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Numerical Study on Implication of Geogrid in the Pavement Construction: A Case Study on Ring Road Section, Khasibazaar Kathmandu

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Abstract

This research studies about the behavior of geogrid in pavement construction contrast its results with the unreinforced case. A section of the Ring road, Khasibazaar Kathmandu is taken to study the behavior using a numerical simulation method with the help of the Finite element method (FEM) modeling software, Plaxis-2D. The strata of the road (base, sub-base, capping layer and sub-grade) are modeled using the Mohr-coulomb model, while the geogrid and bituminous layer are modeled as linearly elastic. Static load with contact pressure 550 kPa is used in the study. Surface deformation was selected as main criteria to study the benifit of geogrid in pavement. Surface deformation is found to be decreased by the inclusion of geogrid. Maximum reduction in the surface deformation is observed when geogrid is placed at the interface of subbase and capping layer in all pavement thicknesses. Surface deformation has reduced up to the maximum value by 13% in the thin pavement of thickness 790mm. Based on maximum reduction in surface reduction optimum location of geogrid reinforcement is observed at interface of subbase and capping layer. Inclusion of geogrid in pavement construction is found to have a significant improvement in pavement behavior, but its use is more pronounced in the case of thin pavement thickness. Also the effect of geogrid is more pronounced in case of overloading of vehicle.

Keywords

Geogrid, Surface Deformation, Pavement, Optimum Location, Finite Element Method

1. Introduction

Pavements are built for supporting the load induced by the traffic vehicle. Pavement distribute the traffic load safely to the subgrade soil and are designed to prevent the bearing failure of the subgrade. Pavements are constructed to provide a safe and comfortable riding surface with smooth and skid resistant surface. Traditionally flexible pavement is made up of a wearing course with a bituminous binder material (such as asphalt, tar or asphaltic oil) and a base, subbase course layer of the granular materials on the top of the subgrade layer. The main function of base and subbase layer is to provide a stable platform for construction of bituminous layer and reduction in compressive strain at the top of subgrade i.e do not overstress the subgrade soil. Subsisting weak soft subgrade soil is a common problem in road construction; the quality of the subgrade primarily influences the life, serviceability and performance of the road. Pavements constructed on weak soft (low shear strength, CBR and stiffness properties) subgrade have various problems among which rutting is the main. Rutting is the permanent deformation due to the combined effect of compressive and shear strain along the wheelpath. Due to rutting, pavements have to be resurfaced frequently requiring a significant amount of government budget every year. However rut is normally formed by the failure of subgrade so surface overlay will not be a long-term solution.

Current construction practices require avoiding the undesirable weak, soft subgrade replacing with the material of better mechanical properties. But if the mechanical properties of weak soft subgrade can be improved, we need not to replace the weak soft subgrade. Mechanical properties are improved by the chemical stabilization (cement, lime, fly ash. . . .) that improves the strength, reduces the plasticity or use of geosynthetics that increases the bearing strength and reduces the stress and strain to weak subgrade and decreases the plastic deformation i.e. rutting (Koerner 2012). In order to address the problem of weak, soft, unavoidable, unpredictable subgrade and prolonging the service life, minimize the life cycle cost polymer geogrid have been introduced with the motive (incitation) of improvement of structural performance of pavement (to minimize rutting in the pavement).

This research studies the differences in behavior of unreinforced and geogrid reinforced road pavement with respect to surface deformation (rutting) as it is used to solve rutting problems in cost effective manner. There have been limited similar studies using geogrid in the context of Nepal though it's dire need is felt. This research studies the contrasting behavior between the pavement with and without the use of geogrid reinforcement using finite element modeling -utilizing index and engineering properties of sub-grade soil-obtained from laboratory- as input parameter for the model.

A section of Ring road near Khasibazaar is taken for the study. Figure 1 presents the location map of the study.

