An Examination Of a Mathematical Framework for Geogrid Reinforcement on Sub-Base Layers: Insights from the Context of Houston, Texas

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Abstract—The concept of pavement management has evolved overtime owing to the need for roadway, pavement, and pavement network repair and maintenance. Pavement management has also evolved due to growing concerns about the alarming rates at which some pavement systems have deteriorated, a trend which also compromises their durability. One of the areas that have received growing scholarly interest and research is the role of expansive soils. Indeed, expansive soils or clays exhibit extensive strength and volume changes relative to the amount of moisture content. In this study, the main aim is to find out the impact of expansive soils on pavement deterioration and management, with specific insight gained from the context of Houston, Texas.

Keywords—Pavement management, durability, pavement, expansive soils.

1. Introduction

Most of the studies that have strived to unearth some of the benefits accruing from the implementation of geogrid reinforcement in sub-base layers have focused on specific interactions and forces that account for the impact of this reinforcement material on pavement durability. For instance, Moghal, Al-Obaid and Al-Refeai (2014) focused on the relationship between geogrid reinforcement and pavement performance. In the results, the study demonstrated that shear stress tends to be transferred to a pavement’s subgrade and its trickle-down effect involves improved load carrying capacity. Moghal, Basha, Chittoori and Al-Shamrani (2016) observed similarly and stated that geogrid subgrade offers vertical confinement beyond loaded areas experiencing heaving. As such, the subsurface aggregates exhibit increased bearing capacity due to layer reinforcement, having ensured that within the subsurface, some of the induced shear stress is transferred to the geogrid. In turn, tensile stresses are distributed over expansive areas.

Along the geogrid, distributed loads cause tensile stresses. These stresses end up forming interfaces between the surrounding material and the geogrid, causing an increase in the pavement system’s bearing capacity, as well as frictional resistance (Peter, Jayasree, Balan & Alaka, 2016). According to Pradhan, Kar and Naik (2012), an increase in an entire pavement system’s bearing capacity arises from the interaction between the geogrid and the aggregate. In turn, the angle of friction increases effectively, especially in response to shear failure modification. Another beneficial effect associated with geogrid reinforcement has been reported to occur in the form of significant improvement in vertical stress distribution. As contended by Priya, Gopalakrishnan and Jawahar (2017), this improvement arises from a deformed membrane’s tensile stress.

In the study by Radhakrishnan, Kumar and Raju (2014), the main aim was to determine the mechanism behind improved load carrying capacity as a trend arising from the use of geogrid reinforcement on pavement systems constructed over expansive soils. Similar to the findings by Sani, Bello and Nwadiogbu (2014), the study established that by reinforcing sub-bases onto subgrades, geogrid reinforcement improves load dispersion and, in turn, improves a pavement’s load carrying capacity.
Hence, it can be inferred that geogrid reinforcement aids in addressing some of the external causes of pavement deterioration in relation to pavement systems that have been constructed on expansive soils.

Additional scholarly investigations have focused on some of the interactions among forces due to the implementation of geogrid reinforcement, with the interactions perceived to account for a pavement’s improved load carrying capacity. According to Şenol (2012), one of the factors involves tensile stress. Particularly, the study acknowledged that the tensile stress accrues from improvements in vertical stress distribution, which exhibits a direct correlation with improved load carrying capacity (Sivapullaiah & Moghal, 2011). In the observation by Soumendra, Mohanty, Pradhan and Mohanty (2017), it was established that a second factor behind geogrid reinforcement’s ability to improve a pavement’s load carrying capacity, especially on expansive soils, involves shear stress. Particularly, the study indicated that the introduction of geogrid reinforcement curbs pavement deterioration by ensuring that the shear stress extending to the subgrade is reduced. In turn, subgrade outside loaded areas, which are prone to heaving, experience vertical confinements. As avowed by Tang, Wang, Cui, Shi and Li (2016), the latter process ends up limiting subgrade upheaval and rutting, besides reducing shear strain close to the subgrade’s top. Yideti, Birgisson and Jelagin (2014) documented that another factor responsible for geogrid reinforcement’s ability to improve a pavement system’s load carrying capacity (in areas marred by expansive soils) entails the transference of some of the shear stress. According to Zumrawi (2014), the induction of this shear stress occurs in the geogrid’s subsurface. With tensile forces accepted, the geogrid ensures that they are transferred to a large region.

