaced highway for the passage of wheeled vehicles, each vehicle being controlled and guided by a driver/02/. Road transport has a great advantage over other modes of transportation as it is the only mode that has the capability of providing door-to-door services/04/. It is an essential feeder to other modes of transport, and most suitable for short and medium distance traffic. The quality control for construction of roads are therefore very vital to its economic as well as its durability aspect, thus it is the quality of materials used, standard procedures followed that will give rise to quality roads that have sound durability, giving a better service to vehicles/02/.

Road maintenance can be defined as the function of protecting the highway structure and keeping it in condition for safe use/02/. A newly completed highway without a maintenance plan or schedule will certainly not serve its intended life span. The need for maintenance planning schedule by the maintenance department cannot be therefore over-emphasized. FERMA is doing a good job in this aspect. Constant survey of the road, measurement along the road to form or obtain maintenance data leading to maintenance schedule and maintenance budgets are of vital importance for proper maintenance. The quality of maintenance is tied to the quality of materials, equipments, correct data collection along the road and proper re-construction procedure in accordance to standards laid down to correct the defects observed in the highway/02/.

This paper therefore attempts to present the opinion that it is only a good quality controlled road construction and good quality control maintenance that could keep our Nigerian highway in a good safe condition for use by vehicles, passengers, giving rise to quality controlled road construction and maintenance.

2.0 QUALITY CONTROL

The issue of quality dated back as far as four (4) millennium ago in Ur, an ancient city between Egypt and Iraq where a purchaser of copper drew the attention of his broker to the ingot supplied to him was below the expected standard assured by the supplier/01/. Ever since then, there had been several incidences of quality deficiencies over the ages such as collapse of buildings, roads, faulty cars, etc. The impact of quality is much more felt and appreciated in a competitive and industrialized free-market economy with diversified sectors of economy than in a monoculture economy/01/.

Nigeria is a mono-cultural economy, thus the issue of quality is even more compounded by the persistent syndrome of under-installed capacity production. Thus, the issue is not that of quality but that of availability and supply. This applies also to highways in Nigeria. The idea of quality in this kind of economic environment will usually not immediately come to mind, where the consumer has no freedom of choice with regards to availability of goods and services at his/her disposal. The case of former NEPA and NITEL comes to mind.

Quality is free because it pays for itself, reduce operating cost and increase sales through satisfied customers/01/. Quality should be built-in not inspected in and quality also eliminates operation and process variables/02/. Thus, both employee involvement and team work and everybody is a link in the quality chain to produce a quality product that is durable and meet up with the design/01/.

Therefore, one could say that quality control is an activity involving the coordination of effects of various groups or sectors of an organisation or company with the primary purpose of detecting and preventing the occurrence of defects in a cost-effective way. It is to basically eliminate or minimize non-productive activity and enable the production of an item or product which is within the constraints of customer satisfaction. In most efficient and good companies, a full-fledged and constant quality control systems are usually carried out in a unified and documented operational guidelines contained in what is called QUALITY MANUAL or QUALITY HANDBOOK. Although it may appear sometimes complex when all the systems are considered, but on an individual basis, it boils down to "don't lift a finger until you have read and understood the written operational procedures which tell you exactly what to do, the order of doing it and the equipment to be used". On the whole, the over-riding criterion by which any product must be judged is "FITNESS for PURPOSE" and "VALUE for MONEY".

Quality cost may be broken down into three major components namely PREVENTION, APPRAISAL and FAILURE COSTS. *Prevention cost* is referred to as the cost measured in avoiding or minimizing quality failure, for example, using a very accurate machine or high grade raw materials in constructing a road while obeying all the standard procedures. *Appraisal costs* are the expenses incurred in carrying out inspection tests and monitoring of quality performance while *failure costs* refers to the cost incurred in producing rejected product, failure in service, reworking and rectification claims and customer returns. A recent survey indicated that quality costs in United Kingdom industries show the following revelations/02/.

Failure cost	=	87.5%
Appraisal cost	=	10.0%
Prevention cost	=	2.5%
Total of quality cost	=	100%

Thus, it can be seen that it is more advisable and perhaps wiser to re-allocate more resources on prevention aspects in order to minimize failure costs in management planning.

This leads us to what the Japanese entrepreneurs call *Quality Circle*. This is defined as a small group of people sharing the same work area or similar activity whose objective is to solve quality problems. These small groups of people must be honest and sincere people whose aim is to achieve quality. The optimum size of the group is usually eight (8) but can range from 6 to 12 people working together in a particular unit to arrive at good quality through processes employed during production or construction. Unlike the conventional quality control system which is found in Nigeria, the quality circle is built upon collective participation of both those who actually do the work and those who give directives on how the job should be done; analyse the problem and evolve solution. The bigger or larger organisations assigned more than 20 percent of customer complaints to their own circles for response and appropriate corrective action. In this quality circle, "human beings" must become the central focus of the work place. Despotic exercise of authority denies a worker independent personality, turns him into a cogwheel or possible, makes him unhappy as human beings. It inhibits productively, results in the misuse of authority, and naturally to self destruction of the company. Managers and their subordinates alike should listen to the voice of objectivity humbly, and obey them with confidence. What is primarily important is not command and order but rather information.

The advantage of the quality circle as well as other discussions above is that:

a. It enhances quality by avoiding or minimizing beauracracy

b. It inspires more effective team work,

c. It increases employee motivation,

d. It creates a problem-solving capability

e. It promotes personal and leadership development

f. It develops cordial relationship between a manager and worker, and

g. It enhances good relationship between theory and practice; encourages reasoning on why things should be done in particular ways which lead to good quality product.

An organisational structure of *quality circle* consists of:

a. Circle member
b. Circle leader
c. Facilitator/Coordinator and a steering committee

3.0 QUALITY CONTROL IN ROAD CONSTRUCTION

The total cost of construction of road consists of costs for planning, construction, maintenance repairs, re-construction and a certain rest value/02/. The average life time of a road is about 12-15 years, usually in developed countries. If however, the contractor wants to offer a longer service life time for his construction (usually not the case here in Nigeria), the contractor has to implement a reliable quality assurance system from the very start of the construction work; a system that covers each metre square and assists the machine operations to optimize their work, avoiding unnecessary compaction passes/02 /.

In addition, a system for continuous quality assurance will provide both contractor and customer (client) with instant job documentation at site. This is clearly obvious, that such requires not only highly sophisticated measurements and data acquisition technology, but also detailed knowledge of compaction processes, carried out on non-linear soil and visco-elastic hot mix materials /02/.

Increasing quantity in earth moving and asphalt paving demand usually lead to reconsideration of conventional self control concepts/02/. For example, traditional spot test methods interrupts or stops the construction work. This also leads to result presentation which may take hours or even days (weeks) in Nigeria. Thus spot test methods, which is often traditional do not any longer meet the requirements of large construction sites/02/. These tests are to confirm the quality of construction work done. The present ratio of between compacted volume and checked volumes is another matter of concern: a few litres (vol.) sample or one asphalt core is used to check thousand of metre cube giving a ratio of one to one million(1:1,000,000) which would be totally unacceptable in any other technical field as a good representative. In addition to the proceeding examples, there is need for improved self-control for the new tender and contract models i.e. "Public Private Partnership (PPP)", Build-Own-Operate-Transfer' – BOOT) and the usual functional contracts. For the models mentioned, it is in the interest of the contractor to achieve homogeneity and durability of the construction in the most efficient and reliable way. This can only be possible if ***compaction*** of both unbound and asphalt materials is ***controlled*** and ***optimized*** by means of ***continuous construction method*** instant on site with documentation of results. This is expected to be approved by the owner as official result documentation which will contribute to more efficient construction work and considerable reduction of test costs

According to some specialists, continuous control methods are based on relative methods only; while traditional spot test method is "absolute" values/02/. The critics however seem to forget that results from traditional methods can only be defined as "absolute" if they strictly correspond to their specifications in terms of instrumentation, performance and evaluation. It is also well known that results from different spots test methods cannot be compared with each other without calibration under comparable conditions.

In considering the measurement technologies for different methods i.e. the conventional spot-tests, continuous method and the future "intelligent" soil adjusting machines, the methods can be standardized and their results may be expressed in absolute terms and compared with each other as long as their performance meets the standard. It is worth noting that the depth range of the individual methods is different both for soil and in asphalt compaction.

It is also good to note and observe that the method of Continuous Compaction Control (CCC): are now part of the national specification in Austria, Germany and Sweden and have been so for many years. These methods are based on roller integrated compaction meter value from the acceleration signals/ 02/.

