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A REVIEW OF ROAD PAVEMENT FAILURE: A CASE STUDY OF NIGERIAN ROAD

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ABSTRACT: *The magnitude of failure/damages for several Nigerian roadways has prompted several scholars/analysts to look into the causes of these failures. In this paper, the underlying factors for roadway degradation on Nigerian highways are examined, along with potential solutions. An essential infrastructure in any settlement is recognised as the roadway. Solid pathways make it easier to move people and things around, which boosts the economy. High accident rates, longer travel times, higher costs for vehicle maintenance, and high crime rates are just a few consequences of road failure that have been observed. Geology plays a significant role in the construction of roads because they are built on geologic earth materials and are significantly influenced by them. The main reasons why Nigerian roads fail are further identified in this paper as insufficient preliminary geological investigation, poor road design and construction, poor monitoring and quality workmanship, inadequate routine and regular maintenance, poor drainage, employing poor and low-quality materials, traffic congestion, overuse, incorrect use, and inadequate punishment for roadways failures. The majority of experts agree that Nigeria's road failure rate has recently grown despite the lack of concrete statistics. The solutions suggested include providing acceptable and adequate designs, oversight and quality control, clearing traffic on Nigerian roadways, prompt repair of such roads, constructing highway facilities, deploying skilled staff, and supportive government policies.*

KEYWORDS: Pavement, failure, construction, management, review.

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INTRODUCTION

Roads have consistently proven to be the most efficient and popular form of transportation for people and commodities around the world (Alo & Oni, 2018). Since it can offer door-to-door services, which improve accessibility, and because it is appropriate for short hauls of both passengers and freight, road transport has grown in popularity. For the majority of people in Nigeria, road transportation is the most convenient and cost-effective way of transportation because other options are either overpriced or underdeveloped. As a result, most roads in Nigeria have overbearing axle loads. According to Onuoha and Onwuka (2014), road failure can be characterised as an irregularity in the road pavement that causes cracks, potholes, and bulges. For a smooth ride or drive, a road's pavement is intended to be an uninterrupted period of asphalt laid; nevertheless, this smooth ride may be disrupted by obvious cracks, potholes, and bulges. In general, a disruption in a smooth ride is considered a road failure. It is crucial to draw attention to the fact that Nigerian roadways frequently contain extensive cracks, potholes, and other pavement flaws. These have created such a huge problem and tragedy that Nigerians can rarely travel more than a kilometer without seeing significant potholes and fissures.

As a result, the frequency of traffic accidents and the growth of the nation's economy have reduced. Every single road constructed is frequently recognised to possess a predetermined design lifespan, although roads break down far earlier than the anticipated date; some fail during building, some fail after floods, and others last their whole life expectancy with proper maintenance (Emmanuel et al., 2021). The largest road system in West Africa is found in Nigeria. According to the Government Infrastructure Concession Regulatory Commission, Nigeria's road network contains over 195 000 km, of which roughly 60,000 km are paved. Most major road networks were constructed in the 80s and early 90s (Yakubu et al., 2023). Roads are declining due to inadequate maintenance and the use of subpar materials for repairs. Due to potholes and degraded surfaces, travelling is challenging and occasionally nearly impossible in many regions during the rainy season. Nigeria's most important highways run from South to North and were designed to bring farm produce from the hinterlands to the coast for export and to link the economies of Northern and Southern Nigeria. When the basic materials upon which structures or roads are built are not taken into account or deemed to be vital, one prepares to bear the consequences of the inevitable collapse of structures if the "conditions become right for the collapse" to take place. Given the importance of roads to the economy of any nation and the rapid rate at which Nigerian roads are deteriorating, it is important to take a cursory look at the causes of such failures and then proffer solutions to ameliorate such causes, thereby curtailing the huge budgetary expenses spent yearly on roads rebuilding and maintenance by government.

