The Role of Mathematical Models in Responding To Pavement Failures and Distresses in Texas

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Abstract—As acknowledged by Cabalar, Karabash and Mustafa (2014) and Consoli, de Moraes and Festugato (2011), expansive soils are among the leading causes of distresses in pavements. Based on the parameter of moisture levels, Dang, Fatahi and Khabbaz (2016) stated that expansive soils experience significant alterations in their volume. According to Dash and Hussain (2012), this variation is attributed to fluctuations in the amount of moisture in the soil, an outcome in response to seasonal variations. In situations, where a region experiences high moisture, Hasan, Dang and Khabbaz et al. (2016) established that there is a likelihood of swelling beneath pavements established over expansive clays in the region. On the other hand, Hatmoko and Suryadharma (2017) asserted that when the level of soil moisture falls, there is a likelihood of shrinking, a predictor for significant deformation. In a similar observation, Johnson and Gopinath (2016) noted that these cycles of shrinking and swelling exhibit a direct correlation with pavement cracking. Whether this trend holds for the case of Houston, Texas remains unknown. However, the findings from this study suggest that mathematical models are informative in such a way that they explain the relationship between expansive soils and pavement deformation as that which is predicted by seasonal variations that cause alterations in the amount of moisture in soil.

Keywords—moisture, pavement cracking, fluctuations

1. Background

According to Malekzadeh and Bilsel (2012), expansive soils dominate Texas, especially towards the northern zone. Due to this dominance of expansive soils in various districts, pavement failures are common. The situation tends to be exacerbated by the location of pavements in regions experiencing alternating hot, dry periods and cool and wet periods (Mirzaii & Negahban, 2016). It is also worth noting that in Texas, most of the pavements are low-volume. With dominance of expansive subgrade, maintenance problems are frequent (Moghal, Al-Obaid & Al-Refeai, 2014). This section reviews some of the common pavement failures and distresses that characterize Texas’ low-volume roads. Imperatively, these roads are established over high plasticity soils, yet they exhibit narrow cross-sections (Moghal, Al-Obaid, Al-Refeai & Al-Shamrani, 2015). Some of the forms of pavement failures and distresses that the section seeks to review include popouts, shoving, rutting in the wheel path, edge cracking, fatigue or alligator cracking, and longitudinal cracking.
Figure 1: Pavement failure via longitudinal cracking
Source: Aiswarya and Deepthi (2015)

Table 1: Types and causes of pavement failures and stresses on low-volume roads
Source: Alawi and Rajab (2013)
For narrow and low-volume pavements in Texas, a combination of rutting and longitudinal cracking along pavement edges has been reported (Moghal, Basha, Chittoori & Al-Shamrani, 2016). According to Moghal, Dafalla, Elkady and Al-Shamrani (2015), this combination is attributed to the absence of lateral shoulder supports. Thus, edge failures are common on the region’s narrow pavements. As documented by Peter, Jayasree, Balan and Alaka (2016), most of these edge failures occur within 1-2 feet relative to the pavement edges. Pradhan, Kar and Naik (2012) observed similarly that some of the distresses which may combine or occur solely to contribute to edge failure include rutting, alligator cracking and fatigue, and longitudinal cracking. Eventually, transverse cracks arise due to the propagation of such failures toward travel lanes. Priya, Gopalakrishnan and Jawahar (2017) established further that most of the distances between pavement edges and the zones of crack formation are finite, but the majority are likely to propagate along wheel paths. In so doing, the base materials and subgrades experience moisture intrusion.

2. Current Trends in Pavement Management and Expansive Soil Treatment in Texas

In the treatment of expansive soils, several methods are employed. According to Malekzadeh and Bilsel (2012), three major categories through which expansive soils have been treated include expansive soil physical, chemical, and mechanical alteration, geogrid reinforcement, and subgrade moisture control. Whereas the latter approach demands the use of vertical barriers, geogrid reinforcement has been observed to target longitudinal cracking arising from expansive subgrade shrinkage (Mirzaii & Negahban, 2016). On the other hand, expansive soil or subgrade alteration has been achieved through lime stabilization, which is associated with the ability to increase the treated soil’s stiffness and strength while moderating the suction, decreasing the permeability, and reducing the swelling (Moghal, Al-Obaid & Al-Refeai, 2014).