The Transit New Zealand Quality Standard TQS2:2005 is a quality system for road construction, road maintenance and structures physical work contracts /03/ in New Zealand. The standard requires that quality assurance is mandatory for all physical works on state highways. The quality system that must be adopted by the contractor must meet with this standard requirement which is based on NZS ISO 9000. This standard adopts two level concepts that relate quality assurance to the contract. The table 1 below shows how this is related.

Table 1:Quality Assurance Level

Contract Quality Assurance (QA) Level	Minimum Quality Assurance (QA) Requirement
High	Compliance with Standard Total Quality Standard 1 (QS1) with contract quality plan
Normal	Compliance with Standard TQS2 together with a contract quality plan

To maintain a quality control in the road construction, the TQS1 standard requires the contractor to have a system that incorporates most of the elements of NZSISO 9000 which also requires third party certification by an approved certification body. The elements of the NZS ISO 9000 which must be included in the quality system if it is to comply with the requirements of the standard, include the following:

a. Management (quality policy, organisation)
b. Contract quality system [quality policy, work instructions (methodologies), inspection list and contract quality plan].
c. Purchasing and subcontracting (purchasing instructions, in coming materials, sub-contract or quality control and product identification and traceability).
d. Control and inspection of the work (general, identify and plan, inspection and recording).
e. Non-conformance and quality improvement (control of non-conforming work, quality improvement)
f. Training. and

g. Safety and Environmental Management (Health and Safety; Environmental Management).

In applying this standard, it will be assessed to determine the quality assurance level using the seven elements mentioned above. For an accessed contract having a normal quality assurance level suggests that its compliance with standard TQS2 is the minimum requirement; while high contract quality assurance level is **TQS1**.

4.0 QUALITY CONTROL IN ROAD MAINTENANCE

It is assumed that from the preceeding discussions, good quality materials used in construction or maintenance of road must have undergone tests to prove that it is of good quality prior to use; as such, discussions are concentrated on quality procedure to obtain quality products. These tests for good materials must comply with Federal Government general Specifications for Roads and Bridges Vol. II 1994/04/.

Maintenance and repair works delay traffic flow and transports, causing increasing losses and slowing down economic growth. This trend can only be broken by longer life time of construction. Longer life-time (durability) means improved homogeneity and durability of the construction. Both can be achieved by continuous self control during construction/03, 07/.

It is worth observing that most of the quality control of Road Construction will eventually apply to maintenance. For proper maintenance to take place, the problems mitigating against highway maintenance especially in Nigeria should be cleared prior to quality maintenance. Such problems include insufficient funding; deficient institutional arrangements; shortage of manpower with requisite skills and qualifications; poor management capability/framework; poor utilization of available resources; poor policy environment and undue politicization of technical issues/05/. There must be proper assessment of maintenance by carrying out proper condition survey and Traffic Counts and Axle – load measurement. When these are properly put in the right perspectives, the quality assurance that applies to road construction as earlier discussed will apply. Depending on the road conditions and condition survey, procedure for repair follows the same trend. Quality control needs for normal road control will apply for maintenance.

5.0 CONCLUSIONS

From the preceding discussions, the following conclusions can be made:

a) Quality roads can only be achieved by controlling all the features and characteristics which will impact desired quality on the road during construction.
b) Quality should be built-in and inspected-in as it eliminates operation and process variables.
c) For a quality road by an efficient company, such company must have a full-fledged and constant quality control system, presented in unified documented operational guidelines called **Quality Manual** or **Quality Handbook**.
d) It is more beneficial to allocate more resources to prevention to minimize failures in management planning to produce quality.
e) The use of *quality circle* improve quality product in big companies. It always leads to better quality control.
f) For quality road, the use of continuous construction method with instant site documentation of results is recommended. Thus compaction of unbound materials and

asphalt materials are controlled and optimized.

g) For quality roads, all materials used for such roads, must have been tested to comply with good quality materials.

h) For good quality maintenance, all problems mitigating against maintenance condition survey and proper traffic count must be carefully and properly resolved or cleared; after which the use of continuous construction method is applied to achieve quality of compaction for quality road.

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ROAD PAVEMENT FAILURE: A CASE STUDY OF ENUGU-PORT HARCOURT EXPRESSWAY

By

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ABSTRACT

The purpose of the paper is to determine the extent to which the Enugu-Port Harcourt Expressway has deteriorated or failed; identify causes of failure and proffer solutions. Failures of flexible pavements (bituminous roads) have been prevalent in Nigeria, a trend causing concern to both the government and road users. In this regard, it was found necessary that an investigation be initiated to determine the possible causes of such failures, and a case study was carried out on Enugu-Port Harcourt dual carriageway in South-eastern Nigeria. The investigations were conducted in several categories to determine the pavement characteristics such as properties of base, sub-base and sub-grade soils; traffic volumes by traffic counting; and characteristics of the type of the bitumen used by cutting cores and extracting the bitumen for the standard tests, such as Marshal Stability, flow, bitumen content, air voids, void mix aggregate and grading. The visual inspection of the pavement showed that due to the infiltration of both surface and groundwater into the plastic shale sub-grade soil and overloading, cracks and potholes and structural base failure were very common for the whole stretch of the road. Traffic count data revealed a high volume of heavy vehicles with probable high axle load. As a result, there has been a tendency to exceed the maximum allowed axle load limits. Flexible pavements deteriorate under traffic loads and climate effects. This fact, together with the revelation that the road is a very busy one as depicted in the traffic counts, poor sub-grade soil, poor drainage system and high water table, could be major causes of the road's fast deterioration. The possible solutions could be to increase the thickness of pavement, use of concrete as base/sub-base, regular maintenance of the road, design of adequate drainage system, adequate supervision etc.

Keywords: Pavement, failure, distress, traffic, axle load, asphalt

1.0 INTRODUCTION

Goods and passenger movements in Nigeria are performed mainly by road, with the railway and inland waterways playing less important roles as they are less developed. Nigeria's economy therefore, is highly dependent on a good road network in the absence of effective rail and water transportation systems to facilitate haulage of people, goods and services. Its inadequacy can, therefore, be a serious constraint to national development.

Road transport is the most important mode. The replacement value of road network in Nigeria at 2001 prices was estimated at between #3,500 and #4,300 billion (National Transport Policy, 2010). The road sub-sector suffers from the effects of past shortages of resources and this inadequacy has consistently been reflected in inadequate or lack of maintenance which often necessitates subsequent reconstruction. The inadequate replacement and the poor maintenance of vehicles contribute to high social costs of atmospheric pollution and results in high operating costs.

The introduction to the National Transport Policy document of 1993 states that: "At present, the Nigerian transport system functions in a crisis situation", and one of the principal causes, it identified was "a major imbalance between the needs of Nigerian society and economy for adequate transport facilities and the ability of the transport sector to meet such demands". Roads are the most important elements in transport communication and are used by almost everyone on a daily basis. Besides the fact that roads are provided for the benefit of the road user, they also play a significant role in promoting economic growth and the living standard of the population. Nigeria is a fast developing country and desires to catch up with rest of the world as enshrined in the Vision NV20:2020 of the Federal Government. Not only has the traffic volume increased but also the tendency of most heavy vehicle drivers to overload their vehicle in order to save operation cost. As a major capital investment which should be expected to show adequate returns on expenditure, the problem of road deterioration with consequent increases in vehicle operating cost and accidents has been the common features of most roads in the country. These roads have shown signs of distress in the form of cracking, rutting, deformation, bond failure, etc. Thus, adequate consideration should be given to the causes of road deterioration and failure in several roads in the country.

Over the last few years, the Federal Government of Nigeria has made tremendous efforts in developing and improving the road network to enable efficient development of the country's infrastructure. In order to secure and preserve such valuable asset, timely and appropriate maintenance/rehabilitation interventions must take place. Further development of the road network is expected to continue and both the maintenance/rehabilitation activities and the design of new roads will require traffic load data as one of the basic inputs. This information needs to be collected as accurately as possible since the importance of reliable and correct information on sub-grade soil and axle loads for pavement design cannot be overemphasized. The need to collect data on all existing roads, research into the use of local materials for use in road constructions and the knowledge of soil profile within the entire country to certain depth below ground is of importance.