Highway Pavement

Highway pavement is an underlying structure made up of layers of manufactured materials overlaid atop the subgrade of natural soil, and its primary purpose is to distribute the vehicle weights being applied to the subgrade (Mathew, 2009). The pavement construction ought to further provide a surface with appropriate riding qualities, sufficient skid opposition, advantageous light-reflecting qualities, and low pollution levels. The final goal is to guarantee that the communicated axle load is substantially lowered to ensure it does not exceed the subgrade's bearing capability (Mathew, 2009).

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Classification of Highway Pavement

The pavement is classified into two categories: flexible pavement and rigid/stiff pavement. Flexible pavements, according to Mallick et al. (2008), Jamal (2017) and Rotimi (2022), are formed of bituminous or unattached materials, and their longitudinal dispersion of the load being placed deep enables the pressure from the vehicle load to be transmitted to the subgrade. Wheel loads are thus conveyed by the aggregate contacting other grains within the granular structure.

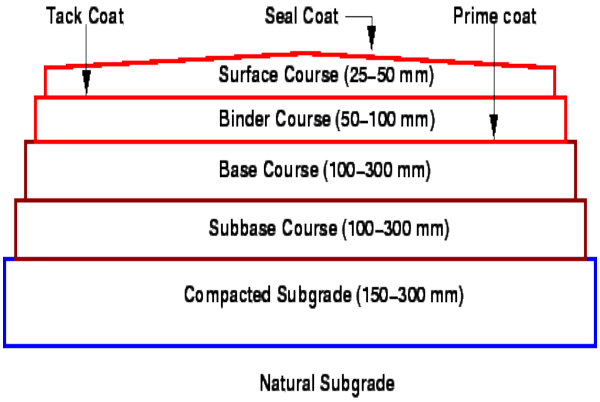

Figure 2.2: Cross section of flexible pavement.

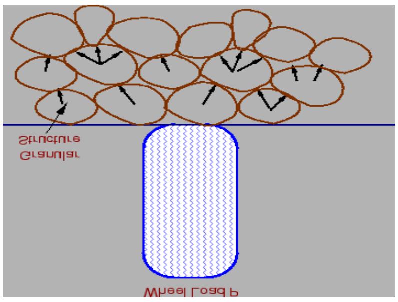

Figure 2.3: Load transfer in granular structure.

Source: (Suryakanta, 2015)

However, stiff highway pavements or pathways are typically made of Portland cement concrete, with or without a base between the subgrade and the concrete surface. Rigid pavement has roughly flexural strength that can maintain a beam-like action over slight variations in the underlying material. Meanwhile, the flexural strength of the pavement works as a rigid plate transferring the wheel stresses to the sub-grade soil (Suryakanta, 2015).

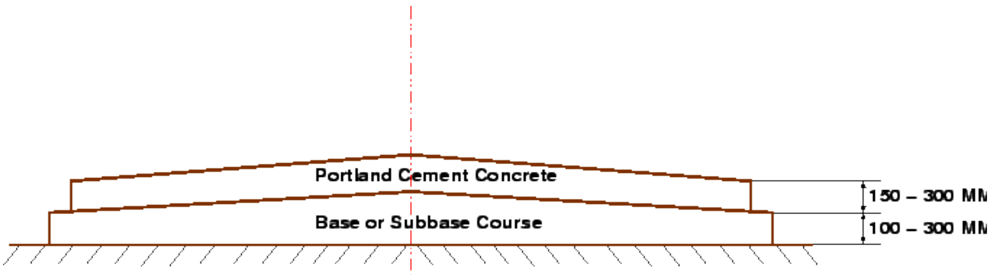

Figure 2.4: A Cross section of rigid pavement.

Source: (Suryakanta, 2015)

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The Nigerian Road

A road is a long piece of hard ground constructed between two locations to facilitate travel by vehicle, whether a rural or urban route (Collins, 2022). It is crucial in combating unemployment, improving economic aspects, and connecting underdeveloped and developed areas (Fred & Maxwell, 2022). In Nigeria, the unemployment rate increased to 33.3% in the fourth quarter of 2020, resulting in an 11.56 per cent decrease in the Gross Domestic Product (Fikayo, 2021). Investing in roads can create more jobs as individuals seek to establish businesses within the newly constructed or improved roads, leading to town development.

