RESEARCH ARTICLE

International Journal of Multidisciplinary and Scientific Emerging Research

Available at http://www.ijmser.com/ (ISSN 2349 – 6037)

The Impacts of Poor Drainage on Road Performance in Khartoum

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Accepted 17 September 2014, Available online 01 October 2014, **Vol.3, No.1 (October 2014)**

Abstract

This paper aims to study the various impacts of inadequate drainage on road pavement condition. Poor drainage causes early pavement distresses lead to driving problems and structural failures of road. To prevent or minimize premature pavement failures and to enhance the road performance, it is imperative to provide adequate drainage. As case study, two major roads in Khartoum state were selected for field survey of the existing condition of the provided drainage system and its subsequent impacts on pavement performance. As a result of this investigation, it was found that most roads in Khartoum state suffered from poor drainage which causes severe distresses and damages of pavement. Based on the previous experiences of design and construction of proper drainage, design guidelines are suggested to assist the highway engineers in designing proper drainage and will be helpful in increasing the service life of pavement. General conclusions are drawn with regard to design pavement integrated with efficient drainage.

Keywords: *Impacts; road performance; poor drainage; premature failures; design guidelines.*

1. INTRODUCTION

Water is the main contributor to the failure and damage of roads. Water can be in the form of ground water, surface water (streams and rivers) or rain, as runoff from the surrounding areas. In addition, water may flow laterally from the pavement edges or it may seep upward from a high ground water table. The water flow can damage the road in several ways. Rokade et al [1] reported that water-related damage to pavement can cause one or more of the following forms of deteriorations: a) reduction of base, subbase and sub grade strength, b) differential swelling in expansive sub-grade soils, c) stripping of asphalt in flexible pavements, d) frost heave and reduction of strength during frost melt, and e) movement of fine particles into base or subbase materials resulting in a reduction of the hydraulic conductivity considerably. The damage to the road can be reduced if the flow of water is controlled. Minor damages can easily be repaired as part of the regular maintenance provided to the road and its structures. If the flow of water is not properly managed, the deterioration of the road will be more serious and occur more rapidly. This will lead to higher maintenance demands and in the worst cases result in serious damage which may obstruct the traffic flow.

Recently Khartoum is facing extensive water logging during the rainy season (July to September) as result of a serious problem of poor drainage. Inadequate drainage problems become one of the most common sources of compliant from the residents in Khartoum and this problem becoming worse in this year. Poor existing drains and their improper operation and management mainly cause severe flooding which creates damages and problems to the road pavement and road users. As shown in Plate 1 a flooded road obstructed traffic flow.

Plate1. Flooded road obstructed traffic flow.

In addition, deceases are spread and give problems to the population such as malaria and diarrhea. This critical situation was severely aggravated because the natural drainage system, which conveys storm runoff from the areas to the river were not fully operated and the existing drains blocked with huge amount of garbage, solid waste, silt sand accumulation and vegetation.

2. LITERATURE REVIEW

A drainage system includes the pavement and the water handling system. They must be properly designed, built, and maintained. The water handling system includes: road surface, shoulders, drains and culverts; curb, gutter and storm sewer. When a road fails, whether it's concrete, asphalt or gravel, inadequate drainage often is a major factor. Poor design can direct water back onto the road or keep it from draining away. Too much water remaining on the surface combine with traffic action to cause potholes, cracks and pavement failure.

Many researches clearly demonstrating that poor drainage can adversely affect pavement performance. Rokade et al [1] reported that inadequate drainage leads to major cause of pavement distresses due to large amount of costly repairs before reaching their design life. He found that pavement service life can be increased by 50% if water can be drained without delay. Similarly, pavement systems incorporating good drainage can be expected to have a design life of two to three times that of undrained pavement sections. Cedergreenet al [2] evaluated early field tests that included both drained and undrained pavement sections. Based on these field data, he estimated that a flooded undrained pavement experiences 10 to 70,000 times the damage from a load event compared to a drained pavement. As a conservative single value, he suggested that an undrained pavement experiences 15 times the damage compared to a well-drained pavement.
To achieve proper drainage, drains (or ditches) a long side of road are essential to collect water from road surface and surrounding areas and lead it to an exit point where it can be safely discharged. Forsyth et al. [3] presented a number of case studies related to pavement drainage. They report that the use of edge drains usually improve the durability of pavements. Forsyth et al. concluded that the percentage of cracked slabs in the undrained sections exceeds that in the drained sections by a ratio of 2.4 to 1. The use of edge drains was also examined by NCHRP [4] for conventional asphalt pavements with unbound dense-graded aggregate bases, the addition of edgedrains appeared to reduce fatigue cracking, but not rutting. The use of asphalt-treated permeable base sections with edgedrains produced significantly less rutting than did unbound dense-graded aggregate base sections. However, the fatigue cracking performance for both types of base sections with edgedrains was comparable.

