Behavior of Foundation Rested on Geogrid-Reinforced Soil: A Review

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Abstract. In many cases, the soil in Nasseriyah, Iraq, is not suitable to support the shallow foundations of low to medium rise buildings without improvement or replacing the founded layer with a strong layer. Therefore, the reinforcement method as one of many types of improvement methods may be used to increase the bearing capacity and reduce the settlement when the replacement soil is not enough to support the foundation. This paper reviews the most important reinforcement materials such as geogrid that may be used to increase the strength of the soil and other details of the number of layers, the distance between layers and the optimum location of the top reinforced layer for clay and sand soil. Experimental studies and theoretical modeling performed through the last decades are reviewed to choose the best arrangement of geogrid material that gives the best performance when it is used with soil. It is found that the geogrid can be used to increase the bearing capacity, however, the studies on clay reinforced with geogrid compared to sand soil are few. Since the researches on the behavior of foundation resting on clay reinforced with geogrid are few and because the soil in Nasseriyah is mostly clay soil, it is recommended to study the behavior of foundation resting on clay reinforced soil.

Keywords. Geosynthetics, Geogrid, Bearing Capacity, Settlement.

1. Introduction
To improve the properties of engineering soil, various reinforcing materials are used. The soil can be classified into four main groups: gravel, sand, clay, and silt. The weak tensile strength property is the main characteristic of the soil, which depends largely on environmental conditions [1]. The method of reinforcing the soil improves the mechanical properties of the soil such as shear, hydraulic conductivity, compression, and density. For soil reinforcement used of soil nailing, stone columns, micro piles, and reinforced soil [2]. Building houses and roads on fiber-reinforced earth with different types of reinforcement interventions is an ancient concept. Rope and bamboo fibers were used to strengthen the rules of rural roads and low-cost buildings in low-cost soil, despite the existence of these practices, but the concept of armed land was not studied or explained until the work of Vidal (1967) who showed its application and developed design procedures rational. The concept of soil reinforcing the soil was mainly related to mineral reinforcement in the early days. At present, this concept has expanded to include other materials such as fabrics, geotextiles, geomembranes, geogrid, geocell, and is often called ‘Geosynthetic’ [3]. The main purpose of using geosynthetic materials is to improve the mechanical and physical properties of the soil. The geosynthetic materials used in construction are mostly geofoam, geotextile, geogrid, geonet, geocomposites, geomembrane, and geocell. Geosynthetic materials have been used in many applications such as foundations of buildings,
and railroads, and earth structures like retaining walls, embankments, landfills, dams, etc.[4]. Figure 1. Shows the pictures of different types of geosynthetics.

![Image of geosynthetics](image1)

**Figure. 1** The types of geosynthetics.

At present, the use of geosynthetic materials has expanded and has become widely used in Civil engineering. Using these materials in construction projects in the world results in successful projects [9]. In this paper, a review of the experimental and the numerical studies conducted on reinforced soil with geogrid, and the effect of using geogrid to improve the bearing capacity (BC) and to reduce settlement of soil is presented.

2. Geosynthetic reinforcement type

According to (ASTM D 4439-11, 2011) the geosynthetic material is defined "as a planer product manufactured from a polymeric material which is used with soil, rock, earth or other geotechnical related material as an integral part of the civil engineering project, structure, or system". The principle type of geosynthetics is Geotextile, Geogrid, and Geocell. Geosynthetics are usually identified by polymer, type of yarn or fiber, if appropriate, type of geosynthetic, mass per unit area or thickness, if appropriate, and any physical properties or additional information necessary to depict the material [10]. Geosynthetic applications are often defined by their main or primary function. In some applications, geosynthetics perform secondary functions, in addition to the primary functions. The primary and secondary functions both shall be considered in design calculations and specifications. Many applications of geosynthetics have been identified [11],[12] while six functions are briefly used. They are reinforcement, separation, drainage, filtration, protection, and containment.

