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Survey and Evaluation of flexible Pavement Failures

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Abstract: ***This paper will visually inspect and evaluate the flexible pavement failures for maintenance planning. It is quite important to examine and identify the causes of the failed pavement to select a proper treatment option. Based on previous experiences, obtained through literature reviews, systematic guidelines for evaluation of damaged pavement are proposed to provide useful information for maintenance work. The study consisted of two tasks: the first covered the visual inspection of the existing pavement failures, whereas the second investigated the actual causes of these failures. As a case study, Obeid Khatim road in Khartoum was selected for investigation. An intensive field work was carried out on the existing pavement condition of this road. It was found that most of the damaged pavement sections suffered from severe cracking and rutting failures. These failures might have been caused by fatigue failure on pavement structure due to the movement of heavily loaded truck-trailers. The damage could also be attributed to poor drainage, inadequate design and improper pavement materials used.***

Keywords: failures, inspection, evaluation, maintenance**.**

1. Introduction

Pavement deterioration process starts directly after opening the road to traffic. This process starts very slowly so that it may not be noticeable, and over time it accelerates at faster rates. To ensure the risk of premature deterioration is minimized, it is necessary to use the best practice method in planning, design, construction and maintenance of the road. This can be achieved by examining pavements that have failed prematurely, with the focus being on determining the causes of failure so that it can be prevented in the future. The greater understanding of pavement failures that could be gained from detailed investigations could be valuable in reducing the costs associated with pavement failures in the future. In many cases the failure of pavement structure can be directly attributed to inadequate maintenance and ineffective evaluation programs. It is important to find out a method to minimize the maintenance cost under a limited budget, [1]. For that purpose it is quite important to consider a simplified method for inspection and evaluation of pavement failures.

In Sudan, the evaluation process of pavement failures is often done in a relatively informal manner. The main reason for this choice of action is that the cost associated with the evaluation is not justified by the importance of the road on which the failure is occurring, or the magnitude of the failure. There may also be a reluctance to spend money on a pavement failure evaluation, instead of using these funds directly for maintenance work. Because of these factors, there is a reliance on the past experience of the investigator in evaluating the failure, determining the testing required to be done, and making a final decision regarding the appropriate maintenance work. This means that the failure may be incorrectly diagnosed if the wrong testing is selected, or the investigator's experience is lacking.

The development of a systematic and simplified method for evaluation pavement failures will help to ensure that even if the evaluation is carried out by inexperienced staff, there is a reasonable chance of success in diagnosing the problem, and determining the best maintenance option.

2. Literature Review

Pavement failure is defined in terms of decreasing serviceability caused by the development of surface distresses such as cracks, potholes and ruts, [2]. They reported that before going into the maintenance strategies, highway engineers must look into the causes of failures of bituminous pavements. They found that failures of bituminous pavements are caused due to many reasons or combination of reasons. It has been seen that only three parameters i.e. unevenness index, pavement cracking and rutting are considered while other distresses have been omitted while going for maintenance operations.

According to Woods and Adcox [3], pavement failure may be considered as structural, functional, or materials failure, or a combination of these factors. Structural failure is the loss of load carrying capability, where the pavement is no longer able to absorb and transmit the wheel loading through the structure of the road without causing further deterioration. Functional failure is a broader term, which may indicate the loss of any function of the pavement such as skid resistance, structural capacity, and serviceability or passenger comfort. Materials failure occurs due to the disintegration or loss of material characteristics of any of the component materials.

Caltrans [4] categorized the main types of pavement failures as either deformation failures or surface texture failures. Deformation failures include corrugations, depressions, potholes, rutting and shoving. These failures may be due to either traffic (load associated) or environmental (non load associated) influences. It may also reflect serious underlying structural or material problems that may lead to cracking. Surface texture failures include bleeding, cracking, polishing, stripping and raveling. These failures indicate that while the road pavement may still be structurally sound, the surface no longer performs the function it is designed to do, which is normally to provide skid resistance, a smooth running surface and water tightness. Other miscellaneous types of pavement failures include edge defects, patching and roughness.

The Cracking consists of visible discontinuities in surface and can be an indication of the pavement's structural condition and serious, [5]. The main problem with cracks is that they allow moisture into pavement, giving accelerated deterioration of pavement. Cracks can occur in a wide variety of patterns (see Plate 1). They may result from a large number of causes, but generally are the result of either ageing and embrittlement of surfacing, environmental conditions, structural or fatigue failure of the pavement, or any other causes, [5]. The formation of cracks in the pavement surface causes numerous problems such as discomfort to the users, reduction of safety, etc. In addition to the above, intrusion of water causing reduction of the strength in lower layers as well as lowering of bearing capacity of subgrade soil by pumping of soil particles through the cracks is also a major problem associated with the pavements, [6]. This leads to the progressive degradation of the road pavement structure in the neighborhood of the cracks. The origin of cracks differs by their shapes, configuration, amplitude of loading, movement of traffic and rate of deformation.