2. The Case of Houston

Since 1995, most of the districts and institutions such as airports in the U.S. have had to abide by a policy requiring implementation of a pavement maintenance program, a condition through which the institutions or regions could receive Federal grant assurances. According to Mirzaii and Negahban (2016), this provision has been applied to pavements whose repairs or construction have relied on Federal money. In Houston, the central objective of pavement management involves the establishment of optimally timed repairs, as well as pavements that are likely to receive the most benefit. Moghal, Al-Obaid and Al-Refeai (2014) documented that this process involves the projection of the rate of the region’s pavement deterioration, upon which optimal times through which treatments could be determined are established. In the study by Moghal, Bashia, Chittoori and Al-Shamrani (2016), it was documented that optimal repair times in a region such as Houston reflect points where gradual deterioration rates increase faster. The figure below illustrates this trend.
Figure 1: An illustration of the rate of pavement deterioration and associated costs

Source: Dang, Fatahi and Khabbaz (2016)

As asserted by Peter, Jayasree, Balan and Alaka (2016), Houston’s pavement management approach has been that in which the rate of pavement deterioration is identified in time to reduce the cost of rehabilitation, with Pradhan, Kar and Naik (2012) documenting that when excess deterioration is evident, the cost of rehabilitation tends to increase significantly. In this case, it becomes important to investigate the extent to which expansive soils have played a contributory role in shaping this correlation, as well as
the implication for Houston’s engineers and geologists’ quest to project the rate of pavement deterioration while considering the parameter of expansive soil dominance.

To predict the rate of pavement deterioration in Houston, Priya, Gopalakrishnan and Jawahar (2017) documented that the pavement condition index (PCI) has gained increasing application. According to Radhakrishnan, Kumar and Raju (2014), PCI inspection involves the identification of visible distress signs in certain sample units before classifying the distresses into a high, medium, or low severity. Notably, the foreign object damage (FOD) potential increases with an increase in the severity of pavement deterioration. It is also worth indicating that in Houston, the use of PCI values has been informed by the need to gain information and predict the level of rehabilitation needed towards pavement repair. When the PCI value is above 60, Sani, Bello and Nwadiogbu (2014) documented that some of the interventions that could be embraced include patching and crack sealing. However, Şenol (2012) cautioned that with continued pavement deterioration, more expensive and complex treatments are required. For PCI values that range from 40 to 60, most of the current literature advocates for the use of various major repairs. As asserted by Sivapullaiah and Moghal (2011), some of the needed repairs include reconstruction and overlays. Indeed, these observations are informative whereby they sensitize geotechnical engineers in Houston regarding the criticality of embracing PCI evaluations to predict the rate of pavement deterioration, as well as the importance of the PCI values in informing the most appropriate techniques that could be employed during pavement management. However, it is imperative to note that the scholarly affirmations falter in such a way that they do not give insight into some of the weaknesses that might accrue relative to the use of PCI evaluations to predict the rate of pavement deterioration in a region such as Houston. The figures below illustrate some of the recent statistical outcomes regarding PCI evaluation data for the case of Houston’s major highways.

A. PCI descriptors
B. PCI values for major roads in Houston

C. PCI values for local roads in Houston

Figure 2: PCI evaluation outcomes for Houston’s major and local roads

Source: Dash and Hussain (2012)
The findings above indicate further that through geogrid reinforcement, material subgrade or sub-base exhibits lateral restraint whereby spread is minimized.

3. Summary and Future Implications

According to Hasan, Dang and Khabbaz et al. (2016), geogrid reinforcement as a pavement management technique has also been avowed to increase the bearing capacity of expansive soils, besides tensile membrane support. With shear stress developing between the geosynthetic and the base course aggregate, the eventuality is that the base’ lateral confining stress increases significantly. For granular materials, there is likely to be an increase in elastic modulus, which has been documented to be a response to the increase in material confining stress (Hatmoko & Suryadharma, 2017). Due to the layer increase in stiffness, the base has lower vertical strains. Another effect of the base’ increase in modulus includes roadway surface recoverable and dynamic vertical deformations. The trickle-down effect of the latter attribute is that there is likely to be a reduction in asphalt concrete layer fatigue (Johnson and Gopinath, 2016). From these observations, it can be inferred that in regions with expansive soils, a pavement management technique involving geogrid reinforcement allows for geogrid meshes to offer soil particle interlock. During loading, Malekzadeh and Bilsel (2012) observed that the latter trend assures adequate anchorage.

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