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An insight on the response of foundations resting on sand with geosynthetic materials as a reinforcement

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Abstract: Application of Geosynthetic to resolve several geotechnical engineering problems is widely accepted and effective methods. It improved the foundation's bearing ability as well as minimizes the settlements associate to footings resting on weak soils. Their use is not only restricted to footings in fact they are widely used in improving the subgrade performance of the pavement sand for slope stabilizations. Over the past few decades numerous researchers have contributed their valuable results based on laboratory tests or numerical investigations. The present study aims to provide a detailed literature survey of research work associated with soil reinforcements together under a common hood which can help the upcoming researchers to understand the work done in this field simply and effectively. It also aims to highlight the effect of depth of geosynthetics, their respective width, relative density of sand or other geo-parameters and layers' number provided with geosynthetic affect the bearing capability and settlement behavior of reinforced and unreinforced soil structures.

1. Introduction

The provision of infrastructure services has a significant impact on a country's development and growth, these facilities are influential in determining economic development and aid in the reduction of poverty in the country. Therefore, "this rapid growth in industrialization and urbanization have led to the need and demand of endless research and innovations in the field of Engineering and Construction" (Ghani S., Kumari S., 2021). In recent years, there has been a phenomenal revolution in the growth of basic infrastructure, and many of these infrastructures are established on natural earth surfaces, requiring significant investments during building. Construction of sub and superstructures on cohesionless soil is extremely hazardous due to the prospect of the differential settlement's occurrence and soil enhancement methods have to be applied to raise the engineering characteristics of soil. Therefore, soil reinforcement by geosynthetic material is required for safety and serviceability criteria and to ensure a sustainable and specific resource-oriented work. "It is well-known that ground reinforcement method is fairly useful for enhancing the strength and deformation characteristics of soil, particularly for the case of cohesionless soils. It has been well perceived that, for small settlement, strains in the soil are in adequate to mobilize tensile load in geotextile reinforcement" (Kumar et al., 2020).

Application of geosynthetics is amongst one of the most efficient ground improvement technique because of its cost efficiency, easy adaptability, and reproducibility. Weak sand with no proper reinforcements is susceptible to liquefaction, landslides failure and several engineering complications.

Therefore, to reinforcement of weak sand to fulfil the need of geotechnical engineers is essential practice.

Geotextiles and Geo-grids have been effectively used to stabilize soil, and use of geosynthetic as one of the main building materials for stabilizing terrains has been shown to be technically effective (Ghani et al., 2021). Presently, nonwoven geotextiles, woven geotextiles, geogrids, geomembrane and geocells are widely used for reinforcing soil. Figure 1 presents different kind of geosynthetics used by engineers to improve the characteristic of soil. As can be seen these materials are highly potential to blend in with the earth to provide massive strength to weak soil. Geocells, geogrids and geotextile can easily enhance the permeability in cases where permeability is required.

