Closure to "Influence of Geogrid Properties on Rutting and Stress Distribution in Reinforced Flexible Pavements under Repetitive Wheel Loading" by Ramu Baadiga, Umashankar Balunaini, Sireesh Saride, and Madhira R. Madhav

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The writers would like to thank the discusser for sharing his views on our technical article. The conclusions drawn from this study were based on the subgrade and geogrid types considered in the study. Based on Sarsby's (1985) study, the discusser pointed out that the highest frictional efficiency of the geogrid occurs when the geogrid aperture width is $3.5 \times d_{50}$ (average particle size). However, many factors influence the frictional efficiency of geogrids used to stabilize pavements. Aperture size, nominal or average aggregate size, polymer type, subgrade condition, pavement layer thickness, and reinforcement location significantly influence optimal pavement performance (Berg et al. 2000; Hufenus et al. 2006; Kwon et al. 2005; Al-Qadi et al. 2011; Byun and Tutumluer 2017; Goud and Umashankar 2018; Baadiga et al. 2021c, b). Baadiga et al. (2021a) investigated the performance of geogrids in relation to nominal aggregate size considering three aperture sizes: polypropylene (PP) geogrids PP30S, PP30M, and PP30L (where S, M, L indicate small, medium, and large). These grids had aperture sizes of about 40×40 mm, 65×65 mm, and 80×80 mm, respectively, and the nominal size of the aggregates was 40 mm. The ratio of geogrid aperture size to nominal aggregate size corresponded to 1.0, 1.63, and 2.0 for PP30S, PP30M, and PP30L. The writers observed that the interlocking mechanism was significant when the normalized ratio ranged between 1 and 1.63. A 2.0 ratio of aperture to aggregate size was found to cause internal slippage of aggregates, leading to improper interlocking. The geogrid with a larger aperture gave the lowest pavement performance because the ribs of the geogrid carry most of the applied loads with minimal particle strikethrough of aggregates within the geogrid openings. In the present study, the normalized ratios of GG1 (polypropylene), GG2 (polyester), and GG3 (polyester) corresponded to 1.0, 0.7, and 0.6, respectively. Interlocking is a significant contributor to resistance in polypropylene geogrids, whereas polyester geogrid performance is mainly governed by frictional interaction with the surrounding material (Venkateswarlu et al. 2018; BIS 2020). Therefore, given the polyester geogrids were able to transfer shear stress predominantly through frictional interaction. The discusser pointed out that the aperture sizes of GG2 and GG3 with normalized ratios of 0.7 and 0.6 may not lead to the highest shear stress transfer efficacy. However, a point to be noted is that, unlike geogrids, polyester materials are flexible, and that manufacturing biaxial geogrids with larger openings can lead to instability in pavement applications. The closer spacing between the opening sizes of a polyester biaxial geogrid can lead to predominantly effective frictional interactions, followed by strikethrough of particles between the geogrid openings. Also, the aperture sizes of the polyester geogrids considered in the study corresponded to geogrids commonly available in the market. Hence, the conclusions drawn in this study based on the considered polypropylene and polyester geogrids are reasonable.

Further, the discusser pointed out that the observed stress reduction levels at the subgrade level due to geogrid reinforcement with GG1, GG2, and GG3 were the same for pavements overlying the 1%- and 5%-CBR subgrades. However, maximum vertical stresses induced at the subgrade level are a function of pavement base layer thicknesses, subgrade condition, and reinforcement type (Abu-Farsakh et al. 2015; Giroud and Han 2004; Han et al. 2011; Qian et al. 2013). The reported reductions in subgrade stresses of 21%, 33%, and 42% due to GG1, GG2, and GG3 geogrids corresponded to pavements overlying the 1%-CBR subgrade, and the percentage reductions differed for pavements overlying the 5%-CBR subgrade. For example, along the axis of loading, measured contact stresses at the subgrade level at the end of the loading cycles ($N = 100{,}000$) were on the order of 149, 109, 66, and 56 kPa, respectively, for the control, GG1, GG2, and GG3 reinforced pavements [Fig. 10(b) in the original paper]. The corresponding stress reductions due to three reinforcement types were 27%, 56%, and 62%, respectively, for the 5%-CBR subgrade. As indicated earlier, the total thickness of the base and asphalt layers considered in the study were of 650 and 490 mm for the 1%- and 5%-CBR subgrades, respectively. Relatively thin pavement sections experienced relatively high stress levels under the induced contact pressure through repetitive load action. The writers intended to convey similar trends in the observed behavior of reinforced pavements. As opined by the discusser, the GG3 geogrid exhibited higher reductions in stress level due to the higher stiffness of the material. Between GG1 and GG2, the identical ultimate tensile strength geogrids, GG2 performed better than GG1 due to superior resilience under repetitive load action.

Regarding Tables 5 and 6 in the original paper, the discusser points out that compared with the higher stiffness geogrid (GG3), the lower stiffness geogrid (GG2) performed better in controlling rut depth at the pavement surface but not at the subgrade for pavement overlying the 5%-CBR subgrade. From Table 6, it can be seen that the differences in rut depth reduction at the subgrade level were marginal for reinforced pavements overlying a relatively fair subgrade. The higher rut depth reductions measured at the subgrade level for GG2 and GG3 could be due to distribution of applied loads over a wider area. The writers used vertically placed rutting rods to measure rut depth levels at the subgrade level. This procedure was not straightforward. Certainly, there is scope to investigate rut depth variation at the subgrade level due to identical reinforcement and reinforcement of varied stiffness over different subgrades. The writers also agree with discusser that the study findings are worthwhile in determining a suitable geogrid for pavement applications.

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