Highways are created to guarantee convenient mobility for vehicles and are needed to be adequately designed and developed. Maintenance is required to ensure the road's design lifespan, security, capacity, and reliability. The level at which roadways begin to fail in service is determined by the building supplies used, craftsmanship requirements, and design and direct supervision throughout construction. Table 2.1 shows that Nigeria has approximately 200,000 kilometres of highways separated into national, state, and local government roadways.

Table 2.1: Nigerian Road Ownership Based on Distance Travelled *(Afolayan & Abidoye, 2023)*

	NATIONAL (km)	STATE ROADS (km)	L.G. ROADWAYS (km)	TOTAL	PERCENTAGE
Main highways that are paved.	26,500	10,400		36,900	19%
Unpaved Main roads	5,600	20,100		25,700	13%
Urban roads			21,900	21,900	11%
Main rural roads			72,800	72,800	38%
Village access roads			35,900	35,900	19%
Total	32,100	30,500	130,600	193,200	100%
Percentage	17%	16%	67%	100%	

Causes of Road Failure

There are several types of highway failure, including potholes, cracking, ravelling, rutting, shove, depression, corrugation, water bleeding and so on. According to a study by Ubido et al. (2021), other variables that contribute to road failure include the soil's poor geotechnical properties, which include low bearing capability, a low optimum dry weight, a high limitation on liquids, a significant flexibility index, the optimal moisture level, California's loading ratio, and high compressible properties.

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Geotechnical Causes

Roads are constructed on geological materials, such as rocks or soils, which impact their transport performance. Pavement deterioration in Nigerian roads may be caused by residual soils with poor geotechnical qualities (Olofinyo et al., 2019). Nigeria's Federal government has established guidelines for the geotechnical characteristics of soils used in road construction, as seen in Table 1. However, Nigerian roads' widespread deterioration and failure can be linked to the usage of lateritic soils without sufficient understanding of their geotechnical constraints. Studies have shown that some lateritic soils may differ significantly from similar particle size distribution and plasticity characteristics, leading to infrastructure failures (Ademilua, 2018).

Table 2.2: General Specifications for Road and Bridges *(F.M.W. & H, 1997)*

Property	Subgrade	Subbase
% passing sieve, No 200 (75µm) (%)	≥ 35	≥ 35
Liquid Limit (%)	≤ 50	≤ 35
Plastic Index (%)	≤ 30	≤ 12
O.M.C (%)	-7	6-7
M.D.D. (Mg/m3)	≥ 1.8	≥ 1.6
CBR Soaked (%)	≥ 7	≥ 30
C.B.R. Unsoaked (%)	≥ 15	≥ 80

Poor Ground Condition and Use of Substandard Construction Materials

Poor grading of aggregates and low soil bearing strength contribute to low-quality materials, worsening pavement and cracking. Pavement performance depends on maintenance and the Nigerian Specifications for Roads and Bridges, which sets standards for the mineralogical and geotechnical qualities of soils prior to when they can be utilised for the construction of roads. Residual soils resemble the parent formation materials because they were created in-situ by the combination of chemical and mechanical deterioration of parent rocks. Some of the soils used to build roads in Nigeria have weak geotechnical characteristics, which causes pavement to deteriorate. The main clay mineral in Abakiliki shale, montmorillonite, is a problematic soil for making roads.

Poor Supervision and Craftsmanship

Without proper design (consultant) oversight, even the best pavement detailing is pointless because it could cause the road to fail. The use of quality tools and materials as well as proper execution of the road construction are ensured via inspection. Therefore, poor supervision has the unfortunate side effect of producing poor craftsmanship. Many Nigerian roads lack quality control, which involves laboratory and in-situ tests on the infill, subbase, and base materials, measurement of the thickness of pavement layers, and other procedures.