3. Geogrids

Geogrids are usually solid net, such as materials with large openings called apertures. These apertures are large enough to help the interlocking with the soil surrounding and rocks to perform the reinforcement function. It is incorporated into the main layers of finished surfaces, or in the surface layers of walls and slopes and provides a stabilizing force within the soil structure itself. When the fill interlocks with the grid, this stabilization occurs. Through the strength of the geogrid, mesh size, and
the basic materials used, the effect of interlocking is determined. Geogrids are made of high modulus polymer materials such as polypropylene (PP) and high-density polyethylene (HDPE) and are prepared by tensile drawing. Several types of geogrids are available such as Biaxial Geogrid which is manufactured by stretching perforated polypropylene sheets in 2 orthogonal directions. It has high tensile strength and a two-way modulus. Figure 2 shows the geogrid strip. The second type is the Uniaxial Geogrid which is manufactured by stretching a high-density extruded polyethylene sheet in one direction. It has high tensile strength and a one-way modulus.

![Biaxial geogrid with typical dimensions.](image)

Figure 2. Biaxial geogrid with typical dimensions.

They are usually used in slope reinforcement such as overpasses, highway embankments, landslide or erosion-prone surface and landfill walls, wall reinforcement such as airport noise barriers, retaining walls, sea walls and bridge supports, base reinforcement such as railroad track beds, foundations for roads, and runways, and berm reinforcement such as waste containment ponds levees and, spillway channels for earthen dams. At present many tests have been performed for models to study the BC of shallow foundations rested on soil reinforced by different materials like geotextiles, geogrids, and fiber ropes. In the past decade, geogrid has been used to reinforcing the soil widely because they are stable in dimensions, and have high tensile strength, open structure of grid (which leads to a reinforced reaction to enhance the soil), a lightweight, a long service life, and positive shear connection properties.

3.1. Geogrid reinforced foundation

Binquet (1975)[13] conducted a laboratory model of strip footing on sand reinforced foundations with a wide strip of aluminum foil to study the mechanism of using reinforcing earth. An analytical method for guessing increased BC was presented based on tests. (Omar et al. 1993) [14] calculated the ultimate BC of square and strip foundations rested on reinforced sand by geogrid layers based on the results of a laboratory model test. The number of geogrid layers and the critical depth of reinforcement for mobilizing the maximum BC ratio have been determined and compared, based on the experimental results of the foundation models. It was reported from this experiment that the maximum BC can be developed when reinforcement has an effective depth of 2B for the strip footing and 1.4B for the square footing. Also, from the results, for strip footing, it is observed that the maximum width of the reinforcement layers for optimal mobilization for the maximum BC ratio is 8B and 4.5 for square footing. Laboratory tests were conducted to determine the ultimate BC of strip foundation embedded on reinforced sand by geogrid layers. The results were compared with the theory of BC developed by [15]. According to these tests, the following results were obtained:

1. With the increase in embedment ratio, Df/B, for the same soil, geogrid and configuration, the ultimate BC increases.

2. For ultimate BC, the theoretical relationship developed by [15] provides somewhat conservative predictions.
(Singh 2009) [16] conducted several laboratory plate load tests on geogrid–reinforced sand bed. A circular geogrid with 120 mm in diameter was used as a the diameter of the footing is 60 mm. The study found that the BC improved when an increase in the number of geogrid and reduce the spacing between it. (Omari 2018) [17] conducted a laboratory model test for the ultimate BC for a strip foundation reinforced by geogrid–reinforced the sand soil and saturated clay were used in this study. They used foundations model rested on two types of soil: sand and clayey soil. The dimension of each foundation is similar to 76.2 mm (B) and (304.88) mm. Depending on the results of the model test, found that the settlement of the footing at the ultimate load in clay soil in reinforced and unreinforced is the same result. The maximum benefit from the reinforcement is obtained when the first layer of geogrid should be placed at a depth of 0.3B to 0.4B. The optimum geogrid layers width is 8B in sand and 5B in clay that value gives the maximum BC ratio. The sand - geogrid system gave the maximum bearing - capacity ratio greater than the ratio from the clay-geogrid system.