Figure 1: Location map of study area

2. Literature review

The main cause for pavement failure (distress) and ruts in the flexible pavements is weak subgrade soil [1].The failure mechanism in subgrade soil is primarily due to two factor: Densification and repetitive shear deformations of pavement component layers [2]. The failure mechanism engender by densification is related to quality control: lack of inadequate compaction or compaction at moisture level other than Optimum Moisture Content (OMC), use of gap-graded base and sub-base material. Use of geogrid was introduced to reduce the failure due to repetitive shear deformation in pavement. It controls the failure in three different mechanisms: lateral restraint, increase bearing capacity and tension membrane effect [3]. In lateral restraint mechanism, using lateral confinement increases the modulus of the base-course. When the modulus of the base course is increased, the vertical stress distribution to the subgrade is improved and the vertical strain on the top of the subgrade is decreased. The base aggregate layer interacts with the geogrid, transferring shear load from the base layer to a tensile load in the geogrid. Likewise, in the case of increased bearing capacity, the geogrid reinforcement can reduce shear loads on the subgrade and offer vertical confinement outside of the loaded area. The sub-grade's bearing failure mode should shift from punching without reinforcement to widespread failure with optimal reinforcement. This results in the increment of bearing capacity of the sub-grade. Finally, the vertical stress distribution is improved because of tensile stress in deformed membrane. Vertical deformations create a concave shape in the geosynthetic, resulting in the tensioned membrane effect. The tension developed in the geosynthetic helps in the support of the wheel load and reduces vertical stress on the subgrade, however this effect requires significant rut depths.

Additionally, study of geogrid reinforcement in pavement has been progressing throughout the years. Hass(1984)[4] through laboratory experiment showed that inserting a polymeric grid at the bottom of the asphalt concrete layers of various thicknesses reduced the maximum vertical compressive stress at the top of the subgrade by 20%–40%. Similarly, he went on further to find out that the addition of geogrid to the pavement test section increased the number of loading cycles by a factor of 3 or reduced the thickness of the base course layer by 25%-50%. The rut depth reduces from 20.3 mm for the unreinforced system to 11.6 mm for the reinforced system after 10,000 load cycles. Reduction in rut depth with inclusion of geogrid was higher for weaker subgrade [5].Barksdale et.al(1989)[6] demonstrated that geogrids were superior to geotextiles when used as reinforcement and found that geosynthetic benefit is significant for pavement with a weaker subgrade. Dondi(1994) [7] modeled and analyzed three-dimensional geosynthetic reinforced flexible pavement with a static and found out that shear strain and stress transmitted to the top of the subgrade are reduced and in the reinforced section, the vertical displacement of the loaded area was reduced by 15–20 percent.

Wathugala et.al(1996) [8] concluded that rut depth is reduced by approximately 20% for a single cycle of load when geogrid is placed at base subgrade interface. Perkins(2001)[9] performed laboratory test varying the stiffness of geogrid, base thickness and subgrade strength and concluded that for the weak subgrade, rut can be reduced to 50 percent at 10000 cycle of load and give higher traffic benefit ratio. Higher the stiffness of geogrid higher will be traffic benefit ratio. Saad et.al(2006) [10] used the commercial FE program ADINA to perform dynamic 3-D FE modeling on geosynthetic-reinforced flexible pavements subjected to a dynamic load with a triangle wave of 0.1 second duration. This study determined the reinforcing efficiency of geosynthetics, such as base quality, thickness, and subgrade quality and found out that geosynthetic reinforcement has a far greater potential for reducing rutting strain and surface deflection when used in a thin base pavement with only a few inches of thickness. Abu-Farsakh et.al(2013) [11] found that reduction in the lateral strain in the base and subgrade and reduction in the surface deformation was observed due to geogrid reinforcement. Neves et.al(2016) [12] carried out study varying the subgrade quality, traffic conditions, pavement thickness and material. Reduction of strain and surface deformation was observed due to geogrid reinforcement on subgrade. The use of the geogrid reinforcement observed that 57 % of the rutting was decreased [13].