As part of the research efforts of the Nigerian Building and Road Research Institute, the Road Research Department of the Institute conducted an investigation of road failure on Enugu-Port Harcourt Expressway. The main objective of the research project is to identify the cause(s) of road pavement failure on Enugu-Port Harcourt dual carriageway and proffer appropriate remedial interventions and solutions. This paper therefore presents the results of the comprehensive investigation carried out on this strategically important federal highway. The characteristics of construction materials, pavement thickness, traffic and condition, pavement distress/failures, etc. of the road investigated and analysed are summarised and presented in this paper.

1.1 Road Pavement Failure

Pavement is an engineering structure placed on natural soils and designed to withstand the traffic loading and the action of the climate with minimal deterioration, and in the most economical way (Hudson et al., 2003). Every vehicle which passes over a road causes a momentary, very small, but significant deformation of the road pavement structure. The passage of many vehicles has a cumulative effect which gradually leads to permanent deformation and road surface deterioration. Magnitude and configuration of vehicular loads together with the environment have a significant effect on induced tensile stresses within flexible pavements (Yu et al., 1998). Heavy vehicle load on the pavements subjects them to high stresses causing damage. However, not all trucks have the same damaging effects; the damage on the road pavement depends on speed, wheel loads, number and location of axles, load distributions, type of suspension, number of wheels, tire types, inflation pressure and other factors (Gillespie et al., 1993).

Several previous studies on road damage that have been done by researchers identified overloaded heavy vehicles as the primary cause of road pavement structure distresses, with service lifetime decreasing during design life time (Rahim, 2000; Koesdarwanto, 2004 and Sulisty and Handayani, 2002). The presence of overloading is indicated by the width area of rutting which is more than 60% of total road structural distress per km and by maximum axle load (MAL) of the heavy vehicle which is larger than the standard MAL. Evaluation of the effect of heavy vehicle overloading to the pavement damage/service life on the road by Sulisty and Handayani (2002) concluded that because of overloading on the road, there was a decrease of 1.4-year design life or 28% of the original design life 5 years.

1.2 Brief Description of Study Area

The Enugu-Port Harcourt dual carriageway is a flexible pavement structure that consists of asphalt surface over on stabilized base and sub base courses. It is a part of the Trans-African highway. The study area is located within the geographical coordinates of between 4°45' and 6° 21'N and between 6° 51' and 7° 30'E (Fig. 1). The dual carriageway is located on Federal link-node system on link A343 Enugu and A231 Port Harcourt with an approximate length of about 217x2 kilometers.

Fig. 1: Location Map

The vegetation of the area varies from mixed savannah to dense vegetation. The climate of the area has general high rainfall and humidity particularly from April-October and relatively even temperatures. The mean annual rainfall varies from 1500mm to 2000mm. The topography is flat to rolling, with swampy portions on the Enugu-Port Harcourt road.

1.3 Geological Setting

The geology of the area has been severally described (Reyment, 1965; Short and Stauble, 1967; Burke et al, 1970; Kogbe, 1976; Agagu et al, 1985; etc.). The Enugu-Port Harcourt dual carriageway geologically lies within the Anambra basin, the Afikpo syncline and runs parallel to

Awka-Orlu escarpment. The Anambra basin is essentially made up of sediments from two geologic eras. The regressive Upper Cretaceous sediments (Asu River group, Eze-Aku shales, Awgu shale and Nkporo shale) and the Transgressive lower Tertiary sediments (Ameke Formation, Enugu shale, Mamu Formation and Ajali sandstone). These deposits consist of shale, sandstone, marl and sandy clay while the youngest Ogwashi-Asaba formation consists essentially of sandy soils with lignite seams (Reyment, 1965) of Oligocene-Miocene age and the Benin formation which is composed of yellowish white continental sands with pebbly bands of Miocene-Recent in age.

Hence, the expressway passes through four important geological Formations: Eze-Aku shale, Awgu shale, Nkporo shale, Enugu shale.

2.0 METHOD OF INVESTIGATION

2.1 Preliminary Field Investigation

Primary data were obtained from topographic maps, geological maps, reports and published journals. As part of site investigation, field inspection of the carriageway, shoulders, drains, cuts, embankments, etc., was conducted in order to assess the structural conditions, the extent of defects, deterioration or failure and identify major surface features which provide sufficient information for the detailed fieldwork.

2.2 Detailed Field Investigation

Field investigation of the dual carriageway involved field sampling of construction materials and subgrade from failed, fairly stable and stable sections of the road, and conducting traffic survey. These field investigations included the following:

2.2.1 Sampling of Asphaltic Concrete Cores

Fifty (50) asphaltic core samples were collected from various locations along the dual carriageway. Standard method of sampling of asphaltic concrete cores was adopted in the exercise. At least two cores were collected in each location using a pavement coring machine (Briggs & Stratton, 500 series, 158cc) with 100mm diameter diamond tipped coring barrel. Samples were properly labeled and delivered in good condition to the Pavement Evaluation Unit (PEU) Laboratory, Federal Ministry of Works, Kaduna; where the samples were tested.

2.2.2 Sampling of Base/Sub-base and Sub-grade Soils

Boring: Boreholes were drilled using 100mm diameter hand auger at the shoulders, road verges and adjacent subgrade soils to obtain the lithology, in situ moisture content and collect soil samples. The in-situ moisture contents of the base/subbase and subgrade were determined using the Ashwort Speedy Moisture Tester. The base/subbase and sub-grade soil samples were collected from the various sections of the road for laboratory tests. The tests include the following; particle size analysis, Atterberg (liquid and plastic limits), Compaction and Strength (CBR) tests, and were conducted in the Soil Laboratory of Nigerian Building and Road Research Institute, Ota, Ogun State.

2.2.3 Groundwater Level

Table 3 shows that the groundwater levels in most of the drilled holes are low, ranging from 0.0m to 1.2m. The penetration of water into and from under (poor drainage) road pavement layers can lead to a loss of load-bearing capacity and consequent increased rate of road structure deformation.

2.2.4 Traffic Survey

2.2.4.1 Traffic Volume

Fourteen (14) days manual vehicle counts were conducted as hand-tallies of visually observed vehicles to estimate the daily traffic and average daily traffic (ADT) taken by direction. Twelve (12) hour counts were taken (6am Monday through 6pm Friday) at various locations. All counts taken have a data recording interval of one hour. All counts were also taken by direction and no count contains data collected within two days before and after any major holiday. The traffic survey was then conducted at five (5) count stations along the carriageway. Two enumerators with separate count forms were used at all times–one for each direction of flow. The axle load survey was not conducted due to the absence of weighing bridges.

However, to quantify traffic loads on the test pavements, the heavy vehicles considered to cause structural damage to the pavement were given special attention. Three classes of vehicles categorized as truck-type (heavy vehicle) were considered in this study, in accordance with 1993 AASHTO Design Guide requirement. They are vehicle-class of 6B for 2-axle trailer, 7A for 3-axle trailer and 7C for more than 3-axle trailer. Vehicle-class 7C consists of three sub-classes; they are 7C1 for 4-axle trailer, 7C2 for 5-axle trailer and 7C3 for 6-axle trailer. Adopting the AASHTO Road test data for the load distribution of axle load in each vehicle, each vehicle axle was then converted to standard (80 kN or 8.16 tons) axle load using equation (1) below to obtain the respective load equivalent factors for the damaging effect of the vehicle on the pavement. This process was repeated for all the categories of the vehicles that have damaging effect as analyzed in the traffic count (Parsley and Ellis, 2003 and Rolt, 1981).

2.2.4.2 Determination of Vehicle Damage Factor (VDF)

The traffic volume on the road is estimated in terms of Equivalent Single Axle Load –ESAL. An Equivalent Standard Axle is defined as "a Single Axle carrying a load of 80kN or 8.16 tonnes spread over two sets of dual tyres, each dual set separated by 300mm (Parsley and Ellis, 2003). Light vehicles and passengers cars are not considered in estimating the damaging effect of the traffic loading on the road. Axle loads were converted to ESALs using the "Fourth Power Rule". Vehicle Damaging Factor or axle load equivalency factor (LEF or E) of each heavy vehicle was determined using 1993 AASHTO Design Guide procedure, as follows.

$$EF = (\text{Axle load} / 80TN)^4 \quad \text{.......eqn 1}$$

2.3 Laboratory Tests

2.3.1 Asphaltic Concrete Testing

Asphaltic concrete testing was carried out on samples collected along Enugu –Port Harcourt dual carriageway in Enugu, Abia and Rivers States, at the Pavement Evaluation Unit (PEU) Laboratory, Federal Ministry of Works, Kaduna. A total of 50 asphaltic cores, each comprising of wearing course and binder course layers, were tested from both carriageways.