Plate 1: Alligator cracking of high severity level

Rutting as described by Caltrans [4] is the permanent downward deformation of the surfacing within wheel paths. It may result from deformation of the surfacing, the pavement materials or the underlying subgrade, or a combination of these. It is important to determine which layer is rutting since this will influence the optimal maintenance strategy. The worse level of rutting is the higher variation in the transverse profile of road surface. Because of this, ruts interfere with surface run-off patterns and increase the risk of wetting in the upper pavement layers. Rutting can also initiate aquaplaning, and hence have adverse impact on safety, [4].

According to Ahmed [6], potholes are an indication of structural surface failure and they result from growth of a break in the surfacing, often as a result of severe alligator cracking as shown in Plate 2. Once water enters pavement layers, the base and/or subgrade become wet and unstable, and the resultant degradation leads to rapid growth of pothole area and depth. Sikdar et al [7] reported that if the potholes are numerous or frequent, it may indicate underlying problem such as inadequate pavement or aged surfacing requiring rehabilitation or replacement. Water entering pavement is often the cause, and could be caused by a cracked surface, high shoulders or pavement depressions ponding water on pavement, porous or open surface, or clogged side ditches.

Plate 2: Severe potholes on pavement surface, [6]

Kumar and Gupta [2] listed in Table 1 below the possible causes of different forms of pavement distresses.

Table 1: The most common pavement distresses and their possible causes, [2]

Distress	*Possible Causes*
Alligator cracking	Fatigue failure due to flexible/brittle base. Inadequate pavement thickness.
Block cracking	Reflection of joints cracking in underlying base.
Longitudinal cracking	Reflection cracking. Poor paving lane joint. Pavement widening. Cut/fill differential settlement. Fatigue failure of asphalt concrete.
Transverse cracking	Reflection of shrinkage cracking. Construction joints.
Rutting	Inadequate pavement thickness. Post construction compaction Instability of base surfacing.
Shoving	Poor bond between layers. Lack of edge containment. Inadequate pavement thickness.
Depression	Settlement of service trench or embankment. Isolated consolidation. Volume change of subgrade.
Corrugation	Instability of asphalt concrete or base course.
Edge drop	Inadequate pavement width. Erodible shoulder material (lack of plasticity).
Edge break	Inadequate pavement width. Inadequate edge support. Traffic travelling on shoulder edge drop. Weak seal coat/loss of adhesion.

Some major roads in Khartoum such as Alazhari and Alarda roads suffered from severe distresses of potholes, rutting, and heavy depressions, [8]. He found the causes of these failures may be due to improper design, excessive loads and poor drainage, leading to poor subgrade conditions. These reasons were supported by the experimental investigation performed by University of Khartoum's Consultancy Corporation. Omer et al [9] studied the pavement failures in the ring road in

Khartoum. They observed from the site visit to the road severe trenched on the west lane that might have been caused by the movements of heavily loaded truck-trailers, tippers, as well as loaded fuel tankers. The damage could also be attributed to insufficient implementation process, inadequate design or improper pavement materials used.

In many pavement failures, excess moisture is the main cause of failure or a contributing cause. Queensland Transport [10] reported the effect of moisture content changes on the strength and stiffness of pavement materials. They found that excess moisture reduces the strength and stiffness of pavement materials, being worse for the subgrade material, than for the subbase or base. Excess moisture and particularly high degrees of saturation result in significant pore pressures within the material. Depending on the degree of saturation, failure may occur as any of rapid shear or bearing failure, premature rutting, lifting of wearing course due to positive pore pressures, or embedment of cover aggregate due to weak base, [10].

It can be seen that for nearly all types of pavement failure, moisture is often the primary or a contributing cause of failure. As clearly seen in Plate 3, moisture entry through the surface may be caused by inadequate pavement surface drainage during construction, exposure of surface to rain during construction, or porous or open graded asphalt, [11]. He found moisture entry from the side may be caused by pondage in pits or poorly constructed surface drainage, and lateral movement of water into pavement. Other factors affecting the moisture in a pavement include the general drainage condition, such as the effectiveness of drainage structures, shoulder cross-fall and condition, longitudinal grade, and whether the pavement is constructed on cut or fill.

