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Impact of pavement layer properties on the structural performance of inundated flexible pavements

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ABSTRACT

The assessment of the structural performance of flooded pavements remains complicated due to the lack of structural data in the aftermath of flooding and the fact that information about the pavement structure and materials is not always readily available. The objective of this study is to acquire a better understanding of the structural response of pavements that have been inundated and the foreseen changes in capacity using two approaches: a mechanistic approach using layer elastic analysis and the AASHTO empirical approach to determine the structural number. The relative impact of parameters such as unbound material type, layer thickness, traffic loads, and interlayer bond conditions on the reduction in expected strain values at critical locations were evaluated. The results show increases of 15–80% in vertical strains at the top of subgrade layer for low volume and interstate sections and 6–15% increase in horizontal strain at the bottom of asphalt layer for low volume sections and 3–8% for interstate sections. Accurate information on the layer thicknesses, traffic type, and interlayer bond condition were found to be most important for the evaluation of the change in expected horizontal strain. The types of base and subgrade materials are the most important factors for evaluating the change in expected vertical strain. The results of this study provide guidance on the type of information that is most important to collect for the assessment of the structural capacity of a pavement following inundation.

Introduction

Evaluating the structural function and integrity of pavements during flooding is complicated and challenges pavement engineers due to the existence of many unknowns during post-flood pavement assessments. In order to evaluate the performance or capacity of a pavement that has been inundated, full understanding of how asphalt pavement behaves under saturated conditions is required. Parameters such as traffic loads and environmental conditions such as temperature and moisture content will influence the amount of damage in pavements over time and, correspondingly, reduced the structural capacity of the road. Pavement materials, bonding interface between layers, and thickness of pavement layers are examples of other parameters that determine the capacity of a pavement that has been flooded as well. The impact of these parameters on the structural response of flooded pavements has not yet been widely investigated [1].

Pore water pressure in the subgrade is another factor might be induced when the subgrade is saturated and subjected to heavy traffic loads. Extreme changes in moisture content within a pavement structure during flooding could lead to increase the pore water pressure, and therefore, influence the soil stress states. The effective stresses in subgrade could be reduced due to increased pore water pressure, and as a result, reduce stiffness and strength of the subgrade. The change in moisture content and pore water pressure could significantly impact the load-bearing capacity and performance of pavement structure. Consequently, this might lead to excessive deformations and failures to pavement structures [2–3].Therefore, for the assessment of short-term impacts due to floods; it is important to examine the behavior of unbound materials, which are sensitive to moisture content under flooding and their influence on the pavement response. For the assessment of long-term impacts due to floods, the sensitivity of the asphalt layer to water damage should also be considered.

Hurricanes Katrina and Rita caused devastating floods in 2005 that affected many roadways and called into question the appropriate way to evaluate the impact of flooding on the integrity of pavements. After these events, many agencies and researchers started to study the impact of flooding on pavement deterioration [1,4–9]. The lack of structural data for pavements before Hurricane Katrina made it difficult to perform a study to obtain the percent of reduction in the pavement strength after flooding. Thus, an alternative approach based on the comparison of the structural data for similar pavement structures, materials, environmental conditions, and traffic loads in different non-

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flooded areas was done. The research team studied the impact of road elevations, road pavement types, and AC pavement thickness. They observed that all damage caused by flooding happened during the first week of flooding. They observed an 18% reduction in the structural number (SN) between flooded and non-flooded pavements and a 25% reduction in the subgrade modulus was detected due to saturation. Based on the investigations, they suggested that the greatest impact from flooding is inundation, which leads to change in the stiffness of pavements over time. The results showed that the thinner pavements were more vulnerable to the damage from floodwaters than thicker pavements. The highest reduction in subgrade resilient modulus and the structural number was identified in thinner AC pavements. Flexible pavements were more vulnerable to flood water damage than rigid or composite pavements [5,6].

Vennapusa et al. [7] proposed a study to evaluate the performance of pavement structures post-Missouri river flooding 2011. The findings from in-situ testing indicated that the reduction of resilient modulus of subgrade soils (A-2-4, A-4, A-6, and A-7) was 25–30% due to flooding at all times of testing; for about 20 days after the flood water recedes and about 6–8 months after flooding. Sultana et al. [1] studied the structural performance of pavements after flooding in 2011 in Queensland, Australia. In-situ tests were conducted within 6 weeks and 2–4 years post-flood event. Modified Structural Number (SNC) was used based on the Falling Weight Deflectometer (FWD) measurements for comparison of pavements before and after flooding. Reductions of up to 50% in structural number were detected within 6 weeks of flooding while the pavements regained their strength 4 years post flooding due to rehabilitation works.