3. Methodology

Based on pavement design guidelines of department of road of Nepal, a finite element study of the influence of geogrids on pavement design was carried out. 5, 10, 50, 100, 150 million cumulative standard axle load (80 kN) is taken as a design traffic volume for the design of pavement thickness. First of all, Ring road local site Khasibazaar, Kathmandu was selected for the sampling the sub-grade soil. All the in-situ tests were conducted at site and soil sample was transported carefully to the lab preserving its initial condition for further laboratory test. Pavement layer consists of capping layer, subbase, base and bituminous layer. Table 1 presents the thickness of the pavement layer based on the traffic volume and subgrade characteristics.

Pavement material subbase and base are taken as crushed limestone aggregates. Capping layer is required due to low stiffness and CBR of subgrade material. Two-dimensional non-linear finite element model with assumption of plain strain condition, which can describe the stress and strain in pavement is used. The final dimension of model along x-axis is 13.75 m and depth of the model along y-axis is taken 8 m for analysis. Both wheeled load with center to center spacing of 1.8 m is simulated considering the contact area to be rectangular (length 321 mm and breadth 220 mm) and static loading with a wheel load of 550 kPa which is equivalent to single axle wheel load of 80 kN (40 kN on each side wheel) is adopted in analysis. Figure 2 presents the finite element numerical model of pavement. Sub-grade, capping layer, sub-base and base was modeled using Mohr-coulomb (MC) constitutive model while geogrid and bituminous layer are modeled using linear isotropic elastic model. Table 2 and Table 3 presents the properties of the material used in the modeling. The interface between geogrid and other pavement material is considered rigid i.e. there will be no slipping when rutting occurs. Conventional kinematic boundary condition is used in model with no normal displacement in two vertical sides and bottom of model, allowing top surface to remain free of restrain [14]. 15-noded triangular element mesh with a coarseness factor of 1 is used to model the pavement material whereas geogrid and loaded area is locally refined with coarseness factor of 0.5.

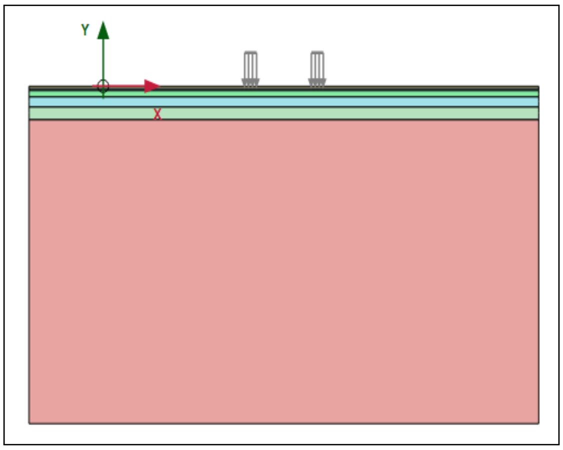

Figure 2: Finite element model of pavement

Table 1: Pavement layer thickness based on the traffic volume and subgrade characteristics

CBR 2 %						
Cumulative Traffic msa	Total Pavement Thickness (mm)	Pavement Composition				
		Bituminous Surfacing		Granular Base (mm)	Granular Sub-base (mm)	Capping layer (mm)
		Wearing Course (mm)	Binder Course (mm)			
5	790	50 AC	50 DBM	150	240	300
10	850	50 AC	100 DBM	200	200	300
50	925	50 AC	100 DBM	250	225	300
100	950	50 AC	100 DBM	250	250	300
150	975	50 AC	150 DBM	250	225	300

Table 2: Modeling parameter taken for the base, sub-base, capping layer and sub-grade material