The analysis of the test results was based on the limits set in Federal Ministry of Works General Specifications, Volume II – Roads and Bridges.

2.3.1.1 Asphaltic Concrete Cores

Wearing course and binder course layers were carefully separated from each asphaltic concrete core. These were properly labeled and tested separately. The following tests were carried out on the samples –

a. Thickness measurement
b. Bulk Density test
c. Maximum Specific Gravity test – Rice Method [AASHTO]
d. Marshall test
e. Extraction test

Tests were carried out in accordance with relevant sections of AASHTO and ASTM testing methods.

2.3.2 Soil Tests of Base/Sub-base and Sub-grade

The particle size analysis, California Bearing Ratio (CBR), compaction tests and plasticity of the samples were determined adopting the American Society for Testing and Materials (ASTM, 1975) method "for determination of properties of soils and rocks" and in accordance with BS 1377: Soils for civil engineering purposes: Part 4, Compaction related tests.

3.0 RESULTS AND DISCUSSION

Table 1 and Figs. 2-3 show the summary of the test results of asphaltic concrete.

Table 1: Summary of important properties of asphaltic concrete in both carriageways

WEARING COURSE							
DIRECTION:	**PH BOUND Carriageway**			**ENUGU BOUND Carriageway**			
THICK	46 - 90mm	Not met:	Na	THICK	20 - 97mm	Not met:	na
<u>% VOIDS</u>	4 - 8%	Not met:	**<u>8/13</u>**	***<u>% VOIDS</u>***	4 - 8%	Not met:	7/11
% BITUMEN	4.8 - 8.6%	Not met:	2/10	% BITUMEN	5 - 6.3%	Not met:	0/7
M/STABILITY	708 - 1974	Not met:	0/13	M/STABILITY	726 - 2088	Not met:	0/11
M/FLOW	3 - 5mm	Not met:	2/13	M/FLOW	3 - 6mm	Not met:	5/11
<u>AGGR GRADN</u>	Y/N	Not met:	**<u>7/10</u>**	AGGR GRADN	Y/N	Not met:	3/8
BINDER COURSE							
DIRECTION:	**PH BOUND Carriageway**			**ENUGU BOUND Carriageway**			
THICK	53 - 90mm	Not met:	Na	THICK	48 - 98mm	Not met:	Na
% VOIDS	4 - 6%	Not met:	<u>0/13</u>	% VOIDS	4 - 6%	Not met:	1/10
<u>% BITUMEN</u>	3.9 - 7.6%	Not met:	**<u>6/10</u>**	% BITUMEN	4.1 - 6.3%	Not met:	1/6
M/STABILITY	613 - 1358	Not met:	0/13	M/STABILITY	708 - 1,678	Not met:	0/10
M/FLOW	3 - 5mm	Not met:	0/13	M/FLOW	3 - 4mm	Not met:	0/10
<u>AGGR GRADN</u>	Y/N	Not met:	**<u>6/10</u>**	***<u>AGGR GRADN</u>***	Y/N	Not met:	**<u>6/6</u>**

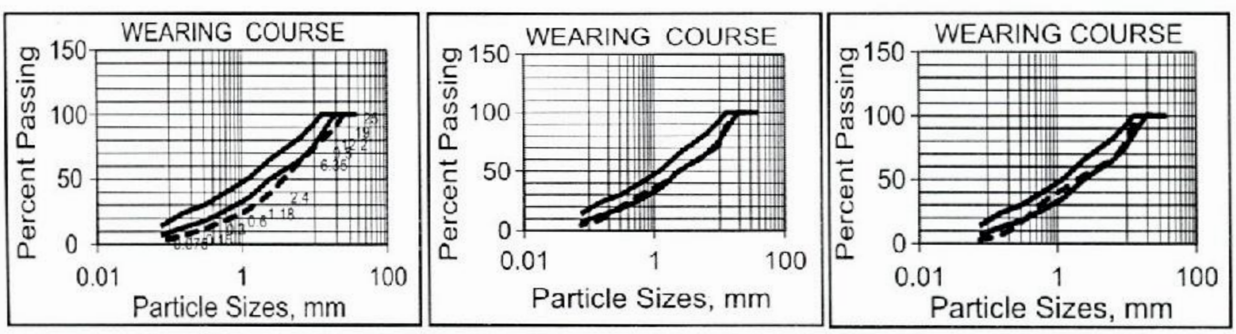

Fig. 2: Typical Asphalt Concrete Aggregate Grading of the wearing course (Specification Grading Envelope)

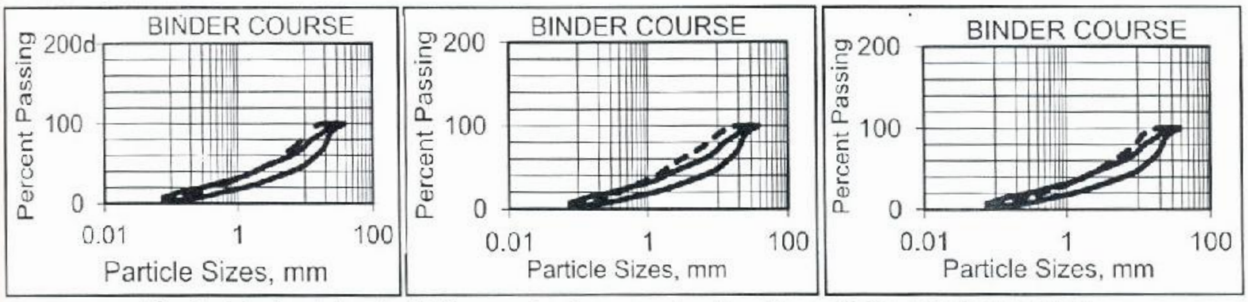

Fig. 3: Typical Asphalt Concrete Aggregate Grading of the binder course (Specification Grading Envelope)

3.1 Asphaltic Concrete

Discussions on the test results were based on the limits set in Federal Ministry of Works General Specification – Volume II – Roads and Bridges. Relevant sections of the Specifications are summarized in Table 2.0 for ease of reference –

Table 2.0: Relevant section of FMW & H Specification

CLAUSE(S)	SPECIFICATION		REMARK
	<u>Materials Suitable for asphaltic concrete</u>		
	<u>Wearing</u>	**Binder**	
6201	Optimum Bit. Content 5–8 %	4.5–6.5 %	
	Marshall Stability, min 350Kg min	350Kg	
	Marshall Flow, 2–4mm	2 – 6mm	
	Void in Total Mix 3 - 5%	3 - 8%	

3.1.1. Wearing Course

i) **Port Harcourt Bound Carriageway**

Test results (Table 1) show that the asphalt core measurement exhibited a wide variation in surface course thickness along the carriageway ranging from 46-90mm. Contract thickness during construction/rehabilitation is unknown. Voids content ranges from 4–8%. The Specification requirement of void content in the wearing course was not met in 61% of the samples tested. Bitumen content ranges from 4.8 – 8.6%. Only 80% of the samples tested on bitumen content of wearing course met the Specification requirement. Marshall Stability ranges from 708–1,974Kg. All (i.e. 100%) the samples tested met the Specification requirement for Marshall Stability. Marshall Flow ranges from 3–5mm. The Specification requirement of Marshall Flow was met in 84% of the samples tested. Finally the test result (Figs. 2-4) shows that aggregates grading is not within the Specification Envelope in 70% of the samples tested.

It is seen that voids content and aggregates grading were not met in many locations. Poor aggregates grading must have contributed to the high voids content in the asphaltic concrete.

ii. **Enugu Bound Carriageway**

Test results (Table 1) show that thickness ranges from 20-97mm along the carriageway. Voids content ranges from 4–8%. The Specification requirement of void content in the wearing course was not met in 63% of the samples tested. Bitumen content ranges from 5–6.3%. All (100%) of the tested samples met the Specification requirement on bitumen content of wearing course. Marshall Stability ranges from 726–2,088Kg. The Specification requirement of Marshall Stability was met in the 100% of the samples tested. Marshall Flow ranges from 3 – 6mm. Only 54% of the tested samples met the Specification requirement of Marshall Flow teat. Finally the test result shows that aggregates grading is within the Specification Envelope in 62% of the samples tested.

Generally, fair quality asphaltic concrete wearing course was used in the construction/rehabilitated sections of the Enugu-bound carriageway of Enugu-Port Harcourt road.

