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Applications and Performance of Geogrids in Structures

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Abstract*: A type of geosynthetic material named geogrid plays a pivotal role in the behaviour of concrete by implementing them as an additional reinforcement. Geogrids have good tensile strength as they are formed by the reticulation of tensile elements with an opening of an ample size which allows interlock with the nearby fill materials. These grids are flexible mesh which is highly effective and enhances the life of the structure. The prime constituents of geogrid are polyester, high-density polyethylene, and polypropylene. More often, in the field of civil engineering,uni-axial, bi-axial and tri-axial geogrids are used. As the cost and duration of construction are nominal, geogrids can be optedfor cost-effective and resilient construction. They are frequently used as reinforcement and for stabilization in structures like retaining walls, pavements, foundations, slopes, and embankments. The geogrids are employed in various construction which results in sustainable development. Thus, this paper discusses diverse studies that have been carried out by using different types of geogrids for various purposes by different research scholars.

Keywords*: Geogrids, Geosynthetics, reinforcement, slope, structural elements.

I. INTRODUCTION

Early in 1982, Frank Brian Merce invented geogrids. Later, geogrids were popularized among engineering community by a conference held at the United Kingdom in the year 1984 [1]. Geogrids, commonly known as geosynthetics and polymer grids, are commonly used for stabilization (pavements), protection (slope stability), drainage and strengthening [2]. For instance, geogrids are used for reinforcing retaining walls [3]-[9], pavements [10-18], foundations in soft soil [19]-[39], slope stability [40]-[44], embankments[45]-[47] and for structural components such as beams and columns[48]-[68]. The usage of geogrids may be considered as highly economical and safe towards the environment as it creates less environmental effects [69]. Generally, three types of geogrids such asuni-axial (strength in one direction), bi-axial (strength in two directions) and tri-axial (strength in three directions) geogrids are used in the construction field. The tri-axial geogrids with ribs extended in three directions are found to be more effective compared with uni-axial and bi-axial geogrids [70]. The application of geogrids in civil engineering projects depends on the factors such as cost, purpose and tensile strength of geogrids. Geogrids with high-tensile strength are successfully used in recent times in the structural applications. The performance of geogrid in pre-fabricated construction proves to be effective [57]. For the construction of steep slopes, high strength geogrids are used [69].Geogrid reinforcement increases the strength and stiffness of soil [4], [5], [7].

Based on the past credit performance of geogrids, a detailed review on the previous studies in the field of geogrids with structural applications is presented. The parameters such as materials, properties and applications of geogrids are discussed. It includes a detailed review on the salient features of geogrids such as tensile strength and number of layers of geogrids, related to structural performance under various applications. A detailed analysis of performance of geogrids in civil engineering applications such as retaining walls, pavements, slope stability, foundations in soft soil and structural applications is presented in this paper. The objective of the study is to assess the potential use and performance of geogrids in structural applications

A. Significance of geogrids

In general, geogrids are manufactured under three different processes such as extruding, knitting or weaving and by welding and extrusion (Fig. 1). Based on the direction of stretching, the geogrids are grouped as uni-axial, bi-axial and tri-axial geogrids. Use of geogrids category in structural applications gives promising results in terms of strength and durability. In particular, geogrid reinforcements in structural components is a new technology which increases the overall behaviour of structure in terms of improved load carrying capacity and reduced deflection [22], [48], [56], [57], [59], [63], [66], [67]. The conventional steel in reinforced concrete structure is prone to corrosion under severe environmental condition and thereby it affects the life and durability of the structures. Numerous studies were reported suggesting alternate material for steel. However, geogrids proves to be a unique material as they are completely resistant to corrosion. Uni-axial geogrids are mainly used in walls and slopes. The bi-axial and tri-axial geogrids are mainly used in roads and platforms. But all the three types of geogrids are used in the structural component to identify their flexural strength. From the recent studies, it was observed that multi layered geogrids prove to be more effective rather than a single layer in structural components.

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The strength at the junction is considered more important because the loads are transferred from the adjoining ribs through these junctions. Geogrids are used mainly because of their improved flexural behaviour in structural components.