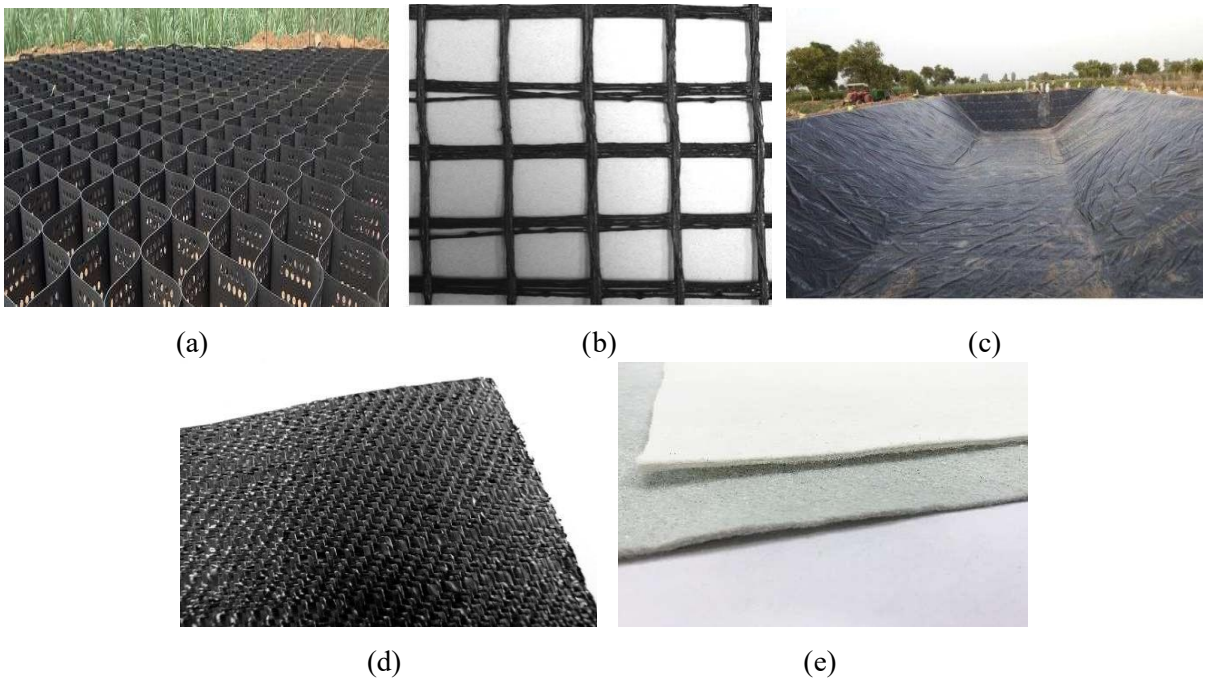

Figure 1. Different kind of Geosynthetics used for ground improvement (a) geocell (b) geogrid (c) geomembrane (d) woven-geotextile (e) non-woven geotextile

Application of geosynthetic in soil can deliver a reinforcement system which develops tensile forces amongst them that contributes to the stability of the complete system. Binquet and Lee (1975) have investigated the behavior in reinforced soil which became the pioneer for the researchers to study reinforced soil. Various researchers have studied the usage of geosynthetic soil strengthening to increase the bearing ability of soils and minimize unequal settlements. Reinforced soil increases the confinement stress at a lower cost than traditional methods which in turn increases the load carrying capacity and settlement problem associated to foundation resting on weak soil. The key motive of the current study is to provide an insight on the behavior of strengthened soil by geosynthetic material.

2. Review of Literature:

2.1 Experimental Investigation

Guido et al. (1986) "studied and performed a comprehensive comparison of the test observations of bearing capacity of a square footing resting on geogrid reinforced soil and geotextile reinforced soil determined from laboratory tests model". Observation made during the investigation for geogrids and geotextiles types of reinforcements, the bearing capacity ratio was established to be decreasing with a raise in ratio of *u/B* up to the acritical depth satisfy this criterion (u/B = 1). Once this criterion is met, it

remains persistent. *BCR* is found to be increased in both cases which means that geotextile and geogrid with a raise in the amount of stratum in reinforcements up to a maximum value of *N*=3, after this we can observe that there were very few differences in response by the raise in the amount of layers. For both of reinforcement's types, *BCR* is found to be increased with increasing *b*/*B*. However, the rate of increase for these reinforcement is quitted is similar specially for the geogrid reinforced soil slab, bearing capacity ratio was establish to increases quickly with a raise in *b*/*B* up to stage of 2.0, once this stage is achieved very little change is witnessed, whereas for the case of geotextile reinforced soil slab, the raise in bearing capability ratio leads to a raise in *b*/*B* ratio which is found to be more steady and residues comparatively unceasing at a bearing capacity ratio value of around 3.0. The results of the tests conclude that the ductile strength of the grid is not the only significant characteristic, in fact it was suggested that the aperture size of the grid should be measured in combination with the grid tensile power.