S.No.	Parameters	Subgrade	Capping layer	Base	Subbase	Bituminous layer
1	Type of model	M-C	M-C	M-C	M-C	Linear elastic
2	Cohesion, c (kPa)	12	12	1	2	
3	Angle of internal friction, ϕ (Degree)	23	23	43	40	
4	Modulus of Elasticity, E (kPa)	20000	99588	279100	157752	2000000
5	Poisson's ratio, ν	0.35	0.35	0.35	0.35	0.35
6	Unsaturated unit weight $\gamma_{unsat}(kN/m^3$	15.36	16	22.54	21.52	22.3
7	Saturated unit weight $\gamma_{unsat}(kN/m^3$	17	17	23	22	
8	Material type	undrained	undrained	drained	drained	Nonporous
9	CBR	2	15	92	52	

Table 3: Modeling parameter taken for the geogrid material

Material	Material Model	Axial Stiffness
Geogrid	Linear Elastic	2000kN/m

4. Results and Discussion

Finite element numerical analysis is carried out in both unreinforced and reinforced pavement varying the position of geogrid. Deformation is selected as main criteria for the discussion of results from the numerical analysis. Figure 3 and Figure 4 presents the surface deformation of unreinforced case and geogrid reinforced at interface of subbase and capping layer in the pavement designed for 5 msa traffic volume i.e. 790 mm pavement thickness including the thickness of capping layer. Figure 5 presents the surface deformation for unreinforced and geogrid reinforced pavement with varying pavement thicknesses.

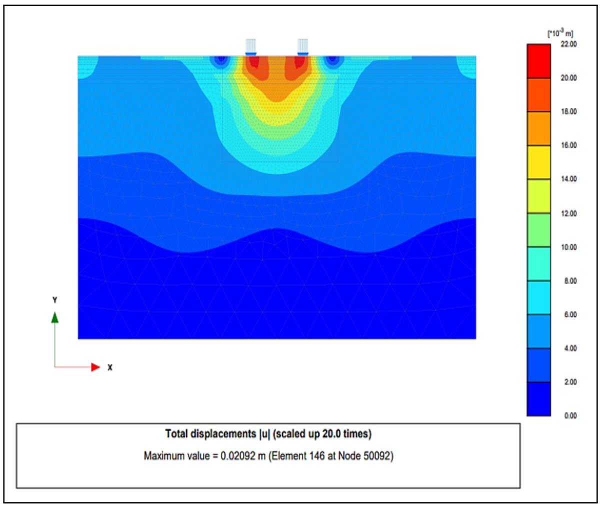

Figure 3: Surface deformation in the unreinforced pavement of thickness 790mm

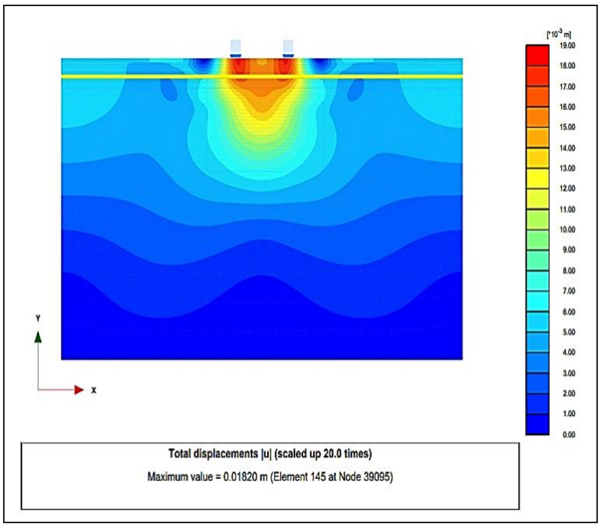

Figure 4: Surface deformation in geogrid reinforced at the interface of subbase and capping layer with pavement thickness of 790mm