3.2. Parameters of geogrid reinforcement foundation

Many parameters can affect the efficiency of the soil foundation reinforced by geogrid (RFS) such as the depth of the first layer of the reinforcement, the distance between layers of reinforcement, the width of reinforcement, and the number of reinforcing layers. The influence of geogrid reinforcement parameters on soil improvement as reported in literature is presented below:

3.2.1. Depth of First Reinforcement Layer (u). Several research works are conducted to study the effect of depth on the first reinforcing layer. The ratio between u and d (u/B) is called the depth ratio. Table 1 shows a list of researches that studied different parameters such as (u/B).

Table 1. Results previous studies of optimum parameters geogrid.

| Year  | Type of footing | Type of reinforcement | (u/B) | (b/B) | (h/B) | (N) |
|-------|----------------|----------------------|-------|-------|-------|-----|
| 1985  | Square         | Geotextile/geogrid   | 0.5   | 2.5   | -     | 3   |
| 1993  | Square         | Geogrid              | 1     | 4.5   | 0.33  | 3   |
| 1994  | Square         | Geogrid              | 0.25  | 4.5   | 0.2   | -   |
| 1997  | Geogrid        |                      | 0.48  | -     | 0.25-1.5 | 3 |
| 2003  | Circular       | Geogrid              | 0.47  | -     | 0.2   | 3   |
| 2005  | Strip          | Geogrid              | 0.35  | 5     | 0.25  | -   |
| 2010  | Square         | Geogrid              | 0.3   | 3     | 0.3   | -   |
| 2017  | Square         | Geogrid              | -     | -     | -     | 3   |
|       | Geogrid        |                      | 1     | 4.5   | 1.4   | 4   |
| 2017  | and            | Geogrid              | and   | and   | and   | and |
|       | Strip          |                      | 1     | 8     | 2     | 6   |
| 2018  | Strip          | Geogrid              | 0.3-0.4 | 8-5 | 2-1.75 | 4 |
| 2020  | Square         | Geogrid              | 0.25  | -     | 0.25  | 4   |
| 2020  | Square         | Geogrid              | 0.6   | -     | -     | -   |

Note: B: width of Footing, W: Diameter of circular footing, u: depth of the first layer of reinforcement, h: vertical distance of between layers, b: length of reinforcement, N: number of reinforcement layers.

It is found that with a decrease in (u/B) value, the ultimate BC of shallow foundation increases [27,28]. The BCR values at the ultimate loads generally decreased as top layer spacing increased. For surface footing conditions for geogrid reinforced sand, no optimum clear top layer spacing was obtained. As such, for different top layer depth (u), the variation of BCRs at the ultimate loads depends on the magnitude and variation of reinforcement tensile force with the reinforcement depth [29]. The BC has direct relationship with u/B ratio. As the u/d increases, the BC also increases [30]. The optimum depth should be (u= 0.33B) which is found to be in good agreement with literature, and the foundation soil should be in higher, for effective utilization of geogrid reinforcement (22). When u=10 mm, the load response was better than when u=20 mm [31,32]. The ultimate load carried by footing obtain to be nearly 26% more as compared to other depth of insertion of geogrid, when geogrid was placed at a distance 0.25b below the base of footing, for a single layer. It is obtained that
BCR in each case was certainly enhanced when x is reduced from 120 mm to 30 mm [25]. With (h/B) or (x/d) is up to 0.75B, the BCR increases after that it decreases [27]. As the number of layer increases it can be observed that the BCR improved with an increasing number of reinforcement layers and by reduction of vertical spacing between layers when the value of (u/d) is 0.2 [28]. The compressive load response was further improved, when the spacing between the geogrid is less [32]. When two adjacent geogrids are kept at a distance of 0.25b, the ultimate bearing pressure has a maximum value. As x and z value reduces from 120mm to 30 mm, BCR is increased [25].

3.2.2. The Width of reinforcement

There are considerable studies that have been adopted to investigate the change of BC ratio (BCR) with width ratio (b/B) for footings rested on sand with different densities. These studies stated that the BCR increases with increasing the geogrid width. For example, as reported by [33] the BC increases significantly up to (b/B = 5) while no significant contributions to increase the ultimate load of the footing with geogrid layer width greater than the above ratio.