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The Absence of Regular and Periodic Maintenance

In Nigeria, upkeep is one of the major issues with highway growth. Rarely are the roads maintained, and when this is done, it is done carelessly. Since maintenance is primarily done during elections or presidential travels, road repair in Nigeria has become politicised. Delay in maintenance causes road faults to spread to areas surrounding the failing stretch. This is mostly a result of moisture seeping into the road's underlying layers from the failed part.

Poor Drainage System

When evaluating a road pavement's capacity to endure the effects of traffic and the environment, drainage is a crucial component. Road pavement with poor drainage has negative impacts and is more susceptible to failures. The lifespan of road pavements can be extended by using appropriate and well-maintained drainage systems. However, inadequate drainage systems lead to premature pavement failure, significantly shortening the useful life of the pavement. Nigerian roadways' inadequate and clogged drainage systems have caused the pavement to become waterlogged. The water that may have seeped into the lowermost parts cannot escape via the sides because of this. Potholes and cracks emerge from this.

Misuse and Overloading of Roadways

Another significant factor that can cause failure is improper road usage. Excessive vehicle weight, careless parking, and oil spills on asphaltic areas are a few instances of behaviours that put an undue strain on the road. Additionally, traffic loads on major and local roads have increased over time despite not being intended for it.

Alternatives to the Issue of Road Failure on Nigerian Highways

After determining the reasons for failures on the country's roadways, many authors (Afolayan & Abidoye, 2017) proposed various remedies to these issues, some of which will be described here.

a) Creation of Sufficient and Acceptable Designs: The design phase of any project ought to constantly be the first one. A good design produces a good road that works well, and vice versa. Starting with ideas, organising, and design, a road is built. Ndefo (2012) asserts that a functional road may not be attained without a proper design for it. Without having a well-executed design process, even with sufficient oversight and construction, a road project's finished output will not be useful.

b) Quality Assurance and Supervision: The effectiveness of road construction depends heavily on supervision. Without sufficient monitoring, a well-designed road does not guarantee that it will be built well. To make sure that road construction is done according to requirements, relevant laboratory testing and in-situ tests should also be performed. It is impossible to overemphasise the need of using good quality approved material throughout construction if one wants to ensure quality in road building and maintenance.

c) Road Congestion in Nigeria: The number of automobiles on the country's highways is undeniably high. As a result, the government should redirect traffic from roads to rail and waterways. This will lessen the current overloading that occurs on many Nigerian roadways.

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d) Regular Road Maintenance: The government organisations in charge of maintaining the roads must take the initiative. Roads will remain in good shape and be shielded from failure if maintenance is done on schedule.

e) Provision of Highway Infrastructure: Highway amenities must be provided in order for highways to work properly. This includes adequate parking areas, shoulders, sufficient drainage, and roadway signs and labels. Therefore, these facilities should be adequately provided for on Nigerian roadways.

f) Use of Qualified and Well-trained Personnel: The likelihood of failure on Nigerian roads will decrease if these tasks are designed, carried out, overseen, and maintained by competent and well-trained staff. Therefore, it is important for the government to make sure that competent and trained experts are involved in all phases of road building and maintenance. COREN, the Council for the Regulation of Engineering in Nigeria, is responsible for doing this.

g) Government Policies: All levels of government should approve and execute rules that will restrain the avarice of certain government employees and contractors and guarantee high-quality, professional road construction work. The sanctions should also be clearly stated.

Impact of Road Failure

As an anecdote, numerous parameters contribute to the deterioration of roads; some of these parameters include increased vehicle traffic, precipitation, and poor drainage. The following are some general negative effects of road failure:

I. Causes damage to cars.
II. A decrease in the road’s strength.
III. Total damage to the road.
IV. Inaccessible.
V. Loss of customers to businesses located in the area.

