Reviewing the Role of Mathematical Models in Enhancing Regional Pavement Management

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Abstract—Pavement management refers to a process through which roadway networks or facility maintenance and repairs are planned. According to Abdulaziz, Taha, Kenawi and Kamel (2013), the main aim of this process is to ensure that the entire network’s pavement conditions are optimized. According to Aiswarya and Deepthi (2015), pavement management also refers to a program through which the performance and quality of pavements are improved; with Alawi and Rajab (2013) documenting further that the practice strives to ensure that through good management practices costs are minimized.

Keywords—Pavement, management, maintenance

1. Background

On the other hand, Basha and Babu (2010) asserts that the concept of pavement deterioration refers to the development of defects or distress in pavements relative to combined effects of environmental conditions and traffic loading. Additional scholarly assertions suggest that pavement deterioration constitutes decreasing serviceability of a pavement arising from the development of ruts and cracks (Basha & Babu, 2011). Types of pavement deterioration have also been defined; some of the broad categories of pavement deterioration include surface defects (such as bleeding), disintegration (such as the development of potholes), surface deformation, and cracking. If unchecked, pavement deterioration causes economic and safety problems. The safety concerns arise from unevenness and skid resistance whereby the former is linked to the danger of motorist underestimation of vehicle control difficulty while low skid resistance has been observed to account for a high number of accidents (Cabalar & Karabash, 2015); the problem tends to be exacerbated by stagnant water along the paths, often attributed to unevenness during wet weather.

Apart from direct economic costs accruing from the reduced safety level (as a result of unevenness and low skid resistance), economic costs at the country or regional level have also been documented. For example, Chittoori, Puppala, Pedarla and Vanga (2014) stated that in key highways, pavement deterioration increases vehicle wear and tear, as well as fuel consumption. As such, it can be inferred that the majority of pavement management practices and systems have evolved in response to the need to address this economic equation, which poses a dilemma and remains imbalanced.

Another concept worth defining is expansive (clay) soil. According to Consoli, de Moraes and Festugato (2011), expansive soils refer to soils (vertisols) with high contents of expansive minerals and are marred by the formation of deep cracks during drier years or seasons. Indeed, expansive soils can be inferred to be typical clays demonstrating extensive strength and volume changes relative to the amount of moisture content, with the latter trend linked to the chemical composition of the soils. Through time, the changes in the volume of the clays lead to significant foundation damages, with pavements unexceptional (Dang, Fatahi and Khabbaz, 2016). The emerging trend is that aspects of pavement deterioration and pavement management efforts come in the wake of increasing safety and economic concerns relative to the presence of expansive soils beneath major highways and most of the current road networks. These interactions point to the need for an examination of the impact posed by expansive soils on trends in pavement...
deterioration, as well as the impact of the presence of these clays or vertisols on the practice of pavement management. By examining this subject, it is projected that the current study will sensitize engineers and geologists in relation to some of the pavement management mechanisms that could be adopted and implemented to ensure that pavement deterioration linked to expansive soils is curbed via responsive approaches while seeking to assure the safety of road users and a reduction in highway maintenance costs. Imperative to highlight is that the study is based in a specific context of the metropolitan city of Houston, Texas.

2. Problem Statement
For years, engineers and geologists have examined expansive soils with the main aim being to establish ideal construction techniques, especially in situations where the vertisols are unavoidable (Dash & Hussain, 2012). Some of the countries that have continually experienced significant problems in the design and construction of pavements due to expansive soils include South Africa, Israel, the UK, the U.S., India, China, New Zealand, and Australia (Hasan, Dang & Khabbaz et al., 2016); this gives an insight into some of the countries or regions in which expansive soils exist and how they have proved challenging; however, the attribute of context-specificity remains unaddressed, a gap attracting an investigation that focuses on a research setting such as Houston, Texas.