3.1.2 Binder Course

i. **Port Harcourt Bound Carriageway**

Test results (Table 1) show that thickness ranges from 53-90mm along the carriageway. Voids content ranges from 4–6%. The Specification requirement of void content in the binder course was met in all the samples tested. Bitumen content ranges from 3.9 – 7.6%. Only 60% of the samples tested did not meet the Specification requirement on bitumen content of binder course. Marshall Stability ranges from 613 – 1,358Kg. 100% of the tested samples met the Specification requirement of Marshall Stability. Marshall Flow ranges from 3– 5mm. The Specification requirement of Marshall Flow was met in 100% of the samples tested. Finally the test results (Figs 2-4) show that aggregates grading is not within the Specification Envelope in 60% of the samples tested.

ii. **Enugu Bound Carriageway**

Test results (Table 1) show that thickness ranges from 48-98mm along the carriageway. Voids content ranges from 4–6%. The Specification requirement of void content in the binder course ranging from 3 – 8% was met in 90% of the samples tested. Bitumen content ranges from 4.1–6.3%. Specification requirement on bitumen content of wearing course was met in 83% of the samples tested. Marshall Stability ranges from 708–1,678Kg. 100% of the samples tested met the Specification requirement of Marshall Stability. Marshall Flow ranges from 3–4mm. The Specification requirement of Marshall Flow was met in the 100% of the samples tested. Finally, the test results show that aggregates grading is not within the Specification Envelope in 100% of the samples tested. Table 1.0 summarizes the properties of the asphaltic concrete surfacing encountered in the dual carriageway.

The Marshal stability and air void values for the binder in both lanes indicate that adequate compaction energy was exerted on the asphalt mixture during construction. Adequate compactions gave the asphalt mixture the needed mechanical interlock and shear strength and reduced the permeability of the mixture to water and air.

It is seen from Table 1 that the common property that failed to meet the Specification requirement in the wearing course on both directions of road is high voids content. The air void content of bituminous materials is an important control parameter for the quality of bitumen being laid and compacted. If the air void content is too high, it allows for intrusion of air and water. Moreover, it also increases the rate of hardening of binders which produce premature embrittlement of pavements. In addition, too high a void content will lead to differential compaction subject to traffic loads and result in formation of ruts and grooves along the wheel track.

However, a minimum amount of air void should be maintained to avoid instability during compaction process and to provide space for bitumen flow in long-term consolidation under traffic loads. A sufficient amount of air voids should be designed to make room for expansion of binder in dry season and compaction by road traffic as suggested by National Association of Australian State Road Authorities (1968), otherwise bleeding and loss of stability may occur and the pavement will deform readily under severe loads. Aggregates grading was out of the wearing course specification envelope in significant locations along Port Harcourt bound carriageway.

In the binder course, the common deficiency in the property is aggregates grading which is not wholly within the Specification envelope in significant number of locations. Along Port Harcourt bound carriageway, bitumen content was deficient in some cores and in excess in others. These are significant. These imply that an important property varies in the wearing course and binder course of both carriageways. A reduction in the percentage of fine aggregates means reduction in the density of the asphalt, while a reduction in the coarse aggregates result in decrease in stability.

The amount of bitumen to be added to a bituminous mixture cannot be too excessive or too little. The principle of designing the optimum amount of bitumen content is to include sufficient amount of bitumen so that the aggregates are fully coated with bitumen and the voids within the bituminous material are sealed up. As such, the durability of the bituminous pavement can be enhanced by the impermeability achieved. Moreover, a minimum amount of bitumen is essential to prevent the aggregates from being pulled out by the abrasive actions of moving vehicles on the carriageway. However, the bitumen content cannot be too high because it would result in the instability of the bituminous pavement. In essence, the resistance to deformation of bituminous pavement under traffic load is reduced by the inclusion of excessive bitumen content. This is reflective of various repairs that the dual carriageway has been subjected to since construction.

The test results of the asphaltic concrete indicate that good quality bitumen and aggregates were used in the production of the asphaltic concrete of Enugu-Port Harcourt dual carriageway. However, it should be noted that deficiencies observed in the bituminous materials may not be responsible for failures observed in sections of the dual carriageway.

3.2 Base/Sub-base and Sub-grade soil

3.2.1 Particle Size Distribution and Plasticity

The particle size distribution results classified the samples as A-1-b, A-3, A-2-4, A-2-6, A-2-7, A-4, A-7-5 and A-7-6 on the American Association of State Highway and Transportation Officials (AASHTO) classification scheme with maximum dry density (MDD) and optimum moisture content (OMC) ranging from 1.25 to 2.16 mg/cm^{-3} and 9.0 to 23.60% respectively (Table 3). The plasticity values obtained are liquid limits NP – 66%, and NP-59.8% for sub-grade and sub-base respectively. The plasticity index values range from NP-37.7% and NP-35.0% for sub-grade and sub-base soils respectively. Table 3 shows that 56.0% of the tested samples do not meet the Federal Ministry of Works and Housing Specification of not more than 12% plasticity index for sub-base. The result also indicated that 68.0% of samples exceeded the liquid limit of 30% for sub-base. The liquid limit and plasticity indices of over 50% of the samples far exceeded those specified by the FMW Specifications.

3.2.2. California Bearing Ratio (CBR)

The CBR quantitatively evaluates the inherent strength of soils in order for a road pavement to be designed for a particular strength of sub-grade. It is a point load test that can be carried out on almost all kinds of soils, ranging from clay to gravel (Garg, 2009). The summary of results is presented in Table 3. The overall soaked CBR results of sub-grade soils ranged between 3.0 and 30.0%. Though these results partly meet the FMW Specifications for pavement design (Table 3),

Table 3: Summary of engineering properties of Sub-base and Sub-grade Soils

	TEST	SUBGRADE SOIL (Total No. of samples-46)		SUB-BASE SOIL (Total No. of samples-26)		% WITHIN FMW&H SPECIFICATION (%)		FMW&H SPECIFICATION	
		Range	Average	Range	Average	Subgrade	Subbase	Subgrade	Subbase
1.	% Passing Sieve No. 200	0.98 – 95.0	39.88	6.23 – 60.0	33.59	47.8	52.0	= 35	= 30
2.	Liquid Limit (LL) %	NP – 66.0	37.52	NP – 59.8	35.55	-	32	-	= 30
3.	Plasticity index (PI) %	NP – 37.7	17.23	NP – 35.0	17.38	-	44	-	= 12
4.	CBR % (unsoaked)	13.5 -85.0	38.80	16.0 -75.0	49.73	-	-	-	-
5.	CBR % (soaked)	3.0 -30.0	11.7	4.0 -36.0	19.22	47.26	28.83	= 10	= 30
6.	Maximum Dry Density (mg/m³)	1.25-2.13	1.90	1.62 – 2.16	1.83				
7.	Optimum Moisture Content (%)	9.0 – 23.60	15.21	9.6 – 22.0	13.70				
8.	Groundwater level	Surface-1.2m							

71.17% exceeded the CBR (soaked) of not less than 30% for sub-base material. 47.26% of the samples met the FMW&H specification of not less than 10% CBR (soaked) for sub-grade. This confirmed that very poor clayey lateritic soils were used for the sub-base course. The percentage of fines (% passing sieve No. 200) has significant effect on the performance of the base/sub-base materials. Some fines are required to allow for effective compaction to appropriate density. Too much fines will result in reduction in the possible maximum density and strength and increase the susceptibility to weakening from water infiltration or seepage. Only 47.8% of the tested samples met the FMW Specification of not more than 35% percentage passing sieve No. 200 for sub-grade. Table 3 also shows that 52.0% of the tested samples met the specification of not more 30% passing sieve No. 200 for sub-base. These results also confirmed that poor soil materials were used for the sub-base. This probably may explain the widespread failure observed along the road.

It is important to note that while the liquid limit and plasticity index of the samples suggest probable failure, other factors may cause actual failure. These factors include inadequate water-proof bituminous surface, as the soils which were derived from shales tend to lose strength significantly with increase in moisture content. This explains the extensive failures mostly during the rainy season in sections where the pavement is damaged.