The Subsurface drainage is a key element in design of pavement. The NCHRP [4] performed an extensive study of many subsurface drainage systems, NCHRP Project 1-34, Performance of Pavement Subsurface Pavement Drainage, summarized findings on the effectiveness of subsurface drainage on flexible pavements. They found that structural capacity and drain ability were key factors in the performance of flexible pavements. If either factor was poor, there was an increased incidence of rutting and fatigue cracking. It was noted that these factors should be carefully considered during the design phase of flexible pavements. NCHRP [4] stated that another key factor in the performance of subsurface drainage was whether edge drain outlet pipes were clogged. Clogged outlet pipes were found to have a detrimental effect on the performance of flexible pavements. Clogged outlets led to increase fatigue cracking and rutting and could lead to stripping. In addition, permeable base sections were found to have better fatigue performance than all other types of evaluated pavement sections. However, there was not a significant difference in the rutting performance of permeable base sections and other sections. Markow [5] developed a predictive model of pavement performance that includes the effect of moisture on pavement materials properties and the quality of the subsurface drainage. In this model, the duration of pavement wetness is first estimated taking climatic conditions as well as drainage into account. Then, assuming the pavement system has a 50% reduction in strength when wet.

3. DESIGN GUIDELINES

Drainage is the most important aspect of road design. Proper design of drainage is necessary for satisfactory and prolonged performance of pavement. In designing drainage, the primary objective is to properly accommodate water flow along and across road.

3.1 Surface Drainage

The surface drainage elements include road surface, side drains, and culverts; and the curbs, gutters and storm sewer systems. These elements work together as a system to prevent water from penetrating the pavement, remove it from the travel lanes to the side drains or gutter, and carry it away from the road.

1. Road Surface

The road surface geometric features, carriageway cross-section slope and longitudinal gradient and shoulders which enable the water to flow off the road surface to side drains that collect and lead water away from the road.

Cross-section Slope

Drainage of the road pavement is provided by shaping the road carriageway with a camber or cross slope. The camber is the slope from either side of the center line towards the road shoulders. For roads with asphalt surface, the camber is normally 2 to 3%, because water will easily flow off a hard, waterproof surface. On earth and gravel roads, the camber needs to be steeper because the water will flow more slowly and the surface is often uneven. Gravel and earth surfaces also absorb some of the surface water unless it is quickly drained away from the road. Thus, it is recommended that the camber is 5 to 7%. On sharp curves, the camber is often substituted with a super elevation which leads the water to the inside of the curve. The super elevation is installed with gradual change of the road cross-section from a camber shape to a road surface shaped with a cross slope. At the same time the super elevation provides a certain resistance to a vehicle from skidding off the road due to the centrifugal force.

Longitudinal Gradient

Providing the vertical alignment of the road with a gentle longitudinal gradient improves the road surface drainage. This slope facilitates the discharge of water from sections of the road surface with limited cross-slope. Steep road slope causes surface water to move rapidly and makes surface drainage difficult to control. This problem starts when the longitudinal gradient exceeds 8%. Due to the steep grade, it becomes more difficult to evacuate water from the carriageway. This will result in accelerated wear of the road surface. If the steep slopes cannot be avoided by realigning the road, an alternative is to provide an erosion resistant surface to this section, such as stone pavement, asphalt or concrete. Equally, the side drains need to be protected in a similar way.

Shoulders

Shoulders directing water flow to the side drains or ditches. They should slope more than the carriageway to keep water moving to the side drains. If shoulders slope less, water will build up during heavy rain at the join between shoulder and carriageway, flooding traffic lanes. For asphalt roads, the shoulders slope is normally 3 to 5% while for gravel and earth surfaces is 8 to 10%.

When the surface runoff water penetrates shoulders a filter column just below the shoulders can be constructed by making a shallow excavation, then filling it with crushed rock, gravel or sand. At the trench bottom perforated pipes are placed to drain the filtered water into ditches or streams.

2. Side Drains

The function of the drains (or ditches) a long side of road is to collect water from the road surface and the surrounding areas and lead it to an exit point where it can be safely discharged. The side drains need to have sufficient capacity to collect all rainwater from the road surface and dispose it quickly and in a controlled manner to minimize damage.