3.2.3. Number of reinforcing layer. The BC value increases with an increase in the number of reinforcement layers. Several researchers have found that reinforcing the soil with up to three layers with a vertical space up to 0.25 will increase the BC. For depth greater than this depth, the increase in BC is least interested. Placing the geogrid at a depth of more than 1.5B cannot significantly increase the BC. [27] have recommended that using geogrid reinforced layers increases the BC of the shallow foundation model and significantly reduces the settlement ratio. This behavior continues up to two layers, for the same footing size while in the case of N = 3, there was no difference in the value of BCR. The rate of BC increase with geogrid layers more than three layers becomes less important.

The BCR increases with increasing the number of layers when (u/d) is relatively small. When (u/d) is greater than 0.2, a little increase of BC occurs with increasing the number of geogrid layers[28]. Biaxial geogrid layers improve the bearing capacity more than uniaxial geogrid. For instance, the BC increases from 1.9 to 2.6 when the two uniaxial geogrid is used while the BC improves from 3 to 3.3 when two layer of biaxial geogrid is used [34]. Maximum load intensity for a single layer of geogrid reported as 796 KN/m² and the ultimate load intensity was improved from 796 KN/m² to 1981 KN/m², for four layers of geogrid. For N=2, N=3 and N=4, maximum BCR are 5.38,6.21 and 6.87 [25].

3.3. Mechanism of geogrid reinforcement

The reinforced material is considered as mechanically stabilized material in contrast with those depend on the chemical additive. It increases the strength mechanically by increasing the stiffness and then BC of the foundation. The mechanism of reinforcement soil depends mainly on the interaction between soil and the reinforced material. This interaction can be created between soil and the plane surface as a shearing resistance, soil and lateral surface as passive resistance, and soil and soil in the aperture of grid (interfacial shear on the surface of rupture zone created during shearing). According to the above mechanism, several theories of mechanism of failure are developed. A quasi-rigid zone is developed under the foundation directly with width equal to the width of reinforced material which is assumed to be equal to the width of foundation, and the depth of this layer is between base of foundation and the last layer of reinforced material. Under this zone, the failure zones are observed. Therefore, this case is called deep foundation mechanism [35]. [36] suggested “wide slab mechanism” of failure in soil where the width of the triangle zone in greater than the width of the foundation by 2B. Binquet (1975)[13] suggested four cases of analysis assuming strip foundation and reinforcement strips are placed below the foundation at distance u from the base of foundation, Figures 3 to 6.

a) Shear failure is occurred between the base of foundation and the top layer of reinforcement which is induced when the distance between the base of footing and the top layer u, is relatively large. i.e the stresses concentrated in this region. This mode is occurred when the ratio of u > 2/3 B.
b) When the reinforcement layers are placed at shallow depth with insufficient anchorage, the layer may pull out which occurs when $u < 2/3 B$ and the number of layers is between 2 and 3. It is called reinforced pull out failure.

c) When the reinforcement layers are placed at shallow depth and the tensile strength of reinforced material is less than the friction between layers due to pull out resistance, the failure is called reinforced tension failure. It occurs when $u < 2/3B$ and the number of layers $N > 4$ but not more than 6-7.

Figure 3. Deep footing failure [35].

Figure 4. Wide-slab failure.

Figure 5. Bearing capacity failure between the soil surface and the top geogrid layer.

Figure 6. Anchorage pull out of geogrids due to deformation.

Chen (2015) [37] developed an analytical solution to estimate the ultimate BC of strip footing on reinforced soil (RSFs). The first proposition of the general failure mode of (RSFs) established on their studies and results in literature. Based on the proposed failure mechanism, a stability balance analysis was suggested. They proposed formulas of BC, on the increase in ultimate BC which considers the influence of confinement and the membrane of reinforcements for strip footings. Three perhaps failure modes are shown in Figure 7. Failure above the top layer of the reinforcement which are the first two failure modes [38](Figure 7a). Failure between the reinforcement layers [39] Figure (7b), can be avoided by maintaining the distance of the top layer ($u$) and the distance between the reinforcement layers ($h$) within a permissible distance. Figure 7c shows the general failure model of RSFs, in which the punching shear failure occurs then ended by general shear failure (Figure 7c).

(a) Failure top layer of reinforcement [38].