Khing et al. (1993) performed a chain of model trials in laboratory on a strip footing resting on sandy layer which has geogrid layers as a reinforcement. This research highlights the fact that use of geogrids can substantially enhance the response of settlement and *BCR*.

Omar et al. (1993) tested strip and square footings protected by sand and geogrid layers in a laboratory model. According to the findings, successful depths of 2B and 1.4B were observed for strengthened strip foundations and square foundations, respectively, for the advancement of optimum BCR. For the deployment of optimum *BCR* optimum width of buttressing layers required is about 8*B* and 4.5*B* for strip and square foundations.

Chandra and Shukla (1994) used an observational approach to assess the impact of pre-stressed geosynthetic reinforcement on the settlement activity of a granular fill-soft soil environment. Foundation model was fabricated which devises a coarse membrane fixed in a granular layer with alteration to embrace prestressing impact on the geosynthetic reinforcement. The test results from the study concludes that decrease in were perceived for little prestress in the corroboration. It was determined that prestressing the geosynthetics corroboration are important ground improvement method to decrease the settlement appearances of soil that is classification as soft where the enhancement membrane impact is noticed.

Yetimoglu et al. (1994) examined the bearing capability for the rectangular footholds on sand with geogrid layers. Laboratory test was commenced to relate the results determined using finite-element analyses. At the optimal embedment depth for the first reinforcing layer, the bearing ability was found to be optimum. It was also indicated that raising the hardness of the reinforcing layer above a certain point would only result in small increases in reinforced sand bearing capability.

Patra et al. (2005) carried out a series of model experiments in the lab to assess the BCR of a strip base braced by sand and multi-layered geogrids. Based on the tests, it was concluded that soil with similar characteristic, the eventual bearing capacity and *BCR* tends to proliferations with the increase in embedment ratio *df/B*.

C.R. Patra et al. (2005) discussed a detailed result of model test performed in laboratory. The test was performed to analyze the eventual bearing capacity of a strip foundation that were being supported by multi-layered geogrid-reinforced sand. The test results when compared to a theory proposed by Huang and Menq concluded that their theory provides a conservative estimate of the ultimate bearing capacity.

Lovisa et al. (2010) conducted experimental model tests in the lab along with numerical simulation to examine sand behavior of bed reinforced with two-dimensional prestressed geotextile which supports circular foundation and derived that the settlement behavior and bearing capability of this soil boosted significantly with the accumulation of prestress on the geotextile reinforcements. For small displacements, soil reinforced with geotextile that are non- prestressed are irrelevant past embedment

depth of 50 mm. Nevertheless, the settlement behavior and load bearing capacity were significantly enriched due to the accumulation of prestress of the geotextile reinforcement at all footing depths.

Unreinforced foundation that rests on sand bed exhibited a good agreement with Meyerhof bearing capacity equations when compared with their evaluated ultimate bearing capacity. The altered bearing capacity equation includes reinforcements which also produced theoretical results that were found analogous to those acquired from laboratory model tests. The results obtained from the laboratory tests were observed to exhibit a good relation with the literature for relationship of modulus of subgrade response for a scrupulous footing embedment depth. As well as conclusion drawn from finite element analysis with Plaxis also exhibited a good correlation by means of the results acquired from laboratory model tests which effectively validate the equation among modulus of elasticity and modulus of subgrade response. To accomplish ideal outcomes in the field the prestressing of geosynthetic should be pulled out ensuing the model test methods and anchor the trenches of the area to be reinforced and they're nearby surrounding before placing the granular fill all over it. However, simulating this procedure of pulling out in field conditions is not an easy task especially when there is the need to have a highly prestressed geosynthetic.

S.A. Naeini et al. (2012) presented the results on the consequence of geosynthetic on bearing capacity of a strip footing resting on geo-reinforced clayey slopes. Sequence of numerical study incorporating finite element analyses on reinforced and unreinforced strip footing was performed and the analysis concluded that the load-settlement behavior and ultimate bearing capacity of footing can be significantly enhanced by the adding reinforcing layer. It was observed that bearing capacity increases with an increase in edge distance for reinforced and unreinforced slopes.