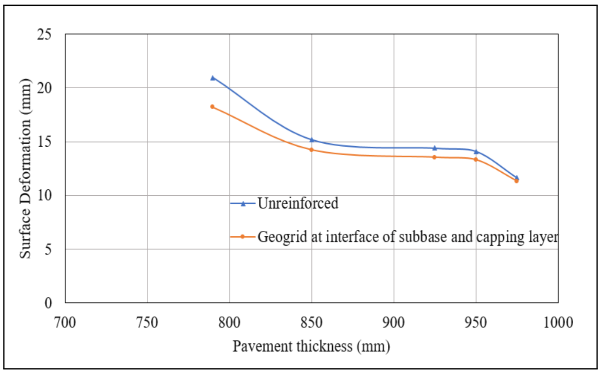

Figure 5: Surface deformation in the pavement for different pavement thickness

It is observed that surface deformation is reduced by the use of geogrid-reinforcement. In all the pavement thickness minimum reduction in surface deformation is observed when geogrid is placed at interface of bituminous and base layer while maximum reduction in surface deformation is observed when geogrid is placed at interface of subbase and capping layer. Maximum 13 % surface deformation reduction is observed when geogrid reinforcement is used in thin pavement of thickness 790mm including the thickness of capping layer. With increase in pavement thickness, percentage reduction in surface deformation with an inclusion of geogrid is reduced. Figure 6 presents the result of percentage reduction in surface deformation in geogrid reinforced pavement compared with unreinforced pavement. This reduction in the surface deformation is due to reduction in lateral,compressive and shear strain in the pavement resulted from combined effect of reinforcement mechanism of geogrid: lateral restraint,increase bearing capacity and tension membrane.

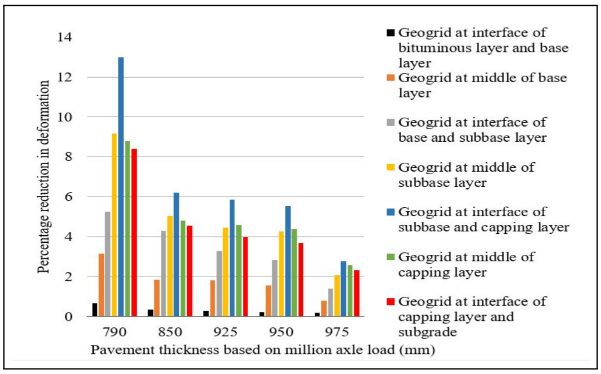

Figure 6: Percentage reduction in surface deformation in geogrid reinforced pavement compared with unreinforced pavement

4.1 Variation of geogrid stiffness

Pavement thickness of 975 mm with a capping layer, subbase, base and bituminous layer is taken for the study with a varying geogrid stiffness. Geogrid is placed at interface of capping layer and subbase where there is maximum reduction in surface deformation. Geogrid stiffness has been varied from 500 to 3000 kN/m. Figure 7 presents the percentage reduction in surface deformation at varying stiffness of geogrid. With an increasing geogrid stiffness more surface deformation has been reduced.

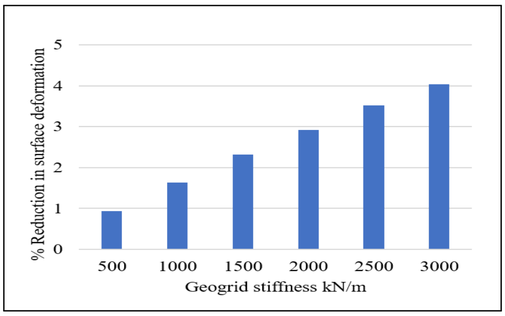

Figure 7: Percentage reduction in surface deformation at varying geogrid stiffness

4.2 Variation of load

Pavement thickness of 975 mm with a capping layer, subbase, base and bituminous layer is taken for the study with a varying load. In general, the design of pavement based on 80 kN axle load i.e. contact pressure of 550 kPa but sometimes it may vary. So for the parametric study load 275 kPa, 550 kPa and 825 kPa are taken. With an increasing wheel load deformation has been increased. With an 50% increase in design load surface deformation is increased by four times. Figure 8 presents the surface deformation for unreinforced pavement at different loading conditions. When the load is half the design load the inclusion of geogrid have no any significant effect but when load is increased by 50% of the design load, reduction in surface deformation will be higher. Maximum reduction in surface deformation, when applied load of 825 kPa is 23.5% when geogrid is placed at top of subgrade. These results demonstrate that the benefit of geogrid is more pronounced when vehicle load is more than design load. Reduction in surface deformation has changed from 2.7% to 23.5% as load changes from 550 kPa to 825 kPa. Figure 9 presents the percentage reduction in surface deformation due to inclusion of geogrid at varying wheel load.