Plate 3: Ponding water on potholes

Mubarak [12] investigated recently buildings and streets in old Omdurman City were noted to deteriorate. These deteriorations were attributed to the presence of penetrated water at foundation level, accumulated on impermeable strata of mudstone at shallow depths. She also noted this type of failure in the main road of Alazhari.

3. Pavement Evaluation Guidelines

The objective of this study is to establish guidelines describing systematic method for inspection and evaluation of pavement failures and to find out the possible causes of these failures. The proposed method has some basic steps as follows:

i. Inspection and Evaluation plan
ii. Documents and literature review
iii. Pavement condition survey
iv. Experimental work
v. Determine probable cause(s) of failure
vi. Select the best maintenance option
vii. Report on outcomes

3.1 Inspection and evaluation plan

Planning is important to ensure that inspection and evaluation of pavement failures were carried out their intended tasks within a reasonable time frame and at the lowest cost.
When planning the evaluation proram, a general review of the problem should first be conducted, along with the possible scope of inspection and maintenance work that may need to be carried out. This plan should be drafted, addressing goals, budgeting constraints, operations planning and the investigative synthesis. The technical team should be decided upon.

3.2 Documents and literature review

Reviewing documents and literature may involve the inspection of plans, pavement history, drainage design, pavement materials information and specifications, previous materials tests results, construction and previous maintenance records, testing methods and frequencies, and other relevant information such as traffic volumes and composition, soil or geological records, and temperature, weather or rainfall data. These collected data are very important for both the field survey task and the evaluation of pavement failures.

3.3 Pavement condition survey

The pavement condition survey may include visual examination of pavement failures, the effectiveness of drainage structures and other details such as topography and alignment should be recorded, and the soil and geology of the surrounding areas may also be of importance in determining the causes of the pavement failure. An effective visual survey of pavement failures is essential, to ensure that the cause of the failure can be diagnosed efficiently and it is a guide to what testing should be carried out and where. In addition, it will provide valuable site information that may have an influence on the best maintenance operation. Distress surveying should be carried out on failed pavement sections to find out the amount, type, and condition or severity level of distress, as well as the condition or effectiveness of any previously applied distress treatments.

3.4 Experimental work

The experimental work includes filed and laboratory testing. Field testing program can assess the strength of the pavement materials. The conventional field tests may be carried out include Benkelman Beams, Dynamic Cone Penetration (DCP) test, roughness and surface evenness measurement, skid resistance testing. Coring on pavement structure may be used to provide material samples for laboratory testing, and also allows visual examination of pavement layers.

Laboratory testing should be conducted on representative samples taken from pavement layers to determine physical characteristics of the materials. The tests on soils and aggregates may aim to measure the index properties by particle size and shape, the plasticity and specific gravity and to assess the strength by the compaction and California Bearing Ratio (CBR) tests. Geotechnical tests may include measurement of the shear strength, consolidation and determine the water table level during site investigation. Asphalt tests may be used to measure the consistency by penetration, viscosity and ductility. Marshall Tests for stability and flow measurements of asphalt concrete sample and extraction test is also necessary to perform.

3.5 Determine probable cause(s) of failure

It is quite important to find out the probable cause(s) of the pavement failure being investigated. The probable causes are normally stated, and there are often multiple factors that contributed to the failure. The first stage in determining the failure cause(s) is the investigative synthesis, where all the information gathered is listed. From this listed information, it is then necessary to determine which information supports or refutes each of the possible failure hypotheses. This may be initially done by considering general failure causes, such as those related to construction, materials, design, or the environment. It is more required that specific cause(s) of the failure be considered. This is achieved by going through possible failure cause(s) for the failure type. Once this has been done, it is necessary to determine the probable cause(s) of the failure.

3.6 Selection of the best maintenance option

To select the best maintenance option, it is necessary to list a variety of alternatives that may be feasible, from an initial examination of the conditions. These possible alternatives can then be subjected to much more detailed examination of economic, design and construction factors.

Other factors to consider include whether the treatment is accepted local practice, and whether a long lasting or simply an economical short-term treatment is required. Once these questions are answered, a list of possible maintenance options could be selected for further study by finding those treatments that satisfy the above criteria. Treatments may include surface treatments, overlays, in-situ stabilization, or any other maintenance treatments.

3.7 Report on outcomes

A report on the outcomes of the pavement evaluation should be produced, as this enables others to learn from the failures, and should help reduce the chances of similar failures in the future. Information that should be included a general description of the project and its location, failures details, a description of any testing carried out, the probable cause(s) of failures expected, how it could be prevented in the future, and possible maintenance options.