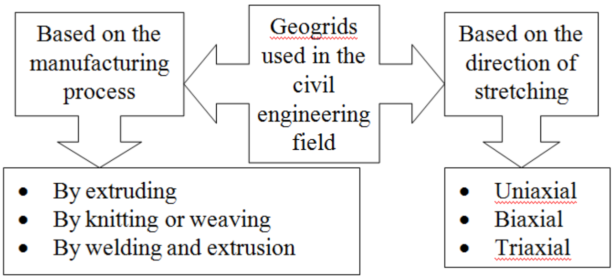

Fig.1. ***Flowchart on types of Geogrids***

II. MATERIALS FOR GEOGRIDS

Generally, geogrids are manufactured from polymers like polypropylene, polyethylene or polyester. The uni-axial, bi-axial and tri-axial can be made by extruding, knitting and welding these polymer materials. The strength of geogrids primarily depends on the material from which they are manufactured. Most commonly, high- density polypropylene geogrids of desired shape and structure are used in the structural application. The grid formation is made by punching holes in the required pattern. Those holes are called as apertures. In the process of knitting or weaving, polyethylene or polyester materials are used to form flexible geogrids [47], [49], [59]. Further, they are coated with polyvinyl chloride or latex or any other bituminous material [42]. In the method of extrusion and welding, the polyester or polypropylene material is passed through the roller where the ribs are extruded and then welding is done. Rarely, geogrids coated with polyvinyl chloride and fibre glass geogrids are used [6], [42], [71].

III. PROPERTIES OF GEOGRID

The strength and durability of geogrids depends mostly on their properties and field of application. The properties are ultimate tensile strength, elongation, initial modulus, aperture dimensions, junction strength, junction efficiency, flexural rigidity, stiffness, thickness and width of rib, installation damage resistance and creep behaviour. The tensile strength of geogrids observed from various studies is enumerated in Table I. High-density polyethylene geogrids shows better performance than polyester geogrids. Several investigations were also reported on the creep and relaxation of stress behaviour of geogrids [9], [50], [72]-[75].The creep property of geogrids are chiefly governed by the material and manufacturing process [72]. Though the creep rate is high at the starting stages of loading, it reduces and becomes stable after some period [9]. The creep strains for knitted and woven geogrids are 9.85% and 7.52% respectively [47]. Greenwood and Curson [76] have predicted the life time of polypropylene geogrid as 65 to 70 years. Auston [53] have reported that elevated temperature, for short duration, doesn't have any significant effect on the behaviour of geogrids.

Table- I: Summary of geogrid properties

Ref.	Material	Aperture size (mm)	Aperture shape	Tensile strength (kN/m)
[6]	Polyethylene + Poly Vinyl Chloride	3.5 x 3.5	Square	11
[16]	Polypropylene	12.5 x 12.5	Square	40
[21]	High-Density Polyethylene	20 x 20	Hexagon	12
[22]	High-Density Polyethylene	8 x 6	Hexagon	9.8
[24]	Polypropylene	31 x 31	Square	22
[26]	High-Density Polyethylene	2.5 x 30	Hexagon	68.7
[32]	High-Density Polyethylene	6 x 6	Square	7.68
[40]	High-Density Polyethylene	27 x 27	Square	58
[42]	Poly Vinyl Chloride Coated polyester	25 x 25	Hexagon	2.675
[47]	Polyester	30 x 30	Square	68.2
[55]	High-Density Polyethylene	220 x 13/20	Hexagon	160

IV. APPLICATIONS OF GEOGRIDS

A. Pavements

Since last two decades, geogrids were employed successfully in pavement and roadway construction. Their applications in pavement and roadway comprise of sub-grade improvement, reinforcing the base course, sub-base and surface courses. The outward displacement of railway ballast is arrested and the settlement is reduced when they are reinforced with geogrids [16 - 18]. As pavements are affected by clayey compressive soils, addition of geogrid reinforcement increases the California Bearing Ratio of sub-grade soil composites. In soft sub-grade, the stiffer geogrids perform better than flexible geogrids as the later quickly reacts to the applied load. The maximum junction strength in geogrids can be calculated by the following equations [17].

$J_{rib} = \sum_{i=1}^{n} Ji \,/n$

$J_{grid} = (J_{rib})$ x (n junctions per unit length)

Where,

J_{rib} is average single junction strength,

J_{grid} is geogrid junction strength per unit width,

N (junctions per unit length) is the number of junctions per unit width.

B. Retaining wall

Geogrids are used for stabilizing the backfill in retaining wall. The stability of earth retaining wall depends on the friction angle.

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Creep and stress relaxation properties affects the performance of geogrids in a retaining wall. Working stress should not exceed 40% of the strength of geogrids. In the middle of the retaining wall high strength geogrids must be provided or else the geogrid reinforcement spacing must be reduced. In deep soil foundation, the creep behavior can be eliminated by using geogrids [9].

The bearing and energy adsorption capacities are increased with the geogrid reinforcement [3]. The problems caused by the marginal backfills can be reduced by the providing stiffer geogrid as soil reinforcement [6]. The strength in bonding between the backfill and geogrid is reduced by large sized particles present in the backfill [8]. The strength of retaining wall depends on the tensile strength of geogrid used and is independent of the number of reinforcing layers (geogrids).

