A Critical Review of Subgrade Soil Reinforced with Geo-synthetics

Ghusoon H Oleiwi¹, Haider H Aodah², Nesreen K Al-obaidy³, Kasim Alomari⁴

¹,²,³,⁴Civil Engineering Department University of Thi-qar, Nasseriya, Iraq

Email: ghusoon.hassan@gmail.com

Abstract. Recently, the application of geosynthetics in the reinforcement of weak subgrade is expanded dramatically. However, selection of the geo-material that fits site conditions and soil type is crucial to achieving the success of the overall performance of such improvement. Also, the road life and cost construction are significant keys for evaluating this type of ground treatment. This paper presents an overview of the subgrade strengthening with geosynthetics to acquire a better understanding of the technique and to provide a clear guide for transportation and geotechnical engineers. The rutting failure along with its main causes are highlighted briefly. The types of geosynthetics, their applications and functions are also listed. Besides, the effect of soil type and properties on the efficiency of geofabrics-subgrade reinforcement are presented. Moreover, the effectiveness of geosynthetics on the road’s life and construction costs are discussed. Findings of the reviewed studies referred to the contributions of the technique in strengthening the soft subgrade, extending the service road life, reducing the construction cost and reducing the associated rutting deformation. Most studies presented in this paper have proven the efficiency of utilizing geosynthetics in the pavements to minimize the vertical stress in the subgrade under the wheel path. However, the influence was related to the geo-material type and site-specific conditions.

Keywords. Rutting, subgrade soil, geo-synthetic reinforcement

1. Introduction

Over the last four decades, geo-synthetics have been progressively used in the geotechnical and the environmental engineering due to their suitability with soils, rocks and other related materials and also, for the advantages of the functions that they have [1, 2]. An example of their applications in the ground improvement when they are employed is embracing a conventional stone column installed into weak or collapsible soil for providing the required confinement [3, 4]. Moreover, they are powerfully connected to the transportation and highway constructions, since observations showed a good performance of geo-synthetic-reinforced sub-bases represented by less associated rutting. The latter considers one of the pavement distresses which have a huge influence on the performance of the roads. The excessive rutting which usually associated with weak subgrades can cause increasing in the road maintenance costs and leading to periodic weaknesses to the traffic [5]. This paper presents a review of research studies that investigated geosynthetics materials use in pavements layer, these comprehensive studies display an introduction of the rutting failure, also present its main causes, they also covered the definitions of the geosynthetics materials, and discussed the efficiency of reinforcement the geofabrics-subgrade by using different soil types and number of layers with varies geosynthetics properties. Also, the effectiveness of geosynthetics on roads life and construction cost are discussed. The main goal is acquiring a better...
understanding of the technique and to provide a clear guide for the transportation and geotechnical engineers.

2. Rutting in Roads

One of the most noticeable defects on the roads is the rutting failure. This failure is so prominent in the situations where the traffic flow is mandatory standing or transportation movement is at a slow pace. The increase in the intensity of loading on the pavement eventually causes a rutting failure and accelerates other weaknesses and faults in the road such as cracking and potholing to occur. Additionally, the increase in the number of trucks and heavyweight vehicles can also contribute to premature pavement failure [6]. Rutting is one of the main damages related to road pavements. This phenomenon is usually demonstrated as a surface longitudinal depression within the wheel paths due to the consolidation or the horizontal movement of the subgrade layer under repeated loads [7], see Figure 1.

![Figure 1. Longitudinal surface depression under wheel paths](image1)

Commonly, there are two main causes of rutting distortion in asphalt pavements; the accumulative permanent deformation in the asphalt surface layer and the permanent deformation of subgrade or underlying stratum [6]. If the pavement rutting occurs in the asphalt mix itself, the performance of the underlying layers will be good and their boundary lines will not be influenced by the distress occurring near the surface of the weak asphalt layer, as shown in Figure 2.

Rutting, in this case, can be the result of an uneven asphalt mix, heavy wheel loads, and/or high pavement temperature. Rutting of such conditions is frequently noticed at intersections, bus stops, ramps, airport runways, or high loading locations [7]. However, a large format of the surface rutting could transfer and affect the other layers underneath over time and with increasing the traffic loading [6].

![Figure 2. Rutting as a result of a weak asphalt layer redrawn after Saeed.](image2)

Thickening design for the applied traffic flow or the strength characteristics of the underlying materials. Also, moisture infiltration into the base layer or subgrade layer can play a significant role in weakening these layers to the limit at which they deform endurably under a repeated applied load. Afterward, the rutted circumstance in the underlying stratum is reflected in the surface of the pavement as illustrated in
Figure 3 [8]. Moreover, rutting failure can be produced as a result to a deficiency in compaction of the subgrade layer as stated by Guler and Atalay. [7].