Additional studies have documented that expansive soils have proved challenging and continue to account for pavement distresses on the majority of pavements, road networks, or roadways (Hatmoko & Suryadarma, 2017). According to Johnson and Gopinath (2016), these challenges arise due to alterations in moisture levels whereby the expansive soils end up experiencing significant changes in their volume, a change attributed to seasonal variations. As such, these observations suggest that expansive soils account for pavement distresses because seasonal variations imply that in some cases, these soils change in volume (in response to moisture changes), leading to problems such as cracking, surface deformation, and disintegration – despite the informative nature of these scholarly findings, they come short in that they fail to sensitize audiences regarding current trends in pavement management in regions containing expansive soils. Also, the findings fail to recommend some of the pavement management strategies which could be embraced to avoid pavement deterioration over surfaces with vertisols. Similarly, the scholarly assertions falter whereby they do not give a specific correlation between expansive soils and pavement deterioration and pavement management in a context such as Houston, Texas; therefore, the need to address these gaps cannot be overstated.

3. Aim and Objectives
In this study, the main aim is to investigate the impact of expansive soils on pavement deterioration and pavement management in Houston, Texas. The study’s specific objectives are stated as follows:

- To determine current trends in pavement deterioration and pavement management in Houston, Texas
- To find out some of the challenges facing geologists and engineers while seeking to establish successful pavement management mechanisms on pavements with expansive soils in Houston, Texas
- To establish solutions to some of the challenges facing geologists and engineers while seeking to establish successful pavement management mechanisms on pavements with expansive soils in Houston, Texas

4. Rationale
Soil properties determine the nature of the interaction between the soil and moisture. Relative to the recommendations by the Texas Department of Transportation (TxDOT), distance from flooding areas and accessibility, this study has selected Houston’s pavement networks for investigation. According to Sivapullaiah and Moghal (2011), most of the pavements in this area are fairly level, but there is evidence
of pavement distresses, including edge cracking. The selection of this research setting has been informed by the need for base and soil stabilization and modification.

A. High expansive soil type in East and Central Texas

B. Thornwait Index

Figure 1: Illustrating the Thornwait Index for East and Central Texas

Source: Abdulaziz, Taha, Kenawi and Kamel (2013)
Thus, the study is important in various ways. For example, an investigation of the current trends in pavement deterioration in Houston is poised to aid in predicting future factors associated with expansive soils and also recommending some of the early interventions that could be adopted to address this adversity. Moreover, the study’s examination of the impact of expansive soils on pavement deterioration and pavement management is predicted to aid in predicting the expansive soil’s movement, upon which pavement managers, geologists, and engineers might gain knowledge regarding the need to design ground supported structural elements and foundations. It is also worth acknowledging that this study’s quest to establish some of the challenges facing geologists and engineers as they seek to establish effective pavement management mechanisms could pave the way for a recommendation of lasting solutions which could yield improvements in the design and construction of pavements in Houston, yielding an additional trickle-down effect in the form of environmental and economic sustainability. Overall, the study is appropriate because an understanding of the impact of expansive soils on pavement deterioration and pavement management strives to promote the development of optimal plans through which road networks in Houston could be maintained in response to various factors linked to the association between expansive soils and pavement deterioration. The timeliness of the study is informed by most of the previous scholarly studies’ affirmations that for already established pavements, maintenance is crucial for safe and efficient operation of a road network in the entirety, prompting the need to gain insights from the current state of Houston.

5. Results

The table below summarizes some of the types of pavement distress and their associated causes in Houston, based on recent PCI investigations.