(b) Failure between layers of reinforcement [39].
4. Conclusion
In this review, a brief discussion about the geogrid reinforced systems for shallow foundations and the various parameters affecting their performance is presented. Parametric developments and studies on the performance of shallow foundations reinforced with these material were discussed, with an indication of optimum values for different parameters. Consideration must be given to the various parameters and their effect and mechanism of work, for the purposes of obtaining better performance of the soil reinforcement by geogrid. A study is recommended for foundation resting on reinforced clay since few studies are available on this type application and because the soil that will be studied in Naseryiah, Iraq is clay soil.

5. References
[1] Ling H I, Leshchinsky D and Tatsuoka F 2003 Reinforced soil engineering: advances in research and practice (CRC Press)
[2] Hejazi S M, Sheikhzadeh M, Abtahi S M and Zadhoush A 2012 A Simple Review of Soil Reinforcement by Using Natural and Synthetic Fibers (Constr. Build. Mater.) vol 30 pp 100–16
[3] Datye K R and Nagaraju S S 1985 Ground Improvement (Commem.) vol Indian Geotech
[4] Han J, Pokharel S K, Yang X, Manandhar C, Leshchinsky D, Halahmi I and Parsons R L 2011 Performance of Geocell-Reinforced Rap Bases Over Weak Subgrade Under Full-Scale Moving Wheel Loads (J. Mater. Civ. Eng.) vol 23 pp 1525–34
[5] Panigrahi B and Pradhan P K 2019 Improvement of Bearing Capacity of Soil by using Natural Geotextile (Int. J. Geo-Engineering) vol 10
[6] Dash S K, Rajagopal K and Krishnaswamy N R 2001 Strip Footing on Geocell Reinforced Sand Beds with Additional Planar Reinforcement (Geotext. Geomembranes) vol 19 pp 529–38
[7] Pokharel S K, Han J, Leshchinsky D, Parsons R L and Halahmi I 2010 Investigation of Factors Influencing Behavior of Single Geocell-Reinforced Bases Under Static Loading (Geotext. Geomembranes) vol 28 pp 570–8
[8] Sitharam T G, Sireesh S and Dash S K 2005 Model Studies of a Circular Footing Supported on Geocell-Reinforced Clay (Can. Geotech. J.) vol 42 pp 693–703
[9] Lackner C, Bergado D T and Semprih S 2013 Prestressed Reinforced Soil by Geosynthetics–Concept and Experimental Investigations (Geotext. Geomembranes) vol 37 pp 109–23
[10] Holtz R D 2014 Geosynthetics for Soil Reinforcement (The Ninth Spencer J. Buchanan Lecture By)
[11] Koerner R M 1998 Designing with Geosynthetics (P rentice Hall, Englewood Cliffs)
[12] Holtz R D, Christoper B R and Berg R R 1997 Geosynthetic Engineering (BiTech)
[13] Binquet J and Lee K L 1975 Bearing Capacity Tests on Reinforced Earth Slabs (J. Geotech. Geoenvironmental Eng.) 101
[14] Omar M T, Das B M, Puri V K and Yen S C 1993 Ultimate Bearing Capacity of Shallow Foundations on Sand with Geogrid Reinforcement (Can. Geotech. J.) vol 30 pp 545–9
[15] Huang C-C and Menq F Y 1997 Deep-Footing and Wide-Slab Effects in Reinforced Sandy Ground (J. Geotech. Geoenvironmental Eng.) vol 123 pp 30–6
[16] Phanikumar B R, Prasad R and Singh A 2009 Compressive Load Response of Geogrid-Reinforced Fine, Medium and Coarse Sands (Geotext. Geomembranes) vol 27 pp 183–6
[17] Omar M 2018 The Bearing Capacity of Surface Strip Foundations on Geogrid-Reinforced Sand and Clay- a Comparative Study