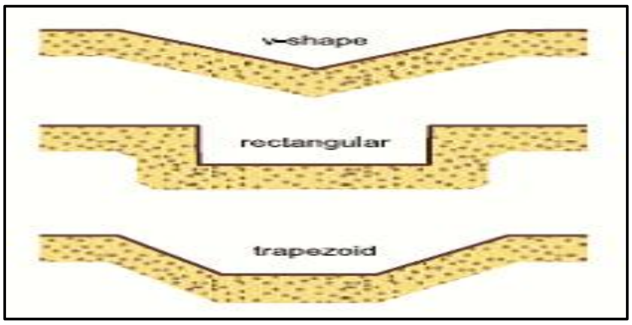

Figure 1. The common shapes of side drains.

Sides drains can be constructed in three common forms: V-shaped, rectangular or as a trapezoid (Figure 1). The V-shape is the standard shape for ditches constructed by a motor grader. However, it carries a lower capacity than other cross-section shapes. The rectangular shape requires less space but needs to be lined with rock or concrete to maintain its shape. This shape is often used in urban areas where there is limited space for the drainage. The trapezoid shaped side drain carries a high flow capacity and by carefully selecting the right gradients for its side slopes, will resist erosion. In urban areas especially commercial and residential areas the drains should be covered with concrete slab or small block for easy inspection and cleaning. The exact dimensions of the side drains are dependent on the expected amount of rainwater and the distance to the next exit point where the water can be diverted away from the road. The rational method and the manning formula can be used in calculations. In flat or slightly undulating terrain, a longitudinal slope to be used between 2% and 5% in the drains. With gradients less than 2%, silting occurs easily while with gradients steeper than 5% the ditches will easily erode. Use rubble, riprap, or fabric to slow water flow on steep slopes, or pave them to prevent serious erosion. Installing a short section of storm sewer may also be considered.

3. Culverts

Culverts are the most common cross drainage structures used on roads. They are built using a variety of materials, in different shapes and sizes, depending on the preferred design and construction practices. Culverts are required in order to (i) allow natural streams to cross the road, and (ii) discharge surface water from drains and the areas adjacent to the road. Culverts form an essential part of the drainage system on most roads.

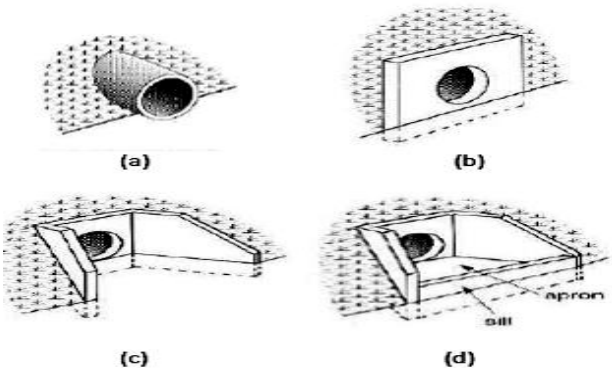

Figure 2. Types of culvert outlets (a) Projecting outlet (b) End-wall structure, (c) End-wall and wing-wall (d) End-wall and wing-wall(with apron and sill).

Culverts are constructed using different materials. The most common practice of culverts is based on the use of pre-cast concrete pipes, in-situ concrete boxes and corrugated steel pipes culverts. The box culvert is generally built with 1 to 3 cells of width 1m to 3m and the pipe culvert is built with 1 to 3 rows of pipes with diameters commonly ranging from 0.6m to 1m. Wing walls and aprons of concrete or stone pitching are used to protect the culverts from water flow erosion and scouring at upstream side (Figure 2). Culverts should slope enough so water will flow. A minimum drop of 15 cm across the road is desirable. This will keep sediment from accumulating in the culvert but will not cause extensive erosion at the discharge end.

4. Curb, Gutter and Storm Sewer Systems

Curb and gutter are preferable in areas with limited right-of-way or where open drains are unacceptable. Short sections of curb and gutter may be used at spot locations without requiring storm sewer. Storm sewer systems collect water from the street and adjoining property and deliver it to open surface waterways (i.e. streams, rivers, lakes). Short sections of storm sewer may be useful in areas with steep slopes where runoff is eroding open drains, causing a problem. Storm sewer is also helpful at intersections and other locations. It is important to maintain curb, gutter, inlets, and storm sewer systems. They should be inspected every year.