4. Case Study

The study was concentrated on Obeid Khatim road in Khartoum; the capital of Sudan. This road is one of the longest and important major collector roads in Khartoum. The road is connecting the most commercial and crowded areas in Khartoum. It is a dual carriageway of six lanes that divided by a median of 1.2m to 2m width. The road length and width are 8.6 km and 21m respectively. A service road of single lane, 5m width and 2km length is located on the west side of the road.

Obeid Khatim road was maintained several times during the last 15 years and still suffered from severe distresses. The last rehabilitation of this road was carried out in 2002 by widening and strengthening the pavement. The road much severs from serious problems that may decrease its efficiency and safety. These problems include traffic jam, inadequate drainage system and damaged pavement surface. The north part of the road suffers from a series of distresses and the pavement surface is not comfortable for riding. The distresses and defects on pavement may be due to deficiency in design and construction. The failures occurring were beginning to reach unacceptable levels, since the failed pavement surface prevented water from flowing off the pavement during rainfall, leading to further deterioration.

4.1 Field Survey of Distresses

A Comprehensive visual survey of distresses on pavement surface was conducted. The road was divided into three sections; A, B& C as shown below in Figure 1.

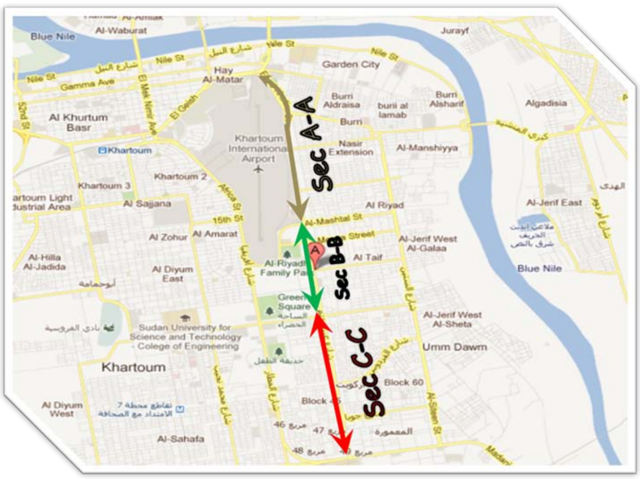

Figure 1: The three sections of Obeid Khatim road

The field survey was carried out visually in two stages: by driving a car, and by walking along the road. In the first stage, while the survey team was driving a car along the road at slow speed, observed the affected pavement sections, and carried out ride quality assessment of the pavement surface. This stage of survey is a kind of reconnaissance of the study area. The second stage of survey was carried out by walking through the study surface area closely observed, identified, and record the defects on failed pavement sections.

The data collected from the field survey of the existing pavement surface failures were analyzed. The most common failures recorded include cracking, rutting, patching, potholes, depressions, raveling, swelling and corrugation. The measured distresses with different level of severity are given in Table 2.

Table 2: Severity levels of the measured distresses

Distress	*Section A*	*Section B*	*Section C*
Rutting	Heavy	Moderate	Light
Depression	High	High	Moderate
Potholes	Low	Moderate	Low
Cracking	High	Moderate	Moderate
Raveling	High	High	High
Polishing	High	Moderate	Low
Patching	Moderate	High	Low

The quantity and the area covered by each distress were determined. When comparing this area to the total damaged area of pavement sections, the distress percent can be calculated. The plot of Figure 2 shows the percentage of the measured distresses on failed pavement.

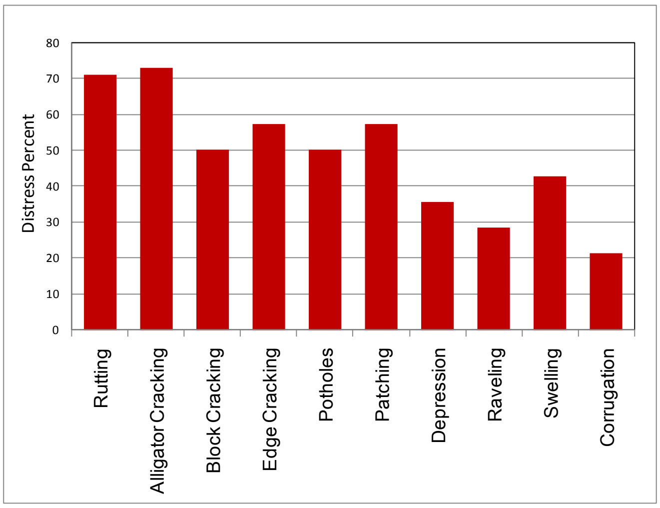

Figure 2: Distresses percentage in Obeid Khatim road

The defects inspected in the damaged pavement sections of the investigated road can be classified, based on the percentage of the distresses in the damaged pavement into three main groups as given below in Table 3.

