DRAINAGE AND FLEXIBLE PAVEMENT PERFORMANCE

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Abstract

Providing adequate drainage to a pavement system has been considered as an important design consideration to prevent premature failures due to water related problems such as pumping action, loss of support, and rutting, among others. Most water in pavements is due to rainfall infiltration into unsaturated pavement layers, through joints, cracks, shoulder edges, and various other defects, especially in older deteriorated pavements. Water also seep upward from a high groundwater table due to capillary suction or vapour movements, or it may flow laterally from the pavement edges and side ditches. Providing adequate drainage to a pavement system has been considered as an important design consideration to ensure satisfactory performance of the pavement, particularly from the perspective of life cycle cost and serviceability. To minimize premature pavement distresses and to enhance the pavement performance, it is imperative to provide adequate drainage to allow infiltrated water to drain out from the base and sub-base, thus avoiding saturation of base and subgrade soils. This paper deals with the analysis of the impact of subsurface drainage on pavement system performance. The requirement of effective subsurface drainage for pavement performance is also discussed.

Keywords: Subsurface Drainage; Pavement Performance; Flexible Pavements.

1. Introduction

Excessive water content in the pavement base, sub-base, and subgrade soils can cause early distress and lead to a structural or functional failure of pavement, if counter measures are not undertaken. Water-related damage can cause one or more of the following forms of deteriorations: a) Reduction of subgrade and base/sub-base strength, b) Differential swelling in expansive subgrade 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 sub-base course materials resulting in a reduction of the hydraulic conductivity considerably (Lytton et al., 1993).

Results from laboratory and field tests conducted on a number of roads indicated that the moduli of base and subgrade materials were strongly affected by moisture content (Yuan et al., 2003). Furthermore, a relatively rapid decrease in the level of serviceability could occur, because the pavement ability to transmit dynamic loads imposed by the traffic would be greatly weakened (Moulton, 1980 and Tangpithakkul, 1997). Movement of the wheel on a pavement with a saturated subgrade can produce a moving pressure wave, which in turn can create large hydrostatic forces within the structural section. These pulsating pore pressures significantly influence the load-carrying capacity of all parts of the pavement structure (Cedergren, 1974). The freeze-thaw
cycles could also cause moisture-induced pavement damage, because the moisture will migrate through the capillary fringe toward the freezing front to increase ice lenses.

The presence of water in the pavement is mainly due to infiltration through the pavement surfaces and shoulders, melting of ice during freezing/thawing cycles, capillary action, and seasonal changes in the water table. The significance of the respective routes depends on the materials, climate, and topography.

2. Drainage Impact on Pavement System Performance

There have been a number of field studies that have shown the benefit of drainage for pavement systems. They studies typically do not identify the precise mechanism or process that causes pavement distress, but rather document the manifestation of the underlying problem. Cedergren (1988) evaluated early field tests that included both drained and undrained sections (WASHO test 1955; AASHO test 1962; University of Illinois test 1970). 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.

Forsyth et al. (1987) 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.

Markow (1982) developed a predictive model of pavement performance that includes the effect of moisture on pavement layer 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, the impact of moisture on pavement performance was calculated using a FHWA model of pavement performance.

Wyatt and Macari (2000) offered a potential explanation of the results of NCHRP 1-34. They evaluated whether the drainage features and designs used in the monitored sections were adequate for the anticipated infiltration. Thus, they considered design adequacy, not the presence of drainage features. For example, just because a pavement section includes an edge-drain does not mean that it has adequate drainage. They found sections that had low permeability base courses with edge-drains, so the pavement was not designed to effectively drain infiltrating water.

3. Effects of Weather-Related Factors on Pavement Performance

It is well known that environmental changes are the major factor in pavement deterioration. The effect of seasonal variation on pavement performance is generally considered to be very important. While the modulus of the bituminous layers is more sensitive to the temperature variation, the modulus of unbound materials is sensitive to the variation of moisture content. These two environmental factors, temperature and moisture content, must be incorporated in the design process of flexible pavements particularly in seasonal frost areas where pavements are likely to heave during winter and then lose part of their bearing capacity during spring thaw.

Elsayed and Lindly (1996) noted that until the study by Ridgeway (1982), high water table and capillary water were thought to be the primary causes of excess water in pavements. Recently, crack and shoulder infiltration, and to some extent subgrade capillary action, were considered to be the major routes of water entry to the pavement. The significance of infiltration was shown by an immediate increase in edge drain outflow following a precipitation event. Van Sambeek (1989) reported that surface water infiltration can account for as much as 90 to 95 percent of the total moisture in a pavement system. He also identified transverse and longitudinal joints as major routes of ingress. For routes of egress, Dawson (1998) noted that the lateral or median drain is the most significant route except when a highly conductive underdrain (subgrade unsaturated hydraulic conductivity >0.1 cm/s) is provided. Thus, infiltration through cracks and joints is thought to be the major ingress route and engineered drainage is believed to be the major egress route. Groundwater conditions may affect the moisture in pavement systems and may be the major factor influencing subgrade water content if the ground water table is within approximately 20 feet from the surface. Capillary water and water vapour may migrate towards ground surface, thus increasing the moisture content especially in subgrades.
4. Effect of Water Content on Resilient Modulus (MR) of Subgrade