C. Foundations in soft soil

Geogrids must have enough stiffness and stability to act as reinforcement for foundations. Both uni-axial and bi-axial geogrids are commonly used in foundation works. The main condition to achieve good stability is the interlocking capacity of geogrid and aggregates [19]. The vibrations are well controlled by geocell reinforcement. Venkateswarlu et al. [20] have compared the displacement behaviour of geogrids and geocell reinforcement and concluded that geocell have less displacement compare with geogrids. The bearing capacity of circular rigid foundations increases when the reinforcement and the friction angle increases. The bearing capacity is said to be high for two-layered reinforcement than single layer reinforcement [23]. The bearing capacity depends on the length of the geogrid layers. For footings, the geogrid reinforcement increases the bearing capacity and limits the settlement [39].

D. Slope stability

The geogrid reinforcement in slope influences mainly the slope deformation and stability. The previous studies denote that the load-settlement behavior and bearing capacity could be improved by the addition of geogrid reinforcement in selected locations of the slope. Based on the length of the geogrids, edge distance and particle size the bearing capacity varies. The bearing capacity mainly depends on the length of the geogrid [40]. To achieve best performance the aperture size should be approximately equal to 0.2 times the width of the footing [41]. Due to higher tensile strength and longer length, there is a downfall in the displacement of the earthen embankments and increase in the safety factor. When the loading is applied at the top of the earthen embankment, the displacement increases which decreases the safety factor [44]. Improper draining in construction may lead to the failure of geogrid reinforced slope. Geogrids in slopes may be uneconomical as lengthy geogrids increases the cost of construction [43]. However, it can be said that geogrids used in slopes as reinforcement increases the slopes' stability [40] – [44].

E. Geogrids in structural elements

In structural components, the geogrids are used as additional reinforcement and as shear reinforcement [67]. To achieve good strength fibers like polypropylene and steel are used [57], [63], [67]. The geogrid reinforcement results in high ultimate load-bearing capacity [22], improved energy absorption and reduced slippage [59], shear and bond strength [67], reduced drying shrinkage [46], [48] and reduced degradation rate [63]. Use of geogrid reinforcement in thin concrete layers [22] and in prefabricated structures [57] was also reported. The factors which allow the accommodation of geogrids in structural components are good tensile strength, resistant to chemical, corrosion, and temperature. The performance of geogrids in structural components is given in Table II.

Table- II: Performance of geogrids in structural components

Refs.	Structural component	Type of geogrid	Grade of concrete	Parameter Investigated
[22]	Beam	Bi-axial	M20	Flexural strength
[48]	Slab & Prism	Bi-axial	M30	Drying shrinkage
[56]	Column	Bi-axial	M35	Compressive strength
[57]	Wall panel	Bi-axial	M30	Flexural strength and compressive strength
[59]	Beam	Tri-axial	M30	Flexural strength
[63]	Beam	Bi-axial	M30	Flexural strength
[66]	Beam	Uni-axial	M30	Flexural strength
[67]	Beam	Bi-axial	M30	Flexural strength

V. SUMMARY AND CONCLUSION

The use of geogrids in engineering applications is significantly improved due to its vast benefits in recent times. The various research activities associated with geogrids in the resent past is critically reviewed in this paper by investigating its wide applications in the areas of slope stability, retaining wall, embankments, foundations in soft soil, pavements and in concrete structural elements and the summary of the review is presented in the Table III. Extensive work has been reported on performance of geogrids in static loading condition. However, the behaviour of geogrids under dynamic loading needs to be explored. Further, the performance of geogrids under adverse environmental condition needs to be addressed. If these gaps are considered and learned in the subject area, it can improve the over-all knowledge about the geogrids and its applications in construction field.

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Table- III: Geogrid reinforcement in engineering structures

Engineering structures	Brief Description
Pavements	• Transfers failure envelope to stronger subgrade base from weaker subgrade. Increases the bearing capacity of the subgrade. • Minimizes the cross-section of the structure.
Retaining wall	• Forces dueto unstable soil are resisted. • Retaining walls of appropriate heights are allowed based on the proportionality of length and size of geogrid.
Foundations in soft soil	• Geogrids are provided to separate foundation and embankment in order to prevent the blending of the two different materials. • Prevents settlement between foundations.
Slope stability	• Increases the shear strength of soil. • Very steep slopes can be provided.
Embankment	• Geogrids prevent erosion. • Less construction cost and enhanced service life.
Concrete structures	• Achieves good flexural strength. • Resistant to chemicals, corrosion, and temperature.