Artidteang et al. (2012) introduced an experimental investigation on relatively new kind of geotextile, its name Limited life Geotextiles (LLGs) created from natural fibers used in three patterns plain, knot-plain, and hexagonal patterns. Test results highlights that plain pattern is the most suitable pattern due to its high tensile strength.

Abu-Farsakh et al. (2013) investigated the behavior of geosynthetic-reinforced grimy soil foundations. Effect of several parameters which tends to influence the behavior of protected sandy soil was also studied using laboratory model tests. Parameters like top layer spacing, vertical spacing between layers, tensile modulus, number of reinforcement layers type of geosynthetic reinforcement, embedment depth, and shape of footing have substantial effect on the footing. The results observed from the study established the advantage of using geosynthetic-reinforced sand foundations. It was also concluded that the reinforcement layout has a very substantial influence on the behavior of reinforced sand foundation.

Davarci et al. (2014) studied the response of ultimate bearing capacity of unreinforced and reinforced geogrid multi edge shallow foundations resting on dense and loose sand bed. Near about 140 model tests were performed in laboratory applying four diverse model with rigid plates and with different shapes. Several parameters that were adopted during the testing procedure includes the thickness of sand soil, vertical spacing of reinforcement layers, depth of first reinforcement and number of reinforcement layers. The findings of the laboratory tests show that the use of geogrid layers in sand beds has a significant impact on the behavior capability. It also highlighted that the optimum corroboration parameters are self-governing from the shape of the footings.

Elifciceka et.al. (2015) investigated the result of on the effect of corroboration length with the help of laboratory ideal tests on unreinforced and reinforced sand beds. To determine the optimum reinforcement length certain variations of type and number of reinforcements were also carried out. The results observed highlighted that load–settlement and bearing ratio attained for the reinforced footing were much better as compared to unreinforced footings.

Shadmand (2017) defines the load-carrying capacity of reinforced sand applied with two kind of corroboration method s that are *FGR* and *GOR*. FGR denotes to the geocell without hole under the

base and GOR denotes to the geocells with a hole under the footing. The amount of geocells stratum, deepness of geocells bed, width of aperture in them and the relative density of the soil were constantly varied along the test series. Results exposed that the use of geocells with an opening reinforcement and full geocell corroboration method boosts the bearing capability significantly and lessen the basis arrangement along with the decrement in surface heave.

Mittaland Gill (2017) performed series of experiments on model footing tests on sand reinforced with trash tire flakes to look at the effectiveness of small pieces of tire chips, reinforcement depths and the respective relative density of the sand used. The test results exposed that the pressure settlement behavior of tire- resistant system is much better than geo grid-reinforced sand. As it provides an alternate reinforcement method which is beneficial from economic and environmental perspective.

Liu et al. (2018) used a mixture of as a soil stabilizer to reinforce sand and performed series of laboratory tests to investigate the properties associated with the strength of sand reinforcement. The results highlight that the strength of sand specimens reinforced with a combination of organic polymer stabilizer as well as polypropylene fibers improved muscularly. The application of such reinforcements that are made up of mixtures of organic polymer as well as fiber can be selected like an efficacious practice to boost the potency of weak sand.

Priya and Muttharam (2019) studied the response of geosynthetic reinforced sand bed by performing a sequence of laboratory test on a square footing resting on geosynthetic reinforced sand bed. Reinforcement configuration was improved by providing variations in parameters like number of reinforcing layers and vertical spacing of reinforcement. They suggested that corroboration increases the bearing capacity as well as reduce the settlement. The development observed in bearing capacity was nearly 2.8 times with the addition of corroboration. They also concluded that influence of breadth of corroboration is more pronounced in case of single layer of support. Presence of anchors also improves foundation soil and their respective bearing capacity by 3.9 times as anchors provided in soil tends to develop passive resistance.