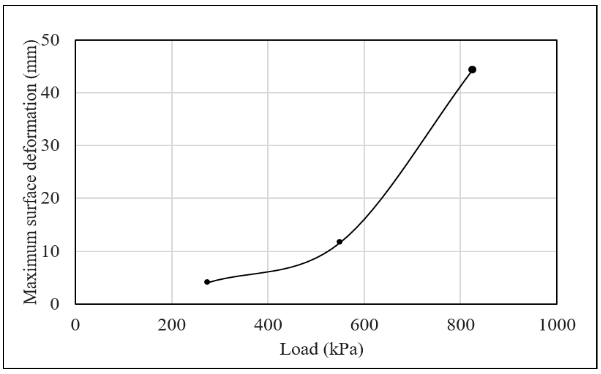

Figure 8: Surface deformation for unreinforced pavement at different loading condition

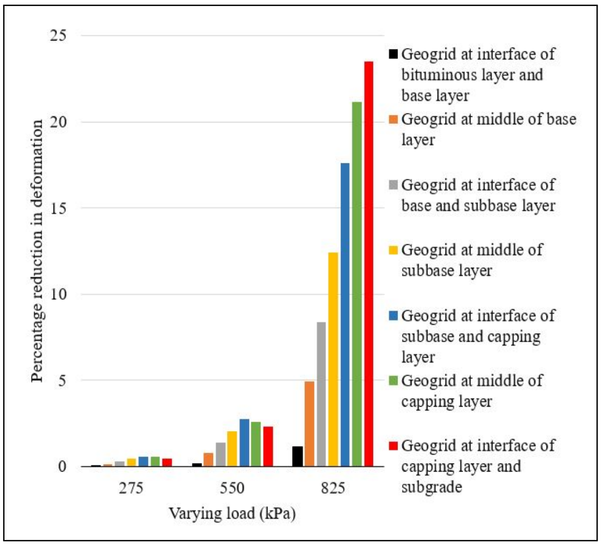

Figure 9: Percentage reduction in surface deformation due to inclusion of geogrid at varying wheel load

5. Conclusion

A series of finite element numerical analysis was performed to study the behavior of unreinforced and geogrid reinforced pavement. Simulation were performed at varying: pavement thickness, position of geogrid, geogrid stiffness and loading condition to see how these parameter influence the favorable benefits of geogrid reinforcement on rutting. Following conclusion can be made from the study:

1. The application of geogrid reinforcement results in a significant improvement in pavement behavior. Surface deformation (rut) is reduced maximum up to 13% in reinforced pavement compared to unreinforced pavement with pavement thickness 790mm.

2. The results and observations regarding the reduction in surface deformation, lead to the conclusion that the geogrid potential for decreasing surface deformation is more pronounced when geogrid is used in a thin pavement thickness than a thick pavement thickness.

3. From the result of reduction in surface deformation, it is concluded that optimum location of geogrid is subbase-capping layer interface.

4. With an increase in geogrid stiffness, more reduction in surface deformation is observed as stiffness is varied from 500 kN/m to 3000 kN/m.

5. As load increases from 550 to 825 kPa for unreinforced pavement deformation increases by approximately to four times. When the traffic load increases from 550 kPa to 825 kPa reduction in surface deformation has increased from 2.7% to 23.5% demonstrating that the effect of geogrid is more pronounced when the traffic loading is increased. More degradation of pavement can be minimized when geogrid is used.

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