REFERENCES

1. I. M. Ward, "The orientation of polymers to produce high performance materials" Proc. of the Symp. on Polymer Grid Reinforcement in Civil Eng., Institution of Civil Engineers, UK., 1984.
2. Ir. Zakaria Che Muda, Salah F. A. Sharif and Ng Jun Hong, "Flexural behavior of lightweight oil palm shells concrete slab reinforced with geogrid," Int. J. of Scientific & Eng. Res., vol. 3, no. 11, pp. 1-18, Nov. 2012.
3. Dan Yang, Bin Jia, Hui Huang and Chuangli Deng, "Study on seismic performance of BFRP geogrid reinforced tibetan rubble wall," Advances in Energy Science and Environment Engineering II, AIP Conf. Proc. 1944, pp. 020014-1–020014-7, 2018, doi: 10.1063/1.5029728.
4. Felix Jacobs, Axel Ruiken and Martin Ziegler, "Investigation of kinematic behavior and earth pressure development of geogrid reinforced soil walls," Transportation Geotechnics, vol. 8, pp. 57-68, Sep. 2016, doi: 10.1016/j.trgeo.2016.07.004.
5. Y. Miyata, R. J. Bathurst and H. Miyatake, "Performance of three geogrid-reinforced soil walls before and after foundation failure," Geosynthetics International, vol. 22, no. 4, pp. 311–326, Aug. 2015, doi: 10.1680/gein.15.00014.
6. S. Balakrishnan and B. V. S. Viswanadham, "Performance evaluation of geogrid reinforced soil walls with marginal backfills through centrifuge model tests," Geotextiles and Geomembranes, vol. 44, no. 1, pp. 95-108, Feb. 2016, doi: 10.1016/j.geotexmem.2015.06.002.
7. Guangqing Yang, Baojian Zhang, Peng Lv and Qiaoyong Zhou, "Behaviour of geogrid reinforced soil retaining wall with concrete-rigid facing," Geotextiles and Geomembranes, vol. 27, pp. 350–356, Oct. 2009, doi:10.1016/j.geotexmem.2009.03.001.
8. Guang-Qing Yang, Huabei Liu, Yi-Tao Zhou and Bao-Lin Xiong, "Post-construction performance of a two-tiered geogrid reinforced soil wall backfilled with soil-rock mixture," Geotextiles and Geomembranes, vol. 42, pp. 91-97, Apr. 2014, doi: 10.1016/j.geotexmem.2014.01.007.
9. Chao Zou, Yimin Wang, Junyong Lin and Yekai Chen, "Creep behaviors and constitutive model for high density polyethylene geogrid and its application to reinforced soil retaining wall on soft soil foundation," Construction and Building Materials, vol. 114, pp. 763–771, Jul. 2016, doi: 10.1016/j.conbuildmat.2016.0p3.194
10. N. S. Correia and J. G. Zornberg, "Strain distribution along geogrid-reinforced asphalt overlays under traffic loading," Geotextiles and Geomembranes ., vol. 46, no. 1, pp. 111-120, Feb. 2018, doi: 10.1016/j.geotexmem.2017.10.002.
11. G. Ferrotti, F. Canestrari, E. Pasquini and A. Virgili, "Experimental evaluation of the influence of surface coating on fiber glass geogrid performance in asphalt pavements," Geotextiles and Geomembranes, vol. 34, pp. 11-18, Oct. 2012, doi: 10.1016/j.geotexmem.2012.02.011.
12. Bingye Han, Jianming Ling, Xiang Shu, Hongren Gong and Baoshan Huang, "Laboratory investigation of particle size effects on the shear behavior of aggregate-geogrid interface," Construction and Building Materials, vol. 158, pp. 1015-1025, Jan. 2018, doi: 10.1016/j.conbuildmat.2017.10.045.
13. Syed Khaja Karimullah Hussaini, Buddhima Indraratna and Jayan S. Vinod, "A laboratory investigation to assess the functioning of railway ballast with and without geogrids," Transportation Geotechnics., vol. 6, pp. 45-54, Mar. 2016, doi: 10.1016/j.trgeo.2016.02.001.
14. Emiliano Pasquini, Maurizio Bocci, Gilda Ferrotti and Francesco Canestrari, "Laboratory characterisation and field validation of geogrid-reinforced asphalt pavements," Road Materials and Pavement Design, vol. 14, no. 1, pp. 17-35, Oct. 2012, doi: 10.1080/14680629.2012.735797.