Table 3: Classifications of distresses on basis of covered area percentage

Distress	*Group (1) More than 70%*	*Group (2) 50% to 70%*	*Group (3) Less than 50%*
Patching		X	
Alligator cracking	X		
Block cracking		X	
Edge Cracking		X	
Potholes		X	
Depression			X
Rutting	X		
Raveling			X
Swelling			X
Corrugation			X

From Table 3 and Figures 2, the following observations are drawn:

The first group of distresses which covered most of the road sections inspected, more than 70% of the failed sections includes alligator cracks and rutting. Cracks have different sizes from small hire line cracks to major cracks of 25mm or more. The rutting defect of medium to high severity level covered large areas of the damaged pavement sections. The investigation of these failures, to find out the probable causes of cracking and rutting failures indicated that the roads suffer a lot from fatigue failure in the pavement structure due to excessive traffic loading of heavy trucks and trailers and insufficient pavement thickness.

The medium effect group of distresses, which affect 50% to 70% of the failed pavement sections are cracking in the forms of block and edge cracking, potholes and patching failures. The probable causes of these failures may be improper construction or previous maintenance and poor drainage. The low effect group (less than 50%), depression, raveling, swelling and corrugation are caused due to infiltration of runoff water, weak pavement materials and in combination with traffic loading, lack of stability or asphalt concrete mix.

4.2 Experimental Work

The experimental work program consists of two tasks; field work and laboratory testing. Three trail pitholes of two meter depth were excavated in the road, a pithole in each section. Disturbed soil samples were collected from 1 to 2m depth to represent the subgrade soil. The tests performed include sieve analysis, Atterberg limits, compaction and California Bearing Ratio (CBR) tests. The tests results are given in Table 4.

Table 4: Summary of tests results

Test	*Section A*	*Section B*	*Section C*
Liquid limit (%)	26	33	50
Plasticity limit (%)	15	18	27
Plasticity index (%)	11	15	23
Max. dry density (gm/cm^3)	1.66	1.60	1.48
Optimum moisture content (%)	13.5	15	18.5
Soaked CBR (%)	22	4.0	1.2

From Table 4 it is cleared that the subgrade soils in sections C and B compared to A have high values of liquid limit and plasticity index and low CBR values. These soils of sections B and C can be classified as expansive clay. While the subgrade soil in section A has low liquid limit and plasticity index and relatively high CBR and classified as non-expansive soil. Thus the subgrade soils in sections B and C is considered as weak subgrade.

The Dynamic Cone Penetration (DCP) tests were carried out on the pavement structure at three locations. The penetration depth measured up to 75 cm below the base course level. The data from DCP tests were proceeded to determine the penetration resistance (mm/blow), which is simply the distance that the cone penetrates with each drop of the hammer. The field CBR value was determined using Transportation Research Laboratory (TRL) correlation as follows:

$$\text{Log (CBR)} = 2.48 - 1.057\ \text{Log (DCP)} \quad (1)$$

Table 5: Summary of DCP tests results

Location	*Layer Thickness, mm*	*DCP mm/blow*	*CBR %*
Section A	145	4.5	62
	200	6.4	32
	400	17.4	15
Section B	140	4.1	68
	205	7.2	37
	300	15.2	17
Section C	160	3.9	72
	220	6.6	41
	420	12.6	21

The DCP test is used to evaluate the strength of granular pavement materials; base and subbase. The results of DCP tests are given in Table 5. For the road, the average CBR values of the base, subbase and embankment materials are 67%, 37% and 18% respectively. The results illustrated that the base materials is not comply with the specifications (i.e. CBR $\geq$ 80%). While the subbase and embankment materials comply with the specifications.

5. Conclusion

This study has been undertaken to investigate the pavement failures and propose a method for inspection and evaluation of failed pavement. The results and the conclusions drawn as follows:

- The method developed in this research has been based on previous experiences. The focus is on establishing a systematic, and yet simple and easy to understand guidelines that is flexible enough for use in a variety of situations.
- The pavement failure investigation method developed in this research can serve as a useful guide for the inspection and evaluation of pavement failures. The method, combined with the experience of the highway engineer and adequate materials investigation, will help to ensure that the cause of a pavement failure can be reliably determined.
- The method developed for inspection and evaluation was trialed in pavement failures of Obeid Khatim road, to evaluate the effectiveness of the method for real use. It was found that the method was good as a general guide, particularly for junior highway engineers. However, the experience of the engineer is also an important factor in correctly diagnosing the pavement failures cause and determining the best maintenance option.

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