3. Chemical Treatment

In a quest to stabilize subgrade soils and address the problem of expansive soils, chemicals (including lime-fly ash and cement) and lime have been employed (Moghal, Al-Obaid, Al-Refeai & Al-Shamrani, 2015). In Texas, several research investigations have been conducted (Moghal, Basha, Chittoori & Al-Shamrani, 2016). Based on the resultant DCP and FWD data, the addition of stabilizers yields beneficial outcomes relative to the subgrade (Peter, Jayasree, Balan & Alaka, 2016). According to Pradhan, Kar and Naik (2012), lime or cement treated bases reflect a common approach through which bases are maintained. However, Priya, Gopalakrishnan and Jawahar (2017) cautioned that cement treated bases tend to translate into block cracking. The implication for engineers and geologists in a region such as Houston is that longitudinal cracks are likely to arise due to the presence of expansive soils and the treatment of the subgrade using cement, with weak subgrades experiencing brittle layers (Radhakrishnan, Kumar & Raju, 2014). Whereas these studies point out some of the strengths and weaknesses with which expansive soil stabilization is achieved using lime or cement treated bases, they fail to document or recommend lasting solutions to the weakness with which expansive soil stabilization via the use of chemicals is associated; this dilemma attracts further investigation to predict solutions to the weaknesses of chemicals as subgrade stabilizers – while ensuring cost-effectiveness and environmental friendliness or sustainability.

Some studies have also investigated the impact of several key factors on cracking and shrinkage in cement-treated subgrade and bases. According to Sani, Bello and Nwadiogbu (2014), some of the variables that have been investigated in relation to this subject include the compaction method, curing time, molding moisture content, pre-treatment moisture content, density, material type, and cement content. Regarding cement content, Şenol (2012) observed that when more cement content is incorporated, there is a likelihood of increased shrinkage due to the demand for more moisture content, high tensile strength is achieved. Based on these mixed outcomes, the findings hold that when shrinkage is minimized, optimal cement content is present. However, other scholarly investigations do not establish a statistically significant relationship between shrinkage and cement content (Sivapullaiah & Moghal, 2011).
Apart from the factor of cement content, another parameter that has been investigated involves material type. For instance, Soumendra, Mohanty, Pradhan and Mohanty (2017) strived to unearth the role of clay content and type in shaping the degree or nature of shrinkage in the subgrade. In the findings, it was established that montmorillonite clay increases shrinkage and that a manual approach to cement stabilization is unlikely to be feasible when the plasticity index of these soils exceeds 20-25. In Texas, high plasticity sites in a context such as Austin have been used to obtain DCP data. From the scholarly investigations, findings suggest that with time, the use of lime leads to a significant reduction in penetration rate (Tang, Wang, Cui, Shi & Li, 2016). According to Yideti, Birgisson and Jelagin (2014), the implication is that after treatment, lime-treated soils are likely to gain strength. The findings also lead to the inference that the stabilization of expansive soils via the addition of lime increases the strength of the subgrade. However, these findings do not suggest some of the challenges that could arise during the application of lime stabilizer to increase the strength of the subgrade over which pavements are established, a gap worth filling. The figure below summarizes these scholarly findings.

![Figure 2: The role of lime treatment in attaining subgrade strength](source: Cabalar and Karabash (2015))

4. Pavement Reinforcement

In Texas, Bryan District forms one of the regions that have embraced geogrids and geotextiles to reinforce pavements while responding to the impact of expansive soils on the pavements. According to Zumrawi (2014), the objective behind the use of these pavement reinforcement techniques has been informed by the need to curb adverse effects with which expansive soils have had on longitudinal cracks. In the investigation by Abdulaziz, Taha, Kenawi and Kamel (2013), it was established that geogrids and geotextiles prevent cracks from an upward effect to the surface, providing a crucial barrier. In highly plastic clay areas, geosynthetic products have also been used to reinforce pavements. Specifically, fibrillated polypropylene fibers have been proposed. According to Aiswarya and Deepthi (2015), mixing these fibers into highly plastic clay soils tend to reinforce the soils mechanically. Alawi and Rajab (2013) observed further that when the fibers are included in stabilized sand and clay, they cause a significant increase in subgrade durability. Upon subjection to compression testing, expansive soils that have been
treated with fibers have been found to exhibit better load-carrying post-peak ability (Basha & Babu, 2011), findings that are similar to those established by Cabalar and Karabash (2015).

\[ \text{Figure 3: Expansive soil geogrid reinforcement} \]

\[ \text{Source: Cabalar, Karabash and Mustafa (2014)} \]

5. Summary

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