15. Unnam Rajesh, Satish Sajja and V. K. Chakravarthi, "Studies on engineering performance of geogrid reinforced soft subgrade," Transportation Research Procedia., vol. 17, pp. 164 – 173, 2016, doi: 10.1016/j.trpro.2016.11.072.
16. Gerald Raymonda and Issa Ismail, "The effect of geogrid reinforcement on unbound aggregates," Geotextiles and Geomembranes, vol. 21, pp. 355–380, Dec. 2003, doi: 10.1016/S0266-1144(03)00044-X.
17. Venkata Abhishek Sakleshpur, Monica Prezzi, Rodrigo Salgado, Nayyar Zia Siddiki and Yoon Seok Choi, "Large-scale direct shear testing of geogridreinforced aggregate base over weak subgrade," International Journal of Pavement Engineering, vol. 20, no. 6, pp. 649-658, Apr. 2017, doi: 10.1080/10298436.2017.1321419.
18. Kumari Sweta and Syed Khaja Karimullah Hussaini, "Effect of shearing rate on the behavior of geogrid-reinforced railroad ballast under direct shear conditions," Geotextiles and Geomembranes., vol. 46, pp. 251–256, Jun. 2018, doi: 10.1016/j.geotexmem.2017.12.001.
19. Zikmund Rakowski, "An attempt of the synthesis of recent knowledge about mechanisms involved in stabilization function of geogrids in infrastructure constructions," Procedia Engineering., vol. 189, pp. 166-173, 2017, doi: 10.1016/j.proeng.2017.05.027.
20. Hasthi Venkateswarlu, K. N. Ujjawal and A. Hegde, "Laboratory and numerical investigation of machine foundations reinforced with geogrids and geocells," Geotextiles and Geomembranes., vol. 46, pp. 882-896, Dec. 2018, doi: 10.1016/j.geotexmem.2018.08.006.
21. H. A. Alawaji, "Settlement and bearing capacity of geogrid-reinforced sand over collapsible soil," Geotextiles and Geomembranes., vol. 19, pp. 75-88, Mar. 2001, doi: 10.1016/S0266-1144(01)00002-4.
22. Alaa H. J. Al-Rkaby, A. Chegenizadeh and H. R. Nikraz, "Anisotropic strength of large scale geogrid-reinforced sand: Experimental study," Soils and Foundations, vol.57, no. 4, pp. 557-574, Aug. 2017, 10.1016/j.sandf.2017.03.008.
23. Manash Chakraborty and JyantKumar, "Bearing capacity of circular foundations reinforced with geogrid sheets," Soils and Foundations., vol. 54, no. 4, pp. 820-832, Aug. 2014, doi: 10.1016/j.sandf.2014.06.013.
24. Ahmet Demir, Abdulazim Yildiz, Mustafa Laman and Murat Ornek, "Experimental and numerical analyses of circular footing on geogrid-reinforced granular fill underlain by soft clay," Acta Geotechnica, vol.9, no. 4, pp. 711-723, Aug. 2014, doi: 10.1007/s11440-013-0207-x.
25. Joel Gniel and Abdelmalek Bouazza, "Improvement of soft soils using geogrid encased stone columns," Geotextiles and Geomembranes., vol. 27, pp. 167–175, Jun. 2009, doi:10.1016/j.geotexmem.2008.11.001.
26. Soheil Jahandari, Jie Li and Mohammad Saberian, Mohammad Shahsavarigoughari, "Experimental study of the effects of geogrids on elasticity modulus, brittleness, strength, and stress-strain behavior of lime stabilized kaolinitic clay," GeoResJ ., vol. 13, pp. 49–58, Feb. 2017, doi: 10.1016/j.grj.2017.02.001.
27. Cafer Kayadelen, Taha Okkes Onal and Gokhan Altay, "Experimental study for pull-out load of reinforced sand soil with geogrid," Measurement, vol. 117, pp. 390-396, Jun. 2019, doi: 10.1016/j.measurement.2017.12.024.
28. Chia-Nan Liu, Kuo-Hsin Yang and Minh Duc Nguyen, "Behavior of geogride reinforced sand and effect of reinforcement anchorage in large-scale plane strain compression," Geotextiles and Geomembranes., vol. 42, no. 5, pp. 479-493, Oct. 2014, doi: 10.1016/j.geotexmem.2014.07.007.