Over the road service life, there are small permanent deformations start and increase gradually under application or repetition and often follow in later stages by a disorder along the rut sides. The decreasing of thickness in the rutted portions can accelerate fatigue cracking and subsequent loss of the road serviceability [9]. According to the American Association of State Highway and Transportation Officials [10], rutting distortion does not only decrease the lifetime of the road but also cause a serious safety issue for road users. Once the vehicle moves along the portion subjected to the rutting of the pavement, steering becomes problematic and uncomfortable. Moreover, if rainwater pools are formed in the rutted wheel path, it can consequence in hydroplaning and the resulted spray could affect the visibility. By considering the abovementioned effects on the driving security and performance of the drivers, numerous countries admit different allowable rut depths according to their standards and specifications for highway road failure criteria [8].

3. The Reinforcement with Geo-synthetics

Geo-synthetics are man-made products that mainly manufactured from polymeric materials such as polypropylene, polyethylene, and polyester. They are usually shaped in many forms such as geotextile, geo-grid, geonet, and geocell. Figure 4 shows some typical of geosynthetics [2]. A geo-synthetic-reinforced sub-base is usually fabricated above rather soft subgrades and tolerates for thinner stratum of base and surface courses above [11]. The conventional and typically expensive alternate method for highway construction consists of replacing soft subgrades with thick granular and/or base course layers to grante the required support of the pavement surface [11]. Thus, geo-synthetics products are mostly used in roadway network (paved and unpaved) more than other types of civil engineering structures, especially in the rural areas where it requires to reinforce and support the weak soil layer for provisional or long-lasting roads [2].

Recent investigations demonstrated strengthened roads with natural ingredients like trees, branches, and other plant fibers. More recently, a development from those natural materials to stronger, more durable, manmade fabrics (geo-synthetics) has occurred. Each type of geo-synthetics may have one or more of the following tasks as discussed by Shukla. [2]:
• Separation: separating two materials or soil layers by geo-synthetic can prevent the materials from migration thus the function of each material can last for a long term.
• Reinforcement: geo-synthetics produce tensile forces that can control the stability of the soil.
• Stiffening: geo-synthetics work on strengthening the weak soil and increasing its stiffness due to the offered high tensile strength and the capability to the elongation that will resist the stress.
• Filtration: the geo-synthetics is used to prevent the fine particles from passing throw it while it allows the water to pass.
• Drainage: geo-synthetics permit the liquid to flow along the surface of the structure.

Figure 5 shows the section in a pavement layer and illustrates different possible geo-synthetics functions.

Figure 5. Potential functions of geo-synthetics in a pavement layer redrawn after Christopher. [12]

It is worth mentioned here that both products, geotextiles, and geogrids are largely used for two main reasons: separation and reinforcement with a priority to the latter [13]. Geotextiles are mainly classified into woven, nonwoven, and knitted fabrics. They are employed according to the requirements of the projects [2]. The interaction between the composite of the soil and geotextile material can enhance the stiffness and load-carrying capacity of the soil itself [2]. The geogrid reinforcement mechanisms include: the lateral confinement, the increasing of the bearing capacity of the reinforced soil with geogrids, and the tension membrane effect [14]. The intersections of the longitudinal and transverse ribs are called “junctons” and the internal space among ribs is called “aperture” which is ranging between 10 and 100 mm. Geogrid is classified into three types according to their aperture: uniaxial geogrid, biaxial geogrid, and triaxial geogrids [9]. In comparison to the uniaxial and biaxial geogrids, the triaxial geogrid provides a higher tensile strength because of the productivity of the tensile strength in all directions and consequently a higher stiffness can be obtained [14]. On the other hand, the ribs of geogrid are stiffer than the fabric of geotextile and that gives a higher tensile strength [2]. The strengthening function by geo-synthetics is attained via improving the mechanical properties (peak tensile strength, modulus of elasticity, upper and lower yield strength, etc.) of the reinforced soil [15]. It is well known that the soil itself is good in compression and weak in tension for that reason, reinforcing the soil with the geo-synthetics leads to an increase in the tensile strength and then in the bearing capacity of the reinforced soil, thus the reinforcement with the geo-fabrics can be considered a good solution for many problems that related to the poor capacity of the soil [2].