| Asphalt Distresses          | Cause Classification | PCC Distresses    | Cause Classification |
|-----------------------------|----------------------|-------------------|----------------------|
| Alligator cracking          | Load                 | Blowup            | Climate              |
| Bleeding                    | Other                | Corner break      | Load                 |
| Block cracking              | Climate              | Linear cracking   | Load                 |
| Corrugation                 | Other                | Durability cracking| Climate             |
| Depression                  | Other                | Joint seal damage | Climate              |
| Jet blast                   | Other                | Small patch       | Other                |
| Joint reflection cracking   | Climate              | Large patch       | Other                |
| L&T cracking                | Climate              | Popouts           | Other                |
| Oil spillage                | Other                | Pumping           | Other                |
| Patching                    | Other                | Scaling/crazing   | Other                |
| Polished aggregate         | Other                | Faulting          | Other                |
| Raveling                    | Climate              | Shattered slab    | Load                 |
| Rutting                     | Load                 | Shrinkage cracking| Other                |
| Shoving                     | Other                | Joint spalling    | Other                |
| Slippage cracking           | Other                | Corner spalling   | Other                |
| Swelling                    | Other                | Alkali Silica Reaction| Climate             |
| Weathering                  | Climate              |                   |                      |

Table 1: Causes of pavement deterioration in the study area
Source: Malekzadeh and Bilsel (2012)
6. Longitudinal and transverse cracking

According to Aiswarya and Deepthi (2015), causes of longitudinal and transverse cracking in Houston include subsurface movement (due to the presence of expansive shrink-swell soils or clays), construction, and pavement aging. Through aging, some of the region’s pavements have ended up losing certain components to the atmosphere, eventually becoming brittle (Alawi & Rajab, 2013). These types of cracks have also been documented to arise from poor construction of pavement lane joints, a situation exacerbated by a combination of the poor construction designs with temperature differences and soil moisture content variations (Basha & Babu, 2012). Thus, these assertions are important to the current literature on the impact of expansive soils on pavement management and the rate of pavement deterioration, sensitizing geotechnical engineers regarding the importance of implementing strategies that target these causes of longitudinal and transverse cracks in Houston. However, these assertions fail to highlight some of the specific cost-effective interventions through which engineers and geologists could respond to the problem of pavement deterioration via longitudinal and transverse cracking in Houston, a gap that becomes imperative to address.

Figure 2: Longitudinal and transverse cracking in the study area
Source: Mirzaii and Negahban (2016)

7. Block Cracking in Houston

In Houston, block cracking, which combines longitudinal and transverse cracks to yield block pattern, has led to blocks whose sizes range from one square foot to ten square feet (Cabalar & Karabash, 2015). With expansive soils and their impact on pavement deterioration on focus, Chittoori, Puppala, Pedarla and Vanga (2014) avowed that in Houston, the flexibility of bituminous binders is likely to be compromised due to the presence of older asphalt pavements. Based on these conclusions, it can be inferred that block cracking has arisen from a combination of internal and external factors with which pavement deterioration (in Houston) is associated. However, these observations fail to document feasible pavement management strategies through which block cracking could be managed.
8. **Alligator cracking in parts of Houston**

Also referred to as fatigue cracks, alligator cracks have been documented to occur in the form of interconnected load-related cracks. According to Dang, Fatahi and Khabbaz (2016), the asphalt surface’s fatigue forms a major parameter accounting for the dominance of alligator cracks in parts of Houston, with expansive soils playing an additional moderating or predictive role. Also, traffic loads have been observed to account for significant structural distresses at the asphalt layer bottom, with this location of the alligator cracks attributed to upward propagation and the presence of the highest tensile strain (Dash & Hussain, 2012). Hence, visible alligator cracks imply that the asphalt layer bottom is likely to have experienced significant damage.
9. Summary

Overall, these affirmations aid in understanding how factors such as traffic load and asphalt surface fatigue combine with the shrink–swell behavior of expansive soils to account for the dominance of alligator cracks on highways in regions such as parts of Houston. On the other hand, most of the scholarly studies fail to unearth some of the geotechnical engineering interventions that could be embraced to respond to these adverse effects accruing from the parameters mentioned above. By gaining insights from Houston as a study area, it is projected that the current study will contribute to the literature by establishing relevant pavement management strategies whose implementation might restore effective functionality and improve the durability of pavements that have been designed and constructed on the expansive soil subsurface.

10. References

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