29. M. Mosallanezhad, M. C. Alfaro, N. Hataf and S. H. Sadat Taghav, "Performance of the new reinforcement system in the increase of shear strength of typical geogrid interface with soil," Geotextiles and Geomembranes, vol. 44, no. 3, pp. 457-462, Jun. 2016, doi: 10.1016/j.geotexmem.2015.07.005.
30. M. R. Abdi and H. Mirzaeifar, "Experimental and PIV evaluation of grain size and distribution on soil–geogrid interactions in pullout test," Soils and Foundations., vol. 57, pp. 1045–1058, 2017, doi: 10.1016/j.sandf.2017.08.030.
31. C. R. Patra, B. M. Dasb, M. Bhoia and E. C. Shin, "Eccentrically loaded strip foundation on geogrid-reinforced sand," Geotextiles and Geomembranes., vol. 24, pp. 254–259, Aug. 2006, doi: 10.1016/j.geotexmem.2005.12.001.
32. B. R. Phanikumar, Ram Prasad and Abhishek Singh, "Compressive load response of geogrid-reinforced fine, medium and coarse sands," Geotextiles and Geomembranes., vol. 27, pp. 183–186, Jun. 2009, doi: 10.1016/j.geotexmem.2008.11.003.
33. Eder C. G. Santos, Ennio M. Palmeira and Richard J. Bathurst, "Behaviour of a geogrid reinforced wall built with recycled construction and demolition waste backfill on a collapsible foundation," Geotextiles and Geomembranes., vol. 39, pp. 9-19, Aug. 2013, doi: 10.1016/j.geotexmem.2013.07.002.
34. Ana Cristina C. F. Sieira and Denise M. S. Gerscovich and Alberto S. F. J. Sayao, "Displacement and load transfer mechanisms of geogrids under pullout condition," Geotextiles and Geomembranes., vol. 27, pp. 241–253, Aug. 2009, doi:10.1016/j.geotexmem.2008.11.012.
35. Lekshmi Suku, Sudheer S. Prabhu and G. L. Sivakumar Babu, "Effect of geogrid-reinforcement in granular bases under repeated loading," Geotextiles and Geomembranes vol. 45, no. 4, pp. 377–389, Aug. 2017, doi: 10.1016/j.geotexmem.2017.04.008.
36. J. Wang, F. Y. Liu, P. Wang and Y. Q. Cai, "Particle size effects on coarse soil-geogrid interface response in cyclic and post-cyclic direct shear tests," Geotextiles and Geomembranes vol. 44, no. 6, pp. 854–861, Dec. 2016, doi: 10.1016/j.geotexmem.2016.06.011.
37. Jia-Quan Wang, Liang-Liang Zhang, Jian-Feng Xue and Yi Tang, "Load-settlement response of shallow square footings on geogrid-reinforced sand under cyclic loading," Geotextiles and Geomembranes., vol. 46, pp. 586–596, Oct. 2018, doi: 10.1016/j.geotexmem.2018.04.009.
38. Haofeng Xing, Zhen Zhang, Huabei Liu and Hua Wei, "Large-scale tests of pile-supported earth platform with and without geogrid," Geotextiles and Geomembranes vol. 42, no. 6, pp. 586–598, Nov. 2014, doi: 10.1016/j.geotexmem.2014.10.005.
39. Laxmikant Yadua, R. K. Tripathi, "Effect of the length of geogrid layers in the bearing capacity ratio of geogrid reinforced granular fill-soft subgrade soil system," Procedia - Social and Behavioral Sciences., vol. 104, pp. 225-234, 2013, doi: 10.1016/j.sbspro.2013.11.115.
40. Gh. Tavakoli Mehrjardi, A. Ghanbari and H. Mehdizadeh, "Experimental study on the behaviour of geogrid-reinforced slopes with respect to aggregate size," Geotextiles and Geomembranes, vol. 44, no.6, Dec. 2016, pp. 862-871, doi: 10.1016/j.geotexmem.2016.06.006.
41. Gh. Tavakoli Mehrjardi and M. Khazaei, "Scale effect on the behaviour of geogrid-reinforced soil under repeated loads," Geotextiles and Geomembranes., vol. 45, pp. 603-615, 2017, doi: 10.1016/j.geotexmem.2017.08.002.
42. Gholam, Arvin Abdolmaleki, Parham Solta and Masoud Ahmadvand, "A laboratory and numerical study on the effect of geogrid-box method on bearing capacity of rock-soil slopes," Geomechanics and Engineering., vol. 14, no. 4, pp. 345-354, 2018, doi; 10.12989/gae.2018.14.4.345.
43. Chia-Nan Liu, Kuo-Hsin Yang, Yu-Hsien Ho and Chia-Ming Chang, "Lessons learned from three failures on a high steep geogrid-reinforced slope," Geotextiles and Geomembranes., vol. 34, pp. 131-143, 2012, doi:10.1016/j.geotexmem.2012.05.003.
44. Ramin Vali, Mohammad Saberian, Jie Li, Gholamreza Shams and Pieter Van Gelder, "Properties of geogrid-reinforced-marine-slope due to the groundwater level changes," Marine Georesources & Geotechnology, vol. 36, no. 6, pp. 735-748. Apr. 2017, doi: 10.1080/1064119X.2017.1386741.
45. R. P. Chen, Y. W. Wang, X. W. Ye, X. C. Bian and X. P. Dong, "Tensile force of geogrids embedded in pile-supported reinforced embankment: A full-scale experimental study," Geotextiles and Geomembranes., vol. 44, pp. 157-169, 2016, doi: 10.1016/j.geotexmem.2015.08.001.
46. Abbas S.A. Al-Hedad, Ebony Bambridge and Muhammad N.S. Hadi, "Influence of geogrid on the drying shrinkage performance of concrete pavements," Construction and Building Materials., vol. 146, pp. 165-174, 2017, doi: 10.1016/j.conbuildmat.2017.04.076.