4. Effect of Soil Type and Properties on the Efficiency of Geofabrics-Subgrade Reinforcement

Many researchers conducted studies on strengthening locally available weak soils with geosynthetics. The technique is a cost-effective and beneficial solution for mechanically stabilized earth structures [16, 17]. In road design, the weak subgrade without reinforcing possesses a low bearing capacity and it is required to increase the thickness of pavement [18]. The reinforcement of the weak subgrade with woven or nonwoven geotextile is presently a widespread method [19]. In comparison to geotextiles, the geogrids also can offer more pullout resistance for all the soils deliberated due to the passive resistance developed along the ribs of this type of geo-fabrics [20]. Since the properties of the soils are different according to the regions and locations, a different type of soil can be successfully reinforced by various types of geosynthetics but the degree of enhancement in both resilient and permanent strains is basically related to the stiffness of the geosynthetics and soil type [21]. For many soil types, using geo-fabrics
shows a good performance. For an instant in sandy soils, with grains size up to 2 mm, a variant type of geogrids showed similar effects as interaction does not lead to appearing of interlocking effect because of the huge difference between space of geo-grid ribs in comparison to soil particle size [22]. For cohesive soils, it was concluded that those soils can be successfully strengthened by various types of geogrids. Although the better reinforcement effect was achieved with the same geosynthetics for the sandy soils [16]. In expansive soil which is characterized by a high plasticity index and is exposed to swelling and contractive deformations, the geogrids placed at the subgrade-pavement interface contributed to absorbing or smoothing the swelling pressure and considerably decreasing truck geometry damages observed by monitoring systems [23]. Inclusion of the biaxial type geogrids in such soil considerably increases the strength of these weak soils such that the highest subgrade strength is attained by placing the geo-grid layer at 3/4 of the soil depth for a single layer [24]. However, the increase in moisture content can noticeably minimize the reinforcement efficiency due to the drop in the suction of the saturated expansive clays with the increase in moisture content and the potential development of excess pore water pressure which can contribute to reducing both the effective stresses and the shear resistance [16]. Studies showed that soil particle size has a significant influence on the soil geosynthetics interface. Soils with higher average soil particle size D50 showed an increase in the soil geosynthetics interface resistance [17]. It is established that the efficiency of the geogrids soil interlock is governed further to the properties of the geogrids (aperture size and the in-plane stiffness of the geo-grid ribs and junctions), by the soil grain size [18, 22]. For each type of soil, there are optimum grid aperture dimensions based on the soil particle size [25]. Geo-grid’s opening has to be related to the grain size of soil, so the opening of geo-grid ranges between 2-3 times bigger than the average particle size D50 of soil [22]. The insertion of thegeo-grid significantly improves the low strength of poor soils, which was reflected in terms of the higher CBR values. The investigation presented by Yadav et al. [13] indicated that the strength of the subgrade is considerably improved positively by the arranging of the geo grid at different depths. It was concluded that reinforcing the weak soil with geosynthetics material at different locations enhances the penetration resistance and therefore CBR strength in both un-soaked and soaked conditions. In the case of geotextile and for soil specimen with H in height, it was concluded that placing this geo-material in the first quarter (H/4) from the top was considered as an optimal height [17]. Besides, the highest increase in the CBR value was reached when geogrids were placed at (H/5) from the top of the sandy silt soil specimen. The CBR value increases by 50-200% [26].

5. Effectiveness of Geo-synthetics on Roads Life and Construction Cost

The application of geo-synthetics in the situ overlying such weak subgrade can significantly enhance the overall performance of the roads through lessening permanent vertical deformations and rising lateral restraint capability that leads to expanding pavement service life [5]. The road life represents the total period starting from the beginning of construction to the time at which a major reconstruction or rehabilitation is required [27]. For any application in road pavement, the geo-materials can easily extend the life of the pavement by more than 5% [28]. IGCSE I. [29] explained how the service life of the paved road is extended by using geotextile strengthening with altered numbers and locations of layers. Sa’adi et al. [30] confirmed the following values:

- Using one strengthening layer of geo-synthetics causes the road cost to increase by only 14% but it also results in decreasing rutting by 85%.
- Using two strengthening layers of geo-synthetics causes the road cost to increase by only 28% but it also results in decreasing rutting by 93%.
- Using three strengthening layers of geo-synthetics causes the road cost to increase by only 42% but it also results in decreasing rutting by 96%.