3.2 Subsurface Drainage

This type of drainage is quite important factor in pavement design. The basic design strategies promoted are to prevent water from entering in pavement andto remove quickly any water that infiltrates. The changes in moisture content of subgrade soil are caused by fluctuations in ground water table, percolation of rain water and movement of capillary water. In subsurface drainage it is required to keep the variation of moisture in subgrade soil to minimum. To achieve this, a subsurface system was proposed by Zumrawi [6] as given in Figure 3.This system forms of a filter layer of porous materials, well-graded gravel or crushed stones (chipping) of minimum thickness 20cm is to be placed directly below the buffer course. This layer is provided with proper slopes in both longitudinal and transverse directions. It is mainly designed to intercept capillary water and consequently reduces wetting effects of the subbase. A perforated pipe of 15cm diameter is to be placed in the far end of the drainage layer below the filter columns of porous materials, 20cm minimum width is to be located over the pipes to the level of the base.

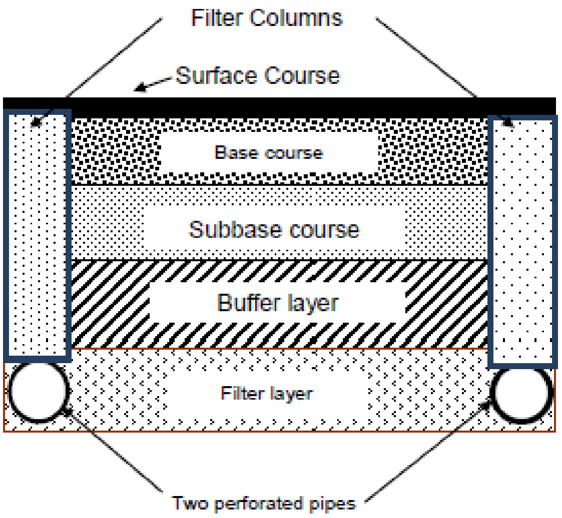

Figure 3. Schematic sketch of recommended subsurface drainage system (after Zumrawi [6]).

4. CASE STUDY

The primary objective of this paper is to investigate the impacts of inadequate drainage on road pavement condition. To achieve this objective a field survey program was conducted on two major roads in Khartoum state, ObaidKhatem road in Khartoum and Alarda road in Omdurman. The field survey was carried out by visual inspection to evaluate the existing conditions of the drainage system and investigate its effects on road performance. Photographs were taken directly from the road sites during the field survey to illustrate the existing condition and related obstacles in the drainage and the pavement.

4.1 ObaidKhatem Road

This is a major collector road in Khartoum running through the most crowded areas in eastern Khartoum. The road 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. Rehabilitation and maintenance of this road by widening and strengthening the pavement was carried out in 2002. A large portion of the road is constructed on expansive clay of high swelling potential and low strength. The road was maintained several times during the last 10 years and still suffered from severe distresses.

Plate 2. The side drain and the culverts were blocked with silt and sand accumulation, debris and vegetation.

Study. It was observed that the eastern carriageway of the road is connected with aside drain located far from the edge of the road at a distance about 5m to 8m. In general, most of the drain is open earth drain with small cross section of about 1m width and not more than 1m depth. The condition of the drain and its structures is very poor and getting deteriorated by the passage of time. The drain suffered from low capacity, natural siltation, absence of inlets, indefinite drainage outlets, lack of proper maintenance and over and above disposal of solid waste into the drain and the crossing culverts. The drain blocked with silt and sand accumulation, debris and vegetation as shown in Plate 2.It is clear that the drain and culverts being converted to dumpy place and subsequently obstructed the water flow.

This bad condition of the side drain and its structures remains the same throughout the year causing the runoff water to flow on the surface of the road and unable to run off through the path far from the failed drain. The resultant effect of this critical situation causes serious distresses and damages on pavement. The road edges suffered from detachment of asphalt layer due to continuous contact of water leading to stripping of asphalt from aggregates resulting in severe pavement distresses of cracking, potholes and failure of edges as shown in Plate 3.

Plate 3. Severe pavement distresses of cracking, potholes and failure of edges.

4.2 Alaarda Road

Alarda road is one of the most important road in Omdurman that connects western with central part of the town. The road of 2.75km length consists of dual carriageways and six lanes divided equally by a central island, 1.2m to 2m width. Unfortunately, the middle part of the road, about 900m length passes through the most expansive soil areas. The free swell of this soil is more than 50% which indicates that the soil is highly expansive. For this reason the study was concentrated on this critical part of the road.

This road is selected as a case study due to the serious problems and failures caused by the sub grade of expansive soil and the accumulation of subsurface water in the pavement structure. The road suffered from severe distresses of potholes, cracking, rutting and heavy depressions. Rehabilitation of the road was carried out in 2008 by the consultant, Dar consult. The expansive soil was removed to 1.5m depth and replaced with embankment layer of granular materials, 50 cm thick. On top of it a layer of boulders, 40 cm thick was placed with a thin filter layer, 10 cm thick of crushed stone (chipping). Vertical moisture barriers (Fonda line Sheets) used to prevent water movement from the road sides and the central island to the depth 2.0 to 2.5m. A covered side drain was constructed on the north side of the road.