47. Hyun-Jin Koo and You-Kyum Kim, "Lifetime prediction of geogrids for reinforcement of embankments and slopes," Polymer Testing., vol. 24, pp. 181–188, 2005, doi:10.1016/j.polymertesting.2004.09.005.
48. Alireza Naseri, Ramin Vafaeipour Sorkhabi and Masoud Naseri, "Evaluation strength nano geogrid concrete mats with high resistance using nanotechnology laboratory model," APCBEE Procedia., vol. 9, pp. 376-380, 2014, doi: 10.1016/j.apcbee.2014.01.066.
49. R. Siva Chidambaram and Pankaj Agarwal, "The confining effect of geo-grid on the mechanical properties of concrete specimens with steel fiber under compression and flexure," Construction and Building Materials., vol. 71, pp. 628-637, 2014, doi; 10.1016/j.conbuildmat.2014.08.059.
50. Sina Mirzapour Mounes, Mohamed Rehan Karim, Ali Khodaii and Mohamad Hadi Almasi, "Evaluation of permanent deformation of geogrid reinforced asphalt concrete using dynamic creep test," Geotextiles and Geomembranes,vol. 44, no. 1, pp. 109-116, Feb. 2016, doi: 10.1016/j.geotexmem.2015.06.003.
51. A. Arulrajah, M. A. Rahman, J. Piratheepan, M. W. Bo and M. A. Imteaz, "Evaluation of interface shear strength properties of geogrid-reinforced construction and demolition materials using a modified large scale direct shear testing apparatus," Journal of Materials in Civil Engineering (2013), doi:10.1061/(ASCE)MT.1943-5533.0000897
52. S. Ramakrishnan, M. Arun, S. Loganayagan and M. Mugeshkanna, "Strength and behaviour of geogrid reinforced concrete beams," International Journal of Civil Engineering and Technology., vol. 9, no. 6, pp. 1295-1303, June 2018.
53. R. A. Austin, "The effect of installation activities and fire exposure on geogrid performance," Geotextiles and Geomembranes., vol. 15, pp. 367-376, 1997, doi: 10.1016/S0266-1144(98)80009-5.
54. Richard J. Bathursta and Yoshihisa Miyata, "Reliability-based analysis of combined installation damage and creep for the tensile rupture limit state of geogrid reinforcement in Japan," Soils and Foundations., vol. 55, no. 2, pp. 437-446, 2015, doi: 10.1016/j.sandf.2015.02.017.
55. Hayssam Itani, George Saad and Ghassan Chehab, "The use of geogrid reinforcement for enhancing the performance of concrete overlays: An experimental and numerical assessment," Construction and Building Materials., vol. 124, pp. 826-837, 2016, doi: 10.1016/j.conbuildmat.2016.08.013.
56. Weiqiang Wang, M. Neaz Sheikh and Muhammad N. S. Hadi, "Confining concrete cover of GFRP tube reinforced concrete columns with polymer grids," The 12th International Symposium on Fiber Reinforced Polymers for Reinforced Concrete Structures (FRPRCS-12) & The 5th Asia-Pacific Conference on Fiber Reinforced Polymers in Structures (APFIS-2015) Joint Conference, 14-16 December 2015, Nanjing, China.
57. S. Geetha and M. Selvakumar, "Fibre reinforced lightweight composite reinforced with geogrid for wall panels," Materials Today: Proceedings, vol. 5, pp. 5623–5630, 2018, doi: 10.1016/j.matpr.2017.12.154.
58. Muhammad N. S. Hadi and Hua Zhao, "Experimental study of high-strength concrete columns confined with different types of mesh under eccentric and concentric loads," Journal of Materials in Civil Engineering, vol. 23, no. 6, June 1, 2011, doi: 10.1061/(ASCE)MT.1943-5533.0000234.
59. Xiaochao Tang, Isaac Higgins and Mohamad N. Jlilati, "Behavior of geogrid-reinforced portland cement concrete under static flexural loading," Infrastructures, vol. 3, no. 41, pp. 1-12, Sep. 2018, doi:10.3390/infrastructures3040041.
60. Tamikuni Komatsu, Hiroshi Kikuta, Yoshinobu Tuji and Eijiro Muramatsu, "Durability assessment of geogrid-reinforced asphalt concrete," Geotextiles and Geomembranes., vol. 16, pp. 257-271, 1998, doi: 10.1016/S0266-1144(97)10011-5.
61. R. Siva Chidambaram and Pankaj Agarwal, "Flexural and shear behavior of geo-grid confined RC beams with steel fiber reinforced concrete," Construction and Building Materials., vol. 78, pp. 271–280, 2015, doi: 10.1016/j.conbuildmat.2015.01.021.
62. Yutian Shao and Amir Mirmiran, "Control of plastic shrinkage cracking of concrete with carbon fiber reinforced polymer grids," Journal of Materials in Civil Engineering, vol. 19, no. 5, May 2007, doi: 10.1061/(ASCE)0899-1561(2007)19:5(441).
63. S. Sivakamasundaria and A. Joshua Daniela, Arun Kumar, "Study on flexural behavior of steel fiber RC beams confined with bi-axial geo-grid," Procedia Engineering, vol. 173, pp. 1431 – 1438, 2017, doi: 10.1016/j.proeng.2016.12.206.