Table 4: Summary of traffic data at each counting station

Type of Vehicle	Ndiagu Amechi, Enugu		Ishiagu Junction		Okigwe		Osisioma, Aba,		Rumuigbo		Total	Total
	Port Harcourt Bound	Enugu Bound	Port Harcourt Bound	Enugu Bound	Port Harcourt Bound	Enugu Bound	Port Harcourt Bound	Enugu Bound	Port Harcourt Bound	Enugu Bound	Port Harcourt Bound	Enugu Bound
Heavy Vehicles	32,690	31,672	27,223	30,112	32,286	33,504	30,678	30,884	24,457	19,812	147,334 (39.26%)	145,990 (38.91%)
Motorcycle	3096	3559	3928	4528	3503	3549	2661	3140	3310	3331	16,498 (4.40%)	18,107 (4.83%)
Passenger cars	40,842	40,592	20,977	20,673	14,775	13,088	12,630	13,414	25,518	23,682	114,742 (30.58%)	111,449 (29.71%)
Mini Bus/pickup	23,088	26,282	21,793	24,609	14,381	14,000	15,522	13,784	21,866	20,936	96,650 (25.76%)	99,611 (26.55%)
Total	**99,716**	**102,105**	**73,921**	**79,922**	**64,945**	**64,141**	**62,491**	**61,222**	**75,151**	**67,761**	**375,224**	**375,157**
Total Traffic Volume on both Directions			= 751,381									
Average Daily Traffic (ADT)			= 53,670									
Number of Heavy Vehicles									147,334	145,990		
Percentage of Heavy vehicles on each lane									39.26%	39.91%		
Overall percentage of Heavy vehicles			=39.0%									

Table 5: Average Daily Traffic for Heavy Vehicles

Direction	Average Daily Traffic (each Heavy Vehicle Classes and Sub-classes-Vehicle)					
	6B	7A	7C			Total
			7C1	7C2	7C3	
Enugu- Port Harcourt	3,013	1,389	2,805	2,112	1,205	10,524
Port Harcourt – Enugu	2,865	1,462	2,764	2,123	1,214	10,428

3.3. Traffic Analysis

The summary of traffic survey data at each counting station and Average Daily Traffic of each of the Heavy Vehicle Classes and Sub-classes (Vehicle) are presented in Tables 4 & 5.

The total traffic volume of vehicles in both directions of Enugu-Port Harcourt Expressway for the period of traffic survey (two weeks) was 751,381. Three classes of vehicles categorized as truck-type (heavy vehicle) in accordance with 1993 AASHTO Design Guide requirement were considered in this study. They are vehicle-class of 6B for 2-axle trailer, 7A for 3-axle trailer and 7C for more than 3-axle trailer. Vehicle-class 7C consists of three sub-classes; they are 7C1 for 4-axle trailer, 7C2 for 5-axle trailer and 7C3 for 6-axle trailer, as earlier mentioned. The average daily traffic (ADT) obtained was 53,670 vehicles per day (vpd). The average daily traffic of each Heavy Vehicle Classes and Sub-classes (Vehicle) as shown in Table 5 indicates that the computed average number of heavy vehicles in the two weeks was 20,952 vpd. This implies that the percentage of trucks to total vehicle per day was 39% and that the estimated annual traffic loading on the expressway, without considering other factors, is 7,647,480 trucks. The percentage of trucks on Port Harcourt bound lane and Enugu bound lane are 39.26% and 39.91% respectively.

Traffic analysis shown in Table 4 revealed that light vehicles and motorcycles accounted for 60.74% and 60.09% on the Port Harcourt bound lane and Enugu bound lane respectively. Of all the trucks, an average of 28.05 percent were two-axle single trailers, six-tyre single; 26.65 percent were four-axle; 20.7 percent were five-axle semitrailers; 13.61 percent were 3-axle while 6-axle trucks accounted for an average of 11.55 percent. The axle load of the heavy vehicles could not be obtained due to the absence of weighing bridges on the heavily trafficked expressway. However, axle load distribution from 1993 AASHTO Design Guideline was adopted.

3.3.1 Axle load analysis

Table 6 is the summary of the axle load distribution, which reflects only those vehicles likely to cause structural damage to the pavement. The axle load distribution adopted from 1993 ASHTO Design Guideline was considered for heavy vehicles. The axle load analysis considered the following:

i. The average standard equivalent factor per vehicle
ii. The load equivalent factor per vehicle
iii. The load distribution factors on the various axles of a truck.

Table 6: Distribution of Equivalent Number of Vehicle Axle Load

Category of Vehicle/No of Axle	Code	Total Load Axle Distribution (ton)	Total No. of Vehicles		Load Equivalency Factor(LEF per Vehicle)						Total Load Equivalency Factor(LEF)	LEF * No. of Vehicle		Av. LEF (All Vehicles)
			P/H Bound lane	Enugu Bound lane	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6		P/H Bound lane	Enugu Bound lane	
Truck 2 - Axle	1.2	16	42,177	40,106	0.2923	2.2555					2.5478	107,459	102,182	
Truck 3 - Axle	1.2.2	24	19,440	20,472	0.2923	2.0362*	2.0362				2.3285	45,266	47,669	2.84
Truck 4 - Axle	1-2.2.2	27	20,229	20,451	0.2923	1.3598**					1.6521	33,420	33,787	
Truck 4 - Axle	1.2-2.2	34	19,038	18,247	0.2923	2.2555	2.0362*				4.5840	87,270	83,245	
Truck 5 - Axle	1.2.2-2.2	42	18,124	18,160	0.2923	2.0362*		2.0362*			4.3648	35,240	35310	
Truck 5 - Axle	1.1-2.2.2	33	11,450	11,565	0.2923	0.2923		1.3598**			1.9444	49,977	50,479	
Truck 6 - Axle	1.2.2-2.2.2	45	16,876	16,989	0.2923*	2.0362*		1.3598**			3.6883	62,244	62,660	

Note: *tandem group axle, ** tridem group axle
1.2: Single wheel single axle
2: Double wheel single axle
2.2: Double wheel double axle
2.2.2: Double wheel triple axle

3.3.2 Computation of equivalent standard axle factors

From the axle load conversion shown in Table 6, it can be seen that an average heavy vehicle on the expressway possesses an average equivalent factor of 2.84 (approximate 3) which is about three times the standard axle weight for road pavements. This implies that an average truck on the road studied caused the same pavement damage as three standard axles of 80kN would cause. It shows that there is high degree of overloading on the road which is one of the major causes of pavement deterioration. Also, the percentage of heavy vehicles that is causing structural damage to the pavement is 39%.

Similarly, the loading application time has more detrimental effect on the pavement deterioration. Pavement of the road subjected to slow-motion loading mechanism deteriorates faster than those subjected to rapid-motion movement. This means that as the time of load application increases, the deterioration increases (Al Sulieman, et al, 1996, Herrin et al, 1986). This is clearly observable in the trafficked areas such as slow lanes used by heavy slow-motion trucks. Several sections of the carriageway particularly Umuahia - Aba section were subjected to slow-motion loading mechanism due to deterioration of the road.

A total of 293,324 heavy vehicles (trucks) of various categories were counted, each possessing an average equivalent factor of 3.0 for the fourteen days of survey. This means that on the average, each heavy vehicle on the Enugu-Port Harcourt expressway causes three times the damage of the standard weight legally permitted on the pavement of Nigerian roads. The computed value is high and excessive and probably constitutes one of the major reasons for the deterioration of road pavements along Enugu-Port Harcourt Expressway. The challenge therefore needs to be more forcefully addressed for the survival of the nation's road asset.

3.4 Visual Field Inspection

A general condition survey of the pavement surface was conducted to assess the type of distress. Various forms of cracks were observed on both lanes of the dual carriageway. Most portions of the road show alligator cracks of width about 1mm to 5 mm and potholes in the centerline. The stretch shows deep deformation of the asphalt and sporadic cracks. The structural base failure observed at some sections was as a result of insufficient strength caused by bad design, overloading or material change due to moisture or weathering. This failure is characterized by plastic deformation of the pavement. In advanced stages, it may also be accompanied by high severity alligator cracking, followed by leaching of fine materials as deterioration progresses.

Some sections of the roadway show minor deformations and few cracks that increase with increase in settlement. These are occasioned by differential settlement especially in sections where the sub-grade soils are shaly and marly materials.

In some sections, mostly between Okigwe and Osisioma (Aba), the bituminous surface was observed to have extensive potholes along the centerline of the pavement, depressions, block cracking, edge failure and settlement of the surfacing accompanied by shoving of the surface layer. Considering the extent and severity of distress, the road was not expected to perform its intended function unless suitable remedial measures were applied. However, there were pot holes and series of both longitudinal and transverse cracks on the road. This may be attributed to heavy traffic load and/or lack of maintenance.