During excavation work, it was observed that the subgrade soil was fully saturated with subsurface water encountered at 2m depth. As seen in Plate 4. accumulation of sewage water disposed from neighbor houses into the subsoil.

Plate 4. Accumulation of subsurface water on the sub grade of expansive soil.

In the field survey, it was observed that the side drain was full with dirty water and refuse dumps. The inlets on the curb was blocked with soil accumulation as shown in Plate 5.

Plate 5. The side drain full with dirty water and refuse dumps.

Failures and severe distresses were observed on the road surface. It was found that the surface runoff water penetrated through the cracks and potholes cause a progressive inward penetration of the zone of soil movement leading to soil expansion and ultimately failure of the pavement. Therefore, the major cause of pavement deterioration is inadequate drainage. Significant cracking, potholes, heavy depression and edge failure as shown in Plate 6 and 7.

Plate 6. Severe failures of road edges due to water ponding on surface.

Plate 7.Sever failure of edgesand potholes.

5. DISCUSSION

In the two cases studied above, the factors which contribute to poor drainage and road pavement conditions in Khartoum state are;

Poor design and construction

In general, most of the side drains provided to roads in Khartoum state are earth drains or ditches. Some drains built from bricks, stones or concrete materials are open drains without covers. Others built drains are covered with concrete slab or blocks. Failures of built drains like collapse of bed, side walls and/or covers caused by improper design and construction, settlement orheave may lead to the development of cracks and subsequent failure. Most of the drains channelsin Khartoum state are designed by the engineers of the ministry of infrastructure or by consultants who have no experience of the drainage work. This leads to a situation where preliminary studies that will help the design and construction decisions are not done. This leads to poor understanding of the drainage which subsequently leads to poor design and construction of drainage system.

Poor maintenance culture

Even if the drainsand their structures, culverts are well built they need adequate maintenance for sustainability. One of the main problem of drainage development in Khartoum state is maintenance. The drainsand culverts are rarely maintained and whenever maintenance is attempted it is done haphazardly. The financing of the maintenance, rehabilitation and conservation of the drainage network in Khartoum state had always been left to the government at the state and local levels who because of their lack of maintenance culture do not release funds for drainage maintenance at the appropriate time. The drainage network was therefore left to deteriorate. The drainage worldwide were considered critical infrastructure in any nation’s life and were paid premium attention.

Negative attitude of residents

The attitude of residents in communities under which these drainage channels are constructed and located is so negative. From the investigation conducted and seen in the photographs which taken from the drains sites during the field survey clearly shows that residents have converted the drainsand the culverts into refuse dump places. This results in blockage of these drains and its subsequent failures which in turn does negatively affect conditions of the road pavement. There is very urgent need for government agencies and concerned bodies to organize sensitization programs towards enlightening residents on the need to keep drains located in their communities clean and not use them as refuse dump places. In situations where these residents refuse to heed environmental sensitizations and warnings, enactment of laws to punish offenders with very strong enforcement machinery should be put in place.

Use of low quality materials

Use of low quality construction materials such as bricks, concrete, corrugated steel adversely affects the quality of the drains and culverts. This sometimes occurs in the form of the improper concrete mixture for construction of drain channels. The use of extreme cohesive and expansive soil as foundation soil results in prolonged consolidation, heave or settlement of the bed of the drain and culvert. The use of soil of low bearing capacity as foundation soil leads to the failure of the drainsand culverts.

No local standard of practice

There is agreat need for adequate monitoring and control in the local construction process. This can be done by the provision of a standard method of practice which will be strictly followed, monitored and maintained. The professional bodies in the country will play a very important role at this stage. They should be able to provide a local standard of practice for the country, maintain it and monitor compliance to the use of the standard. This is because a local standard will take cognizance of the local peculiarities that will affect the environment where drainage works are located.

6. CONCLUSIONS

The impact of poor drainage condition on road pavement is very adverse. It causes pavement distresses and deterioration which affect the safety and riding quality on the pavement. The study investigated cases of pavement failures and damages due to poor drainage experienced during the last few years on a number of roads in Khartoum state.

On Basis of the previous experiences in design and construction of drainage, the study provides design guidelines for a proper and efficient drainage system leads to enhance road performance and increasing the service life of pavement.

Regular annual evaluation of drainage systems is an important part of maintaining and managing road. Before making any pavement surface improvements, make drainage improvements. It is most economical and effective to plan and upgrade drainage as part of road surface improvements.

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