[18] Guido V A, Biesiadecki G L and Sullivan M J 1985 Bearing Capacity of a Geotextile-Reinforced Foundation (Proceedings Of The Eleventh International Conference on Soil Mechanics And Foundation Engineering, San Francisco, 12-16 August 1985 Publ. Balkema
[19] Yetimoglu T, Wu J T H and Saglamer A 1994 Bearing Capacity of Rectangular Footings on Geogrid-Reinforced Sand (J. Geotech. Eng.) vol 120 pp 2083–99
[20] Adams M T and Collin J G 1997 Large Model Spread Footing Load Tests on Geosynthetic Reinforced Soil Foundations (J. Geotech. Geoenvironmental Eng.) vol 123 pp 66–72
[21] Boushehrian J H and Hataf N 2003 Experimental and Numerical Investigation of the Bearing Capacity of Model Circular and Ring Footings on Reinforced Sand (Geotext. Geomembranes) vol 21 pp 241–56
[22] Patra C R, Das B M and Atalar C 2005 Bearing Capacity of Embedded Strip Foundation on Geogrid-Reinforced Sand (Geotext. Geomembranes) vol 23 pp 454–62
[23] Mirzaeiifar H and Ghavami M 2010 Bearing Capacity of Multi-Edge Shallow Foundations on
[24] Chaitanya B 2017 An Experimental Investigation on Effect of High Temperatures on Steel (Int. J. Comput. Sci. Eng.) vol 5
[25] Shrigondekar A and Ullagaddi P 2020 Bearing Capacity Analysis of a Square Footing Supported on Geogrid Reinforced Sand (Int. J. Emerg. Technol) vol 11 pp 169–76
[26] Zhang L liang, Wang J quan, Kaliakin V N and Tang Y 2020 Load-Bearing Characteristics Of Square Footing On Geogrid-Reinforced Sand Subjected To Repeated Loading (J. Cent. South Univ.) vol 27 pp 920–36
[27] Alamshahi S and Hataf N 2009 Bearing Capacity of Strip Footings on Sand Slopes Reinforced with Geogrid and Grid-Anchor (Geotext. Geomembranes) vol 27 pp 217–26
[28] Zidan A F 2012 Numerical Study of Behavior of Circular Footing on Geogrid-Reinforced Sand under Static and Dynamic Loading (Geotech. Geol. Eng.) vol 30 pp 499–510
[29] Abu-Farsakh M, Chen Q and Sharma R 2013 An Experimental Evaluation of the Behavior of Footings on Geosynthetic-Reinforced Sand (Soils Found) vol 53 pp 335–48
[30] Kolay P K, Kumar S and Tiwari D 2013 Improvement of Bearing Capacity of Shallow Foundation on Geogrid Reinforced Silty Clay and Sand (J. Constr. Eng.) vol 2013 pp 1–10
[31] H R 2014 an Experimental Study of Square Footing Resting on Geo-Grid Reinforced Sand (Int. J. Res. Eng. Technol.) vol 03 pp 177–81
[32] Singh A, Phanikumar B R and Prasad R 2016 Effect of Geogrid Reinforcement on Load Carrying Capacity of a Coarse Sand Bed (Int. J. Civ. Eng. Technol) vol 7 pp 1–6
[33] El Sawwaf M A and Nazir A K 2012 Cyclic Settlement Behavior of Strip Footings Resting on Reinforced Layered Sand Slope (J. Adv. Res) vol 3 pp 315–24
[34] Useche Infante D J, Aiassa Martinez G M, Arrúa P A and Eberhardt M 2015 Behavior of Rigid Circular Shallow Footings on Geogrid-Reinforced Sand (Electron. J. Geotech. Eng.) vol 20 pp 11647–64
[35] Huang C-C and Tatsuoka F 1990 Bearing Capacity of Reinforced Horizontal Sand Ground (Geotext. Geomembranes) vol 9 pp 51–82
[36] Schlosser F, Juran I and Jacobsen H M 1983 Soil Reinforcement (general report: session no. 5 Proc. Viii Ecsme) vol 1159–80
[37] Chen Q and Abu-farsakh M 2015 Ultimate Bearing Capacity Analysis of Strip Footings on Reinforced Soil Foundations (Soils Found) vol 55 pp 74–85
[38] Binquet J and Lee K L 1975 Bearing Capacity Analysis of Reinforced Earth Slabs (J. Geotech. Geoenvironmental Eng.) vol 101
[39] Wayne M H, Han J and Akins K 1998 The Design of Geosynthetic Reinforced Foundations (ASCE Geotechnical special publication) vol 76 pp 1–18