Impacts of Failure on Nigerian Roads

In Nigeria, poor road conditions are especially irritating to users and cause auto damage. Some of the repercussions have been reported, including an increase in accident rates, an increase in faulty automobiles, high vehicle maintenance expenses, and an increase in travel times because of traffic jams or poorly constructed sections of roads. Other consequences of road failure include the threat of crime at the failed portions of the road, the risk of floods and eroding processes, and the detrimental influence on economic growth (Afolayan & Abidoye, 2023).

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(a) (b) (c) (d)

Figure 2.1: *Showing the condition of Nigerian roads.*
Sources: (Sulaimon S., 2017), (Amaka 0., 2019)& (Olorundare E., 2020).

REVIEW OF SOME STUDIES

Numerous researches have been conducted to evaluate flexible pavement failure and identify the causes of pavement defects worldwide. Some studies have used geological factors, such as soil and subterranean geological structures, to determine the causes of highway pavement failure. These studies have shown that the load-bearing capacity of the subgrade structure is rarely met due to its heterogeneous nature, low swell or shrinkage properties, low permeability, and drainage characteristics.

Aigbedion (2007) analysed the Ekpoma major road's failure using Abem Wadi equipment and found that clay was used to construct most of the failed road, along with poor drainage systems, inhospitable environments, and poor-quality construction materials. These variables must be thoroughly examined and properly fixed to ensure an everlasting road.

Kishore and Ramu (2020) also studied Indian roads and identified various types of surface failure, such as cracks, rutting, potholes, bleeding, ravelling, and weathering. They found that shoulder settlement and incorrect drainage are likely the causes of each problem. Some suggestions for improving the situation include careful examination, effective drainage system design and maintenance, proper repair of minor damages, and reducing the thickness of overlaying materials.

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Aamni et al. (2020) studied defects in flexible pavement and identified various types of cracks and other road failures. They found that construction material, drainage system, soil or subgrade, positions, road geometric design, weather conditions throughout the year, and traffic volume are the main factors to consider when designing flexible pavement.

Neeraj and Murli (2019) identified the flexible pavement failure and presented corrective actions. The road under study is connected to many cities, factories, colleges, and residential areas, contributing to an increase in traffic volume every year. The research determined that inadequate supervision, poor drainage, poor construction materials, and poor maintenance practices were the primary causes of the deterioration and existence of cracks patterns along the road.

Mohd et al. (2019) performed and assessed the root causes of road failure and provided the best maintenance and treatment options. The findings indicated that surface deformation and crack disintegration are the main causes of road failure, heavy vehicular loads, poor pavement mix design, poor drainage, and inappropriate maintenance. They also suggested that repair work must be done at appropriate times to reduce maintenance costs.

The research paper by Ahmadu et al. (2019) suggests three steps to address early deterioration of newly constructed roads: route survey, data collection, and geometric design. The findings suggest that early deterioration can be stopped using appropriate design plans and laying out information during the geometric design stage. Construction should be done in accordance with design plans.

Irshad and Mohammad (2016) aimed to identify flexible pavement-related road failure, focusing on the main causes of pavement distress, such as rain, snow, and floods. The study used bituminous material content, rigidity, air void, softening point, structural strength, traffic volume analysis, traffic loading, penetration test, and C.B.R. by the Light Drop Weight Analyzer. The main causes of road collapse were determined to be potholes and cracks, and axle load data revealed a propensity to go beyond the highest permitted axle load bounds.

Sultan and Mohmd (2013) used a different method: questionnaires, literature reviews, consulting with and interviewing a group of around 15 managers and experts in the field. The study found that pavement failure was due to poor-quality materials, poor supervision, high traffic axle loads, low thickness of layers and width of the pavement, structural failure, lack of laboratory testing during construction, large traffic volume, inadequate compaction of layers, and poor drainage system.

Zumrawi (2016) used a different method, analysing the condition of the road system using field investigation and laboratory tests. The results revealed that road failures were in the form of severe potholes, cracks, and rutting, low-quality material used, high traffic volume, improper drainage systems, expansive subgrade soils, and climate change. The properties of the earth pavement material did not comply with standard specifications, and it was advised to use a variety of strategies to address the road failure system.