Resilient modulus, MR, of soil is an important material parameter. The resilient modulus of cohesive soils is not a constant stiffness property, but highly dependent upon factors such as the state of stress, soil structures, and water content. Due to complexity of conducting resilient modulus testing, there have been numerous efforts to develop predictive equations by incorporating state variables such as confining stress, bulk stress, deviator stress, and soil physical properties. In view of the sensitivity of the resilient modulus of cohesive soils to the water content and stress state and the likelihood of the soils’ moisture variation underneath the pavement, it is important to develop a simple and accurate prediction equation for predicting the variation of resilient modulus due to changes in stress and moisture content of cohesive soils.

5. Drainage Effectiveness

Bejarno and Harvey (2002) used a heavy vehicle simulator and showed that flexible pavement sections containing both drained layers and conventional dense-graded layers had similar service lives. However, the section containing the dense-graded layers failed because of fatigue cracking and the section containing drained layers failed because of permanent deformation. The drainage layer used in this study consisted of a 75-mm-thick asphalt-treated base layer. It was found that the life of the asphalt-treated layer was shortened because of stripping problems underneath the loading wheel and that the bottom of the drainage layer was clogged with fines from the layer below. This is an important indication, as the drainage layer was separated from the subgrade only by an application of a prime coat and not a dense-graded layer designed using a filter criterion (inclusion of a filter layer was a recommendation from the report). Bejarno et al. (2004) analyzed stripping in a drainage layer and stated that the failure was likely due to high pore pressures created within the aggregate because of the saturated condition. It was postulated that these pore pressures forced the water into the pores of the aggregate and reduced the cohesive bond between the aggregate and the binder in the drainage layer.

Studies of pavements showed that sections of pavement containing a drainage layer drained more rapidly after a rain event than did sections without a drainage layer; thus, the pavement spent less time in a saturated condition. This was shown by comparing the output from instruments to measure the moisture content within the pavement structure. In addition, it was found that the moisture content tended to remain constant in the subgrade below the drainage layer rather than fluctuate with each precipitation event.

The National Cooperative Research Program (NCHRP) 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 (NCHRP, 2002). It was found that structural capacity and drainability 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.

The use of edge-drains was also examined in NCHRP 1-34 (NCHRP, 2002). For conventional bituminous pavements with unbound dense-graded aggregate bases, the addition of edge-drains appeared to reduce fatigue cracking, but not rutting. The use of asphalt-treated permeable base sections with edge-drains produced significantly less rutting than did unbound dense-graded aggregate base sections. However, the fatigue cracking performance for both types of base sections with edge-drains was comparable.

NCHRP 1-34 (NCHRP, 2002) 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 increased fatigue cracking and rutting and could lead to stripping. In addition, daylighted 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 daylighted sections and other sections.
6. Conclusions

Excessive moisture within a pavement system is one of the most influential factors in contributing to the early deterioration of pavements. Moisture enters the pavement through surface infiltration, cracks, and joints and through movement of subsurface moisture. Subsurface moisture may be present in the pavement system because of areas of high water table, interrupted aquifers and springs, subsurface flow, and capillary action. Excessive moisture in the pavement structure will cause one or more of the following: a reduction in the shear strength of unbound subgrade/sub-base materials, creation of weak layers by movement of unbound fines into flexible pavement sub-base/base courses, frost heave, reduction of strength during frost melt, durability cracking, loss of support by pumping of fines in rigid pavements, and stripping in asphalt pavements.

Properly designed and constructed subsurface drainage systems enhance the life of pavement structures. Clogged under-drain outlet pipes are detrimental to the performance of the pavement structure. Therefore, it is recommend that regular inspection of the under-drain outlet pipes needs to be a key part of maintaining a pavement that includes subsurface drainage features. Installation of longitudinal edge-drains in pavements containing no subsurface drainage layers significantly increases the subgrade resilient modulus. Installation of edge-drains improves the fatigue performance of pavements constructed on unbound dense graded aggregate layers. When two types of base layers where both pavement structures contained longitudinal edge-drains were compared, the use of a treated permeable drainage layer improved the rutting performance over that provided by unbound dense-graded aggregate base layers. Pavement drainage is most beneficial when excessive moisture can be rapidly removed from the structure, ideally within 2 hours and preferably within 24 hours; however, the benefits derived from a subsurface drainage system will vary depending on pavement type, annual rainfall, subgrade conditions, geometric design, and design of the overall pavement system.

References