Kumar (2019) performed series experiments on modelled strip footings resting on a reinforced clayey soil. The clayey soil had horizontal layers of strip corroboration along with conclusion plate anchor. The study concluded that application of such end anchors tends to increase the bearing capacity considerably and promotes the use of shorter reinforcement with low coverage ratio.

Debnath and Ghosh (2020) used limit equilibrium method. These methods were under the influence of pseudo-static approach that was used to evaluate the ultimate bearing capacity of shallow strip footing resting on geosynthetic reinforced soils.

All of them came to the conclusion that the proposed approach could be used to assess the bearing capability of geosynthetic hardened soils. Patel and Singh (2020) used glass fiber to reinforce clayey and sandy soil and conducted a comparative analysis to determine their deformation and shear strength behavior. They found that kind of reinforcement which is glass fiber has a more positive response for sand than clay.

2.2 Numerical Investigation

Latha and Somwanshi (2009a) investigated the results of model tests performed in laboratory and numerical simulations carried out on square footings resting on sand. The response of bearing capacity of square footings resting on geosynthetic reinforced sand and the influence of various reinforcement parameters was assessed through such efficient model studies. It was determined that the configuration of the applied soil reinforcements showed a dynamic response in boosting the bearing capability as comparison with the geosynthetic tensile strength. The study also suggested that the effective depth of reinforcement is twice the width of the footing and optimum spacing of geosynthetic layers is half the width of the footing.

On a square basis, Latha and Somwanshi (2009b) present an experimental and numerical analysis supported by geosynthetic in sand beds. Its observed response of diverse form of geosynthetic corroboration applied in foundation beds is compared and discussed. Furthermore, the laboratory tests performed on reinforced and unreinforced basis are simulated in a numerical model and the consequences are explored. Results obtained from the experimental as well as numerical studies established that the geocell is the most beneficial appearance of soil reinforcement technique.

Kazi et al. (2015) described an experimental investigation of a strip footing resting on a homogeneously reinforced sand bed to study the load–settlement behavior of the system. The results observed from the experimental analysis were further compared with numerical findings which were performed on Plaxis 2D software using finite-element modelling. The results highlighted that with increasing footing embedment depth and with the provision of reinforcement there is a substantial enhancement in load-bearing capacity and the stiffness of the sand bed. The numerical results show the similar trend as compared to experimental study.

Tavangar and Shooshpasha (2016) highlight the consequences of using non-woven geotextile on footings resting sand with medium density for improving their ultimate bearing capacity. The test inspects the effects various other parameters like depth, geotextiles width, amount of stratum and spacing on the footings' ultimate bearing capability. The test result signifies that for such system the optimum bearing capacity can be achieved by applying four geotextile layers. Furthermore, the impact of plate size and sample size were also examined numerically with the help of 3-Dfinite element analyses which indicates that with the increase in size of the plate *BCR* decrease.

Tafreshia et al. (2016) performed experimental and numerical study to scrutinize the response of footing using multi layered rubber sand mixture (RSM). They suggested that RSM improves the response of footings exposed to heavy loading. There use of waste tires as a combined soil material used for civil engineering practices to improves the environmental waste impacts. Numerical analysis concludes that the existence of multiple layers of soil and rubber leads to increase of passive zones in the footing. These expansions are associated with the efficiency of the incarceration delivered by the addition of rubbers, and this tends to make the bed ricochet less.

Ouria and Mahmoudi (2017) presented the results of a laboratory and numerical investigation carried out to study the effects of cement dealing on the interface among sand and geotextile and their effects on the bearing capacity of a substance. Based on the obtained results from the laboratory tests indicated that cement treatment increases the bearing capacity of the foundation reliant on the length of the corroboration. Such kind of effects seemed to be more evident in little settlement levels, and reduces as the length of the corroboration is increased. A finite element model was standardized and used for further studies.