Osuolale et al. (2012) obtained samples from the road's failed and successful portions, and conducted laboratory tests to determine the subgrade materials' appropriateness. Hijab et al. (2012) used visual observation and laboratory tests to show that the road failed due to structural failure, poor materials used during construction, low C.B.R. value, and poor geotechnical

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features of the soil. They recommended soil improvement methods, such as soil stabilisation, good drainage system, proper pavement maintenance, guidelines, and policies, to address the road failure system.

Babadiya and Igwe (2021) conducted a unique study based on structural failure on the part of the road, analysing soil samples from the subbase layer at a depth between 400 mm and 500 mm and subgrade material samples collected between 600 mm and 800 mm deep. The study found that poor subbase and moisture in the pavement were the major factors linked to road defects.

Ahmed (2012) studied the impact of axle load on versatile pavement utilising BISAR software and material properties to calculate tensile and compressive exerts happening beneath the asphalt concrete layer as well as compressive strains occurring above the subgrade layer. According to the study, compressive and tensile stresses rose with increasing axle weight while falling with increasing asphalt layer modulus. Rutting and a build-up of wear were the primary causes of pavement failure.

Atul and Anjali (2021) used a different approach to evaluate bituminous pavement, identifying various failure types and their causes. The main goals were to prolong pavement life and prevent failure, addressing how different maintenance methods work to reduce the likelihood of distress. Small defects need to be fixed before performing any maintenance, and adequate design, regular inspection, and maintenance drainage must be essential for the convenience of road users.

Ankur and Shivam (2018) highlighted that pavement deterioration in various regions is a result of various factors, including varying climatic conditions, improper drainage systems, quality control, extreme stresses, and insufficient ability to identify defects before beginning maintenance work. Numerous types of defects have been discussed, including map cracking, corrugation, depression, rutting, longitudinal cracking, potholes, crocodile cracking, edge failure delamination, revelling, and bleeding. Factors influencing failures include weather conditions, traffic wear, organic growth, insufficient pavement thickness, and design failure.

Benjamin’s (2017) research conducted field and laboratory analysis, revealing that the causes of road failure due to cracks were insufficient support from the subgrade layer due to high strength of the base and subbase layers. The recommendation was to have the subgrade layer have high strength to sustain applied wheel load, improve pavement construction, uniformly distribute stabiliser, and properly mix pavement layers.

Bello et al. (2015) studied the index properties of portions of the road with and without failures, determining most types of road failure as cracks, potholes, and ravelling. The results showed that the bituminous road's failure was caused by an insufficient drainage system, poor road design, lack of good maintenance, and the use of low-quality materials. They provided solutions to address these factors for long-lasting, low-maintenance pavement.

Ahmad et al. (2016) analysed the causes of flexible pavement using data from Pakistan as a case study using GAMES (General Analysis of Multi-layered Elastic Systems) and the Relative Damage Factor (RDF). They found that axle load and tire inflation pressure are major factors in pavement failure, in addition to seasonal climate variations. They offered solutions to pavement failure by establishing and using an ongoing method of repetitive repair process,

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management strategy, good construction practice and control, and an active pavement management program.

Khan and Kalyani (2020) focused on the major problems of potholes, a prevalent deteriorating symptom of flexible pavement. Researchers have created various methods to fix these failures, including extreme heat and cold, which can cause damage. Riyaz et al. (2021) focused on flexible pavement failures and their repair, referring to numerous articles related to this topic.