In addition to the road life, the cost could be considered as a controlling factor to assess the efficiency of the geo-fabrics employed in the roads [31, 32] as using geo-fabrics contribute to reducing the base course thickness under the same number of load repetitions [33]. Thus, the additional material thickness at the interface of the sub-base layer, base layer, and the soil subgrade, can be dropped to about 50%,
and that in its role contributes in maintaining the project at cost-effective [2, 34]. The cost by involving geo-synthetics was predicted ranging from less than 1% up to 5% of the initial construction cost [27]. Further to the geo-synthetics role in stopping premature failure of the subgrade, separation from the base layer, and enhancing base support, they can contribute in reducing the cost insurance that covers the proposed surface rehabilitation and design pavement life [28]. The cost profits of using geo-materials may be earned immediately, the long-term or both of them. The immediate saving can be achieved through simplicity of installation or lessening of selected soil materials and/or increasing the speed of construction [28]. It is worth mentioning that some investigators relied on a new analysis which is called life-cycle cost analysis (LCCA) and it was a useful economic tool in producing a reliable transportation investment decisions, that takes into consideration costs to users of the road in addition to costs to agencies [35]. (LCCA) is needed to quantify the benefit-cost ratio of geo-synthetics application in pavements.

6. Conclusions

Strengthening the soil with geotextile improves the CBR and increase the load-carrying capacity of the granular soil as observed during several CBR tests were taken to find the effect of geotextile and the grading of the granular soil on the bearing capacity of reinforced soils for unpaved roads tests was carried out by Rudramurthy and Vikram. [36] who noticed also, a decrease in the surface deformation which occurs upon the stress distribution enhancement. According to the reviewed studies in this paper referred to the contributions of the technique in the field of strengthening soft subgrade. Over the road service life, permanent deformations appear and progressively increased under each application or repetition and often follow in later stages by a disorder along the rut sides. As a result of decreasing thickness in the rutted portions that can accelerate fatigue cracking and subsequent loss of the road serviceability. Using geosynthetics as a reinforcement consider one of the prevention methods against rutting. The studies illustrate function of geosynthetic types. It was observed that both products geotextiles, and geogrids are largely used for separation and reinforcement with a priority to reinforcement by modifying the bearing capacity of weak soils. However, the influence was related to the soil and the geosynthetic materials types, and site-specific conditions. It was found that efficiency of the geogrids soil interlock is governed further to the geogrids properties (aperture size and the in-plane stiffness of the geo-grid ribs and junctions) by the soil grain size. Also, taking into account an effect on increasing the life of the road and thus reducing the maintenance costs, which consider a significant indication of the effectiveness of geosynthetion the roads. For the geosynthetics-soil remedy, location and number of geogrids placed in the soil layers have a large effect on the CBR value.

References

[1] Palmeira E M 2008 Soil-geosynthetics interaction: Modelling and analysis mercer lecture 2007-2008. In Proceedings of the 4th European Geosynthetics Conference. pp 1-30.
[2] Shukla S K 2017 An introduction to geosynthetic engineering. CRC Press, Taylor and Francis, London.
[3] Al-Obaidy N, Jefferson I and Ghataora G 2016 Treatment of Iraqi collapsible soil using encased stone columns. Japanese Geotechnical Society Special Publication, 2(14), pp 564-569.
[4] Al-Obaidy N 2017 Treatment of collapsible soil using encased stone columns (Doctoral dissertation, University of Birmingham).
[5] Calvarano L S, Leonardi G and Palamara R 2017 Finite element modelling of unpaved road reinforced with geosynthetics. Procedia engineering. Elsevier, 189, PP 99-104.
[6] Chilukw N and Lungu R 2019 Determination of layers responsible for rutting failure in a pavement structure. Infrastructures, 4(2), P 29.
[7] Guler E and Atalay I 2016 The Effects of geosynthetics on mitigation of rutting in flexible pavements. June. https://doi.org/10.14311/ee.2016.101
[8] Saeed H 2013 Rutting of asphalt pavement. p 15.
[9] Ghafoori N and Sharbaf M 2016 Use of gagrid for strengthening and reducing the roadway Structural Sections NDOT Research Report No. 327-12-803Nevada. Dept. of Transportation.
[10] AASHTO A 2008 Mechanistic-empirical pavement design guide: A manual of practice.

[11] Maxwell S 2005 Effectiveness of geosynthetics in stabilizing soft subgrades. Wisconsin Highway Research Program.

[12] Christopher B R 2010 A design workshop on geogrids in roadway and pavement systems.

[13] Yadav P M G, Bharath S, Kumar M M, Reddy M N and Reddy G C 2018 Usage of geogrid in flexible pavement design. *International Journal of Engineering Sciences & Research Technology*, 7(4), pp 144–153.