The total thickness of the surface course was not uniform along the pavement width and the length of the road. This also caused variation in strength as well as load distribution of the pavement along the road width and results in cracks. It seems that the deterioration of the above stretch was due to underestimation of the volume of traffic.

In the entire length of the road, longitudinal drainage was missing along the road and cross drainage works were also missing at various locations while the entire pavement was observed to be in saturated condition. That was because water that had percolated into the lower layers could not escape through the sides. At various locations, water was observed 'resident' on the edge of the pavement and with the load distribution of the pavement along the road width, progressive deformation and development of cracks was prevalent.

During heavy rains, water became stagnated on the pavement surface and the edge of the road. With sustained stagnation of water, the surface course layer also allowed percolation of water into lower layers. The pavement failures in some sections of the roads can be attributed to the high water table, the shaly subgrade and overloading. With lack of or inadequate drainage, structural base failure persists as a result of the capillary rise of water in the wet season.

Furthermore, it was observed that water stagnated along the road at some sections and side slopes were eroded. This resulted in the ingress of water into the pavement through cracks developed in the pavement. These cracked sections need to be strengthened.

From the visual inspection, laboratory test results and analysis, it is concluded that:

a. Lack of bond between wearing and binder courses might be the reason for the occurrence of bond failure between the wearing and binder courses.
b. Inadequate asphalt thickness to meet the requirement of number and higher axle loads of commercial vehicles.
c. There were poor sub-base and sub-grade soil material in different sections of the road
d. There was inadequate provision of drainage structures and where provided, the drainage structure was poorly designed
e. High water table, seepage of groundwater and infiltration surface water into the pavement is common phenomenon along the expressway.
f. Poor asphalt mix during rehabilitation (patching) can be deduced
g. There is high traffic volume in addition to overloaded heavy vehicles with high axle loads on the expressway.

4 PREVAILING PAVEMENT FAILURE ON ENUGU-PORT HARCOURT EXPRESSWAY

This section is a summary of the major flexible pavement distresses observed on Enugu-Port Harcourt Expressway. Photographs of different types of pavement distresses like pot holes, alligator cracking (fatigue), longitudinal cracking, block cracking, structural base failure, bond failure, patching, etc. are presented in Plates 1-17. The highlights of the prevailing failures on the expressway are presented below:

4.1 Fatigue (Alligator) Cracking

These are series of interconnected cracks caused by fatigue failure of the asphalt under repeated traffic loading. The cracking may have been initiated at the bottom of the binder layer where the tensile stress is the highest, propagating to the surface as one or more longitudinal cracks due to the observed thin thickness of the asphalt in places. Similarly, in thick pavements, the cracks most likely may have been initiated from the top in areas of high localized tensile stresses resulting from tyre-pavement interaction and asphalt binder aging. This failure is an indicator of structural failure and allows moisture infiltration. It may further deteriorate to a pothole. The alligator cracking are mostly caused by inadequate structural support which can be caused by decrease in pavement load supporting characteristics. On the Enugu-Port Harcourt dual carriageway, the likely pavement support characteristics that will cause alligator or fatigue cracking include the following:

- Loss of base, sub-base or sub-grade support due to poor drainage.
- Increase in loading or overloading (e.g. more or heavier loads than anticipated in design)
- Inadequate structural design
- Poor construction (e.g. inadequate compaction)
- Poor subgrade materials as the terrain is underlain by shales or shaly materials.

The cracks appeared as low severe cracks in small localized areas indicative of loss of sub-grade and large fatigue cracked areas which is indicative of general structural failure.

Remedial Action: The small, localized fatigue can be repaired by removing the cracked pavement area; dig out and replace the area of poor sub-grade and improve the drainage of that area if necessary, and patch over the repaired sub-grade. Similarly, large fatigue cracked areas can be repaired by placing asphalt overlay over the entire pavement surface. This overlay must be strong enough structurally to carry the anticipated loading because the underlying fatigue cracked pavement most likely contributes little or no strength (Roberts et. al., 1996).

4.2 Block Cracking

These are interconnected cracks that divide the pavement up into rectangular pieces. They allow moisture infiltration. The cracks are caused by inability of asphalt binder to expand and contract with temperature cycle due to asphalt binder aging or poor choice of asphalt binder in the mix design.

Remedial Action: The cracks can be repaired on low severity cracks by sealing to prevent the ingress of moisture into the sub-grade through the cracks. Asphalt can provide years of satisfactory service after developing small cracks if they are kept sealed (Roberts et. al., 1996). On severity of cracks, the cracked pavement will be removed and replaced with a well-designed overlay

4.3 Depression

These are localized pavement surface areas with slightly lower elevations than the surrounding pavement. Depressions are very noticeable after a rain when they are filled with water. Depressions are caused by subgrade settlement resulting from inadequate compaction during construction. It could also be a reflection of shaly sub-grade materials which are compressible and subject to deformation under heavy loading as well as high water table and inadequate drainage provision.

Remedial Action: They can be repaired by removing the affected pavement, then digging out and replacing the area of poor subgrade. Patch over the repaired subgrade and provide adequate drainage.

4.4 Longitudinal Cracking

These are cracks parallel to the pavement's centerline or laydown direction. They are usually a type of fatigue cracking, mostly arising from overloading and aging.

Remedial Action: As in 4.3

4.5 Patching

Mix rutting seldom occurred on the pavement surface along Enugu-Port Harcourt expressway. This is where pavement surface exhibits wheel path depressions as a result of compaction/mix design problems. Sub-grade rutting was also observed i.e. when the sub-grade exhibits wheel path depressions due to loading. In this case, the pavement settles into the sub-grade ruts causing surface depressions in the wheel path.

4.6 Rutting

Rutting is caused by permanent deformation in any of the layers of the pavement or sub-grade. It is usually caused by consolidation or lateral movement of the materials due to traffic loading. Some of the specific causes of rutting can be:

- Insufficient compaction of asphalt layers during construction. If it is not compacted enough initially, asphalt pavement may continue to densify under traffic loads.
- Sub-grade rutting as a result of inadequate pavement structure
- Improper mix design or manufacture e.g. excessively high asphalt content, excessive mineral filler, insufficient amount of angular aggregate particles, etc.

Remedial Actions: A heavily rutted pavement should be leveled and overlaid with asphalt but a slight rutted pavement can generally be left untreated.

5 CONCLUSION

Traffic count data revealed a high volume of heavy vehicles with high axle loading. As a result, the maximum allowable axle load limits in service along the expressway has exceeded the design provisions by as much as three folds. This has contributed significantly to the damage of the Enugu-Port Harcourt expressway to its present level of deterioration. It may be noted that road pavement structures are designed to carry a given number of *standard axle load repetitions and* overloading reduces the design life of these structures. Trucks or heavy vehicles carrying much in excess of legal limits are largely responsible for the present condition of the expressway.

With lack of and/or inadequate maintenance on the road, heavy axle loading in combination with poor sub-grade soils and other environmental effects, accelerate cracking and deformation of the road. From the investigation carried out on the road, technical information and data were generated on the subgrade soil, asphaltic concrete, traffic count data and visual inspection of the pavement. The results showed that due to the infiltration of both surface and groundwater into the plastic shale sub-grade soil and overloading, cracks and potholes in varying degrees of severity were very common for the whole stretch of the highway. Poor drainage conditions and high water table, especially during rainy seasons, lead to ingress of water into the pavement structure from the sides as well as from the top surface. It was further noted that the widespread pavement failures observed along the very busy Enugu-Port Harcourt dual carriageway were a combination of several factors which included but are not limited to high traffic counts, overloading, poor sub-grade soil, lack of adequate maintenance, poor/lack of drainage system, poor design/construction materials, subgrade lying in largely shaly terrain and high water table.

It is therefore concluded that the major cause(s) of road pavement failure along the Enugu-Port Harcourt expressway are as a result of combination of one or more of the following factors:

a. The use of poor materials for base and sub-base courses
b. Poor in situ sub-grade soil which is underlain by different shale formations. These shale are plastic and have potential for swelling in the presence of water and shrinking when dry.
c. Poor/lack of adequate drainage system to drain out run-off or storm water or even seepage water from the sub-grade.
d. Poor workmanship and procedural errors in addition to the fact that remedial alterations or modifications (routine & periodic maintenance) which were unprofessionally carried out by probably untrained personnel.
e. High axle loading with attendant damaging impact on the structural competence of the road pavement
f. High water table along most of the road length which traverses a flat terrain in an area prone to high rainfall

These attributes lead to weakening of the pavement structure that failed with time; and in the absence of and/or delayed maintenance, the pavement weakening progressed further.