Table 3.1: A Summary of the Findings

AUTHOR	PROBLEM	CAUSES	METHODS OF ANALYSIS	SOLUTIONS
Momoh et al. (2008)	1. Geological factors that influence highway failure in basement terrain	1. Low load-bearing capacity of the subgrade structure. 2. Low swell or shrinkage properties, low permeability and drainage characteristics.	1. Used Schlumberger Vertical Electrical Sounding & dipole-dipole electrical resistivity, 2. Magnetic and Very Low-Frequency Electromagnetic Methods.	
Aigbedion (2007)	1. Road failure on Ekpoma major road.	1. Drainage system, inhospitable environments. 2. Poor-quality construction materials.	1. Abem Wadi's equipment (conductivity meter) was utilised to conduct the investigation	1. A thorough examination of the causes. 2. The causes should be properly fixed.
Kishore & Ramu (2020)	1. Road failure.	1. Cracks, 2. Rutting, 3. Potholes, 4. Rutting 5. Shoving and bleeding, 6. Raveling and weathering. 7. Shoulder settlement 8. Inadequate drainage system		1. Examining the drainage system design. 2. Maintenance, proper repair of minor damages prior to further maintenance.

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				3. Reducing the thickness of overlaying materials
Aamni et al. (2020)	1. Defect in flexible pavement.	1. Consolidation of pavement layers. Shear failure crack. Longitudinal cracks. Alligator cracks		1. Construction material. 2. Drainage system 3. Soil or Subgrade. 4. Road geometric design. 5. Weather condition. 6. Traffic volume is the main aspect to be considered while designing flexible pavement.
Mohd et al. (2019)	1. Evaluation of flexible pavement condition.	1. Surface deformation. 2. Crack disintegration. 3. Heavy vehicular loads. 4. Poor pavement mix design. 5. Drainage. 6. Inappropriate maintenance	1. Visual evaluation. 2. Field evaluation.	1. Repair work must be carried out at appropriate times to reduce the cost of maintenance. 2. Ensuring the maintenance for cracks and defects are sealed to prevent moisture from entering.
Ahmadu et al. (2019)	1. Deterioration of newly constructed road		1. Route survey. 2. Data collection.	1. Construction should be done in accordance

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				with design plans.
Irshadn & Er. Mohmmad (2016)	1. Flexible pavement failure.	1. Potholes. 2. Cracks. 3. Exceeding the maximum permitted axle load limits.	1. Application of Structural Strength by Benkelman Beam Deflection Test. 2. Traffic volume analysis. 3. Traffic loading by axle load measurement. 4. Penetration test 5. Bitumen content. 6. Softening point and C.B.R. by the application of Light Drop Weight Tester.	
Osuolele et al. (2012)	1. Road failure.	1. some of the subbase material used had geotechnical properties below the specification	1. British standard compaction. 2. Grain size analysis. 3. Atterberg limit. 4. California Bearing test.	
Ahmed (2012)	1. Flexible pavement failure.	2. Tensile and compressive stresses increased as axle weight. 3. Increased while decreasing as asphalt layer modulus increased.	1. BISAR Software.	
Ahmad et al. (2016)	1. Causes of flexible pavement failure.	1. Load and tire inflation pressure. 2. Seasonal climate variations	1. Application of GAMES (General Analysis of Multi-layered Elastic Systems)	

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In many previous studies, flexible pavement failure was evaluated by the application of laboratory investigations such as grain size distribution, Atterberg limit, compaction, density test, natural moisture content, maximum dry density, optimum moisture content, cone penetration, dynamic test, abrasion test, and California bearing ratio. Some researchers used instruments such as Schlumberger Vertical Electrical Sounding (V.E.S.), dipole-dipole electrical resistivity, Very Low Frequency Electromagnetic (VLF-EM), conductivity meter, and by using Electrical Resistivity Imaging (E.R.I.). However, some studies conducted their research by carrying out traffic volume analysis, structural strength by Benkelman Beam Deflection test, and Light Drop Weight Tester while other research use software like BISAR software and GAMES (General Analysis of Multi-layered Elastic system).

CONCLUSION

The majority of Nigerian roads are ineffective because proper planning is not done prior to construction. Another key factor in failure is poor supervision, which can result from supervisors' compromises or from a lack of expertise. Government organisations' maintenance practices enable small road flaws to turn into significant failures. Our roads are now much more vulnerable to various types of exploitation and abuse by other road users as a result of the government's incapacity to enforce legislation against such behaviour.

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