[14] Adams C A, Amofa N Y and Boahen R O 2014 Effect of geogrid reinforced subgrade on layer thickness design of low volume bituminous sealed road pavements. *IRJES*, 3, pp 59-67.

[15] Al-Omari R R and Fekhedralin M K 2012 Measurement of tensile properties of geogrid. In Second *International Conference on Geo technique Construction Materials and Environment, Kuala Lumpur, Malaysia*. PP 19-21.

[16] Mittal A and Shukla S 2019 Strength improvement of poor subgrade soil reinforced with polyester biaxial geogrid. *Jordan Journal of Civil Engineering*, 13(2), pp 214–225.

[17] Unni A, Mithrathmajan A K, Sruthy Rajkumar V and Meril Neenu M B 2017 Efficacy of geosynthetics in subgrade stabilization-A comparative study in laterite soil. https://doi.org/10.15680/IJRSET

[18] Anitha J 2017 Effect of geosynthetic on soft subgrade–literature review. *International Research Journal of Engineering and Technology*, PP 1446-1448.

[19] Deb K and Konai S 2014 Bearing capacity of geotextile-reinforced sand with varying fine fraction. *Geo mechanics and Engineering*, 6(1), PP 33-45.

[20] Choudhary A K and Krishna A M 2016 Experimental investigation of interface behaviour of different types of granular soil/geosynthetics. *International Journal of Geosynthetics and Ground Engineering*, 2(1), P 4.

[21] Kamel A M, Chandra S and Kumar P 2004 Behaviour of subgrade soil reinforced with geogrid. *International Journal of Pavement Engineering*, 5(4), PP 201-209.

[22] Mulabdić M Minažek K and Kaluđer J 2018 January Geogrids-what is important. In *5th International Conference on Road and Rail Infrastructure*.

[23] Keif O 2015 February The hybrid geosynthetic solution for rail track on expansive clay. *In Geosynthetics Conference*, Feb pp 15-18.

[24] Chunhua H 2018 Primary causes and treatment countermeasures of damages of pavement in wuhan: A field investigation. *MS&E, 382*(5). 052047.

[25] Saleh Ahmadi M and Nikbakht Moghadam P 2017 Effect of geogrid aperture size and soil particle size on geogrid-soil interaction under pull-out loading. *Journal of textiles and polymers*, 5(1), PP 25-30.

[26] Suresh A, Jose D and Malayakal G J 2018 CBR characteristics of soils stabilised with geogrid.

[27] Laurinavičius A and Oginskas R 2006 Experimental research on the development of rutting in asphalt concrete pavements reinforced with geosynthetic materials. *Journal of civil engineering and management*, 12(4), PP 311-317.

[28] Christopher B R 2014 September cost savings by using geosynthetics in the construction of civil works projects. In *Proceedings of the 10th International Conference on Geosynthetics, 10ICG, Berlin, Germany*. pp 21-25.

[29] IGCSE I 2013 Transcom. Documenting the New System. at IGCSE ICT. http://www. igceict. info/theory/8/docs/index. html. Accessed February 25.

[30] Sa’adi A H M A, Al-Maimuri N M L and Omar al-mamany D A 2013 Effect of geotextile reinforcement on flexible pavement roads. *Engineering and Technology Journal*, 31(20 Part (A) Engineering), PP 299-315.

[31] Abu-Farsakh M, Hanandeh S, Mohammad L and Chen Q 2016 Performance of geosynthetic reinforced/stabilized paved roads built over soft soil under cyclic plate loads. *Geotextiles and Geomembranes*, 44(6), PP 845-853.

[32] Tiwari Dr S and Vyas M 2017 Effect of geogrid reinforcement on PaTiwari, Shikha Vyas,
Monikavement subgrade. In IJSRD—International Journal for Scientific Research and Development Vol. 5. Retrieved from www.ijsrd.com

[33] Holtz R D, Christopher B R and Berg R R 1997 Geosynthetic engineering. BiTech Publishers, Vancouver, British Columbia, Canada., 451 pp.

[34] Calvarano L S, Palamara R, Leonardi G and Moraci N 2017 December 3D-FEM analysis on geogrid reinforced flexible pavement roads. In IOP Conference Series: Earth and Environmental Science Vol. 95, No. 2, p. 022024.

[35] Yang S H and Al-Qadi I L 2007 Cost-effectiveness of using geotextiles in flexible pavements. Geosynthetics International, 14(1), PP 2-12.

[36] Rudramurthy M and Vikram M B 2016 Effect of geotextiles on CBR values. International Journal of Emerging Trends in Engineering and Development, 1(6), PP 118-125.