64. X. Tang, G. R. Chehab and S. Kim, “Laboratory study of geogrid reinforcement in Portland cement concrete,” 6th RILEM International Conference on Cracking in Pavements, June 16-18, Chicago, Illinois, pp. 769-778, 2008 doi:10.1201/9780203882191.ch75.
65. Weiqiang Wang, M. Neaz Sheikh and Muhammad N. S. Hadi, “Axial compressive behaviour of concrete confined with polymer grid,” Materials and Structures, vol. 49, no. 9, pp. 3893- 3908, Sep. 2016, doi: 10.1617/s11527-015-0761-9.
66. Hakan Yalciner, Atila Kumbasaroglu, Ibrahim Ertuc and Ahmet Ihsan Turan, “Confinement effect of geo-grid and conventional shear reinforcement bars subjected to corrosion,” Structures., vol. 13, pp. 139–152, 2018, doi: 10.1016/j.istruc.2017.12.004.
67. Hakan Yalciner, Atila Kumbasaroglu and Ugurcan Ergun, “Effects of geo-grid and conventional stirrups on reinforced concrete beams with polypropylene fibers,” Structures., vol. 13, pp. 230–242, 2018, doi: 10.1016/j.istruc.2018.01.003.
68. Yu-Zhou Zheng, Wen-Wei Wang, Khalid M. Mosalam and Zhong-Feng Zhu, “Mechanical behavior of ultra-high toughness cementitious composite strengthened with fiber reinforced polymer grid,” Composite Structures, vol. 184, pp. 1-10, Jan. 2018, doi: 10.1016/j.compstruct.2017.09.073.
69. Martin Ziegler, “Application of geogrid reinforced constructions: history, recent and future developments,” Procedia Engineering, vol. 172, pp. 42-51, 2017, doi: 10.1016/j.proeng.2017.02.015.
70. Yan-Li Dong, Jie Han and Xiao-Hong Bai, “Numerical analysis of tensile behavior of geogrids with rectangular and triangular apertures,” Geotextiles and Geomembranes, vol. 29, pp. 83-91, 2011, doi:10.1016/j.geotexmem.2010.10.007.
71. G. Ferrotti, F. Canestrari, A. Virgili and A. Grilli, “A strategic laboratory approach for the performance investigation of geogrids in flexible pavements,” Construction and Building Materials ., vol. 25, pp. 2343–2348, 2011, doi: 10.1016/j.conbuildmat.2010.11.032.
72. Sam Deok Cho, Kwang Wu Lee, and Daniele A. Cazzuffi, Han Yong Jeon, “Evaluation of combination effects of installation damage and creep behavior on long-term design strength of geogrids,” Polymer Testing., vol. 25, pp. 819-828, 2006, doi:10.1016/j.polymertesting.2006.04.007.
73. D. Leshchinsky, M. Dechasakulsom, V. N. Kaliakin and H. I. Ling, “Creep and stress relaxation of geogrids, “creep and stress relaxation of geogrids,” Geosynthetics International, vol. 4, no. 5, pp. 463-479, 1997.
74. Yi-Chong Guo, Chun-Ling Xin, Ming-Shi Song and Ya-Dong He, “Study on short- and long-term creep behavior of plastics geogrid,” Polymer Testing., vol. 24, pp. 793-798, 2005, doi:10.1016/j.polymertesting.2005.02.014.
75. S. S. Yeo and Y. G. Hsuan, “Evaluation of creep behavior of high density polyethylene and polyethylene terephthalate geogrids,” Geotextiles and Geomembranes., vol. 28, pp. 409-421, 2010, doi:10.1016/j.geotexmem.2009.12.003.
76. J. H. Greenwood and A. Curson, “Life prediction of the oxidation of geogrids by three different methods,” Geotextiles and Geomembranes., vol. 34, pp. 93-99, 2012, doi:10.1016/j.geotexmem.2012.05.001.

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