Saevarsdottir et al. [10] investigated the pavement response of two flexible test road structures that were built and tested in an Accelerated Pavement Test (APT) using a Heavy Vehicle Simulator (HVS) at two groundwater table levels. The findings showed 15% increase in the horizontal strain at the bottom of the asphalt layer due to raising the ground water level at one of the road section while the other section showed increase of 40% at the bottom of the asphalt layer. The findings also showed 20% increase in the vertical strain at the top of the subgrade layer due to raising the ground water level at the tested road sections. Salour et al. [11] conducted a study to investigate the impact of groundwater level on the flexible pavement response using FWD. Two different conditions were considered; the groundwater table was 1.0 m below the road surface (blocked drainage) and 2.5 m below the road surface (unblocked drainage). The total thickness of the investigated pavement cross section was 0.56 m placed on top of silty sand subgrade layer. Moreover, the whole subgrade soil was not in the fully saturated condition. The findings showed a 34% increase in the horizontal strain at the bottom of asphalt layer, and a 52% increase in the vertical strain at the top of subgrade layer due to raising the groundwater level.

Overall, several studies investigated the impact of water on the behavior of pavements [2,12–15]. They concluded that once the moisture content reached or exceeded the optimum value the permanent deformation increased dramatically.

In general, previous studies showed that there are many unknowns that influence the performance of flooded pavements that are not fully understood and also presented the percent of reduction in the structural pavement performance based on the limited measurements post-flood events. However, these measurements were also time consuming and expensive. Hence, in this paper, a parametric analytical analysis is presented to better understand the structural response of the flooded pavement structures. In this study, six different parameters are investigated; these include asphalt layer thickness, base course layer thickness, base course material type, subgrade material type, interlayer bond condition, and traffic load. Analyses of these six different parameters for a low volume road and an interstate highway are conducted for two purposes: (1) to accurately determine which parameters affect the pavement's performance when the road is inundated and, (2) to determine the level of accuracy and/or resolution needed for the different parameters.

In this study, the unbound layers were assumed to be at optimum moisture content during non-flood conditions to represent the as-designed strength of the pavement structure. The groundwater table level was assumed to be deep enough to not impact the default moisture content. During the flooding event, the groundwater table level was assumed to be on top of subgrade layer surface. Therefore, the subgrade layer was assumed to be fully saturated to evaluate the worst-case conditions where the pavement structure would be at its weakest. Under actual flood conditions, it will take some amount of time for the unbound pavement layers to become fully saturated; this will be a function of inundation time and the soil type. In this study, the focus was on evaluating the worst-case conditions and the time to full saturation is not a part of the scope.

Two approaches were used to evaluate the structural capacity of pavement structure:

- Mechanistic Approach: layer elastic analysis (LEA) was used to predict the stresses and strains at the bottom of asphalt layer and at the top of subgrade layer
- Empirical Approach: the AASHTO structural number was calculated

Both approaches were performed using saturated and optimum moisture conditions. The ratio of the two values was used to identify the importance of various parameters. Statistical analysis using Analysis of Variance (ANOVA) was conducted to provide a fair comparison amongst different parameters to investigate the impacts on the structural response of inundated pavements. This study will allow engineers to acquire a better understanding of how pavements perform under saturated conditions and to recognize the most critical parameters that affect the structural response of flooded pavement structures.

Methods and data

In this study, the structural capacity of thirteen different pavement

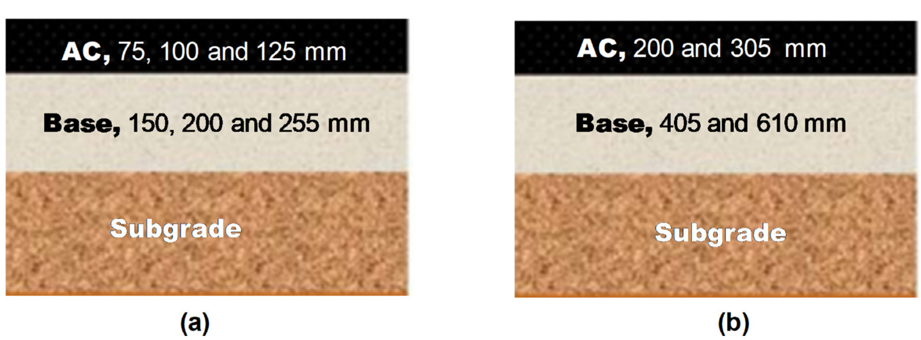

Fig. 1. Typical cross section for (a) low-volume road (b) interstate highway.