It is important to emphasise that a well designed road should be well constructed. But adequate maintenance schedules and strategies should be put in place over the design life of the road. This will checkmate the deterioration which sets in as soon as the road is constructed, even for a well engineered road pavement. Where the use to which the road is put in service far exceeds the designed limits, such as in overloading, water ingress into pavement structure and poor subgrade; coupled with the dearth of funds, the road will fail as was observed on the Enugu-Port Harcourt expressway.

At the design and construction stages, the importance of good supervision cannot be overemphasized. At the design stage, the issue of good detailing is essential while taking all the engineering and environmental factors into consideration. Of more critical concern is the need to include maintenance schedules into the design of roads.

At the construction stage, cognizance should be given to adherence to good construction practices in line with specifications and best practices. During construction, correct asphalt mix, right aggregate ratio, good mixing, compaction using the appropriate equipments etc, are vital for a good and durable pavement structure (Ejeh, 2011). Quality base, sub-base and sub-grade soil materials cannot be over-emphasized. Of critical concern at this stage is the use of competent manpower, especially at the artisan level. While good supervision is critical, the capacity of such manpower as well as for the professional engineers, etc. is essential. Strategies must be evolved to ensure that all levels of manpower are adequately trained. Apart from the above, efforts must be put in place to avoid cutting corners which may be detrimental to the structural integrity of the constructed or rehabilitated road.

While the road is in service, the performance of the road should be monitored. Weigh bridges should be provided at strategic locations to control overloading of the road facility. Periodic traffic counts should be carried out to monitor traffic volume and raise alarm for proper remedial measures when this seems to be getting out of design or allowable limits. Proper maintenance schedules should be carried out as and at when due. Particular emphasis should be given to drainage structures on the road.

6 RECOMMENDATIONS

From the foregoing, the following recommendations are proffered:

a) The maintenance of the road should commence immediately on notice of cracks on the pavement, to avoid further deterioration. Clearly overloading conditions need to be considered in maintenance recommendations

b) The stretch of road with total structural (base) failure should be scarified and reconstructed. The sections with various sizes of potholes should be patched with good quality asphalt. All failed sections established as having poor materials should be dug to at least one meter deep (1.0m) if the sub-grade is also weak, backfilled and given good compaction in layers with good quality materials, since the use of poor materials was identified as part of the major causes of failure. Crushed stone base should be applied on such failed sections.

c) Accurate axle weighing of the vehicles in order to predict the future volume of traffic and the axle loading on the road should be carried out. Clearly overloading conditions need to be considered in maintenance recommendations.

d) Construction of an alternative route to accommodate heavy duty vehicles which will be subjected to toll fee collection for maintenance. Meanwhile, the maintenance schedules on existing road should be carried out to service light vehicular traffic without any toll fee

e) The asphalt thickness (surface course) of the road should not be less than 120mm. Increased overlay thickness of bituminous layer with or without modified binder will help in preventing the cracks.

f) The base, sub-base and sub-grade soil of the road should be improved by stabilization.

Research efforts should be directed on the use of polymer modified bitumen, cement and chemical stabilizers for stabilization and sealing of cracks on the highways. Seal coats should be applied to prevent infiltration of water through cracked surfaces. This is especially important due to the water susceptibility of the materials used for bases and sub-bases.

g) Adequate drains, box/ring culverts turn-out and other drainage facilities should be provided, in order to control the drainage problem. These should be periodically and regularly maintained to ensure good performance always.

h) Regular routine and periodic maintenance practices should be encouraged in order to reduce the level of deterioration of the road. Rehabilitation and reconstruction of the road should be regularly carried out by the Federal Ministry of Works or its agents. Regular training courses on preventive maintenance treatment should also be organized for staff of Highway Agencies (FERMA & FMW) and its agents and contractors. A well-trained workforce is a more efficient and effective workforce.

i) Special attention should be given to quality control to ensure that the specification requirements are fully met so that strength and quality of the pavements will be of the best Standards

j) Traffic studies, particularly traffic loading and volume on major Nigerian roads should be on a continuous basis. Necessary traffic data must be collected, stored and retrieved when necessary for design and decision-making purposes. In this regards, NBRRI should set up and maintain data banks on Nigerian roads to ease information storage and retrieval to service the construction industry.

k) Axle load control with weigh bridges should be installed by the Federal Ministry Works (FMW) on major Nigerian roads to obtain and monitor impact of traffic loading of the heavy vehicles on roads.

l) Effective enforcement of the axle load regulations should be carried out throughout Nigeria in order to reduce the rapid rate of damage and protect the country's most valuable asset.

m) Promote the rail means of carriage more appropriately in order to reduce pressure on road transport mode. This will discourage haulages of goods through road transport.

n) Setting up standard asphalt testing laboratory in NBRRI to serve the construction industry and provide quality assurance service

o) NBRRI in collaboration with FMW, SON and relevant agencies should work together to formulate policies and establish Standards and Specifications for road design, road materials and construction, in addition to improving or modifying of standards and codes.

p) Considerable efforts should be devoted to identify and implement potential research, development and implementation of topics especially on pavement preservation techniques and practices i.e. maintenance techniques.

q) Preventive maintenance treatments must be applied when the pavement is still in good condition, with no structural damage

r) The drainage system is inadequate and should be improved by constructing side drains using geo-fabrics on either side of the road wherever required.

s) To prevent the occurrence of cracks, geo-fabric interlayer is suggested over the exiting surfacing and covered with asphalt concrete layer.

t) Recycling of failed section of the roads as part of pavement preservation should be encouraged.

u) Geo-fabrics should be used at those portions, which require full depth reconstruction because of extensive failures caused by poor drainage.

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ANNEX 1

PLATE 1: Typical overloaded 2 axle single 1.2 lorry

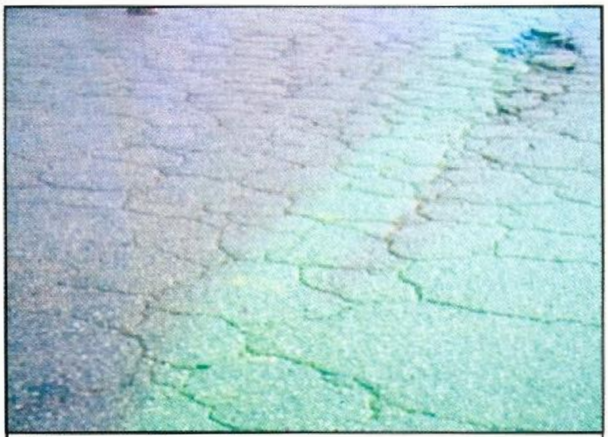

PLATE 2: High severity Alligator crack on the pavement

PLATE 3: High severity alligator cracks with the loosening of the pieces of asphalt

PLATE 4: High severity alligator cracks

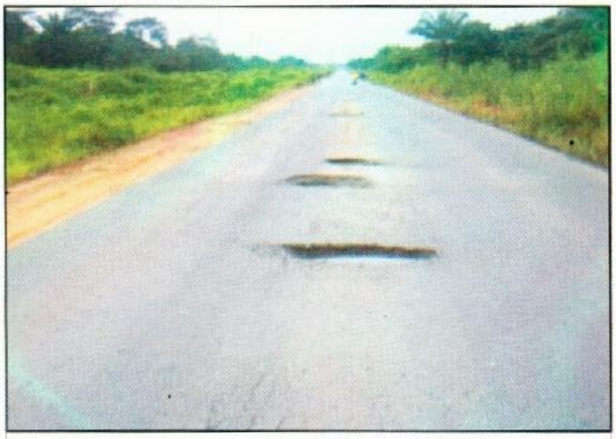

PLATE 5: Moderate severity rutting of the pavement

PLATE 6: Typical potholes at the centerline of the pavement

ANNEX 2

PLATE 7: Poor drainage design and lack of routine maintenance

PLATE 8: Structural failure due poor drainage design at the footslope of the road

PLATE 9: Reconstruction of collapsed box culvert

PLATE 10: High severity longitudinal cracks on the edge of the pavement due to undercutting by erosion, Enugu Bound lane

PLATE 11: Moderate severity longitudinal cracks on the wheelpath of the road

PLATE 12: Low severity longitudinal crack at the edge of the road