Benmebarek et al. (2018) presents a numerical computation using FLAC code which develops a novel reinforcement practice by using geosynthetic reinforcement that has the potential to enhance the load bearing capacity of shallow foundations resting on a sandy soil. A detailed numerical analysis of a strip footing resting on a reinforced sand bed was performed with horizontal layer. These horizontal layers were fully wrapped about the trimmings of geotextile. The results indicate that the reinforced sand bed delivers a substantial enhancement in the bearing capacity. Das et al. (2020) used an inclined load to conduct a numerical analysis when sitting on a strip basis laying on sand soil supported with geogrid. They discussed the relative density of the used sand, reaction of geogrid layers, the load tendency working on the base, and failure mechanisms, and concluded that adding several layers of geogrid could greatly improve footing behavior while also resulting in a more cost-effective footing design.

Xu et al. (2019) performed thirteen model tests on soil mass reinforced with geosynthetic and sand being used as backfill to inspect the definitive bearing capacity of the system. Analytical modelling was performed for calculating the ultimate bearing capacity of the geosynthetic reinforced soil mass

based on the Mohr-Coulomb failure criterion. The observed test results were correlated with the results found in literature. The study concluded that analytical modelling provides a better insight of there in forced system and can be used to understand the bearing capacity response of reinforced systems.

3. Important Findings

Geosynthetic reinforced soil have gained immense popularity in recent years. Such equilibrium methods have been widely worn to improve asset characteristics of sand to fulfil their needs of geotechnical engineering. Numerous kinds of soil reinforcements are used such as geocells, geomembrane, geogrids, woven geotextiles, non-woven geotextiles etc. A tabular summary of different types of geosynthetics used by various researchers have been presented below. Table 1 provides the geosynthetics type used by different authors. The table can be used to analyses the fact that which type of geosynthetic has been extensively used by most of the researchers for better ground improvement. Based on Table 1 geogrid are the most commonly used type of geosynthetics.

Table 1. The various geosynthetics which used by researchers.

NAME OF AUTHER	GEOSYNTHETIC USED
Guido et al. (1980)	Square Sheets of Geogrid
Mandal and Manjunath (1994)	Single Layer of Geosynthetics
Dash et al. (1994)	Geocell Mattress & Geogrid Layer
Benrabah et al. (1996)	Geomembrane Layers
Lopes and Ladeira (1996)	A Uniaxial Geogrid
Zhao et al. (1997)	Multi-layer Geogrid
Palmeira et al. (1998)	Geosynthetic Reinforcement
Dash et al. (2001)	Geocell Mattress
S. K. Dash et al. (2004)	Geocell reinforcement
C. R. Patra et al. (2005)	Geogrid
S. A. Naeini et al. (2012)	Geogrid
Artidteang et al. (2012)	Limited life Geotextiles (LLGs)
Davarci et al. (2014)	Geogrids
ElifCiceka et al. (2015)	Woven Geotextile Different and Geogrids
Tavangar and Shooshpasha (2016)	non-woven geotextile
Tafreshia et al. (2016)	multi layered rubber sand mixture
Mittal and Gill (2017)	sand reinforced with waste tire chips
Benmebarek et al. (2018)	Geosynthetic Reinforcement
Das et al. (2020)	Multi-layer Geogrid

The aforementioned section provides an itemized study on the performance of footings on the reinforced soil by geosynthetics. Various researchers have employed numerous techniques that highlights the fact that geosynthetics reinforcement is a successful and effective tool for ground improvement. Figure 2 represent a donut plot for different categories of geosynthetic used. The plot clearly highlights that geogrids are the most commonly used form of geosynthetics.

Geosynthetics not only improve the bearing capacity characteristics in fact they also enhance the load carrying capability and minimizes surface heave of the footing bed. It also stabilizes the weak subgrade and provides significant savings in material and excavation. The rate of footing settlement also decreases up to a considerable extent. When used for shallow foundation it tends to raise the safety factor of embankments on soft soils. Over the past few decades' geosynthetics have been researched and discussed and still it has the potential to be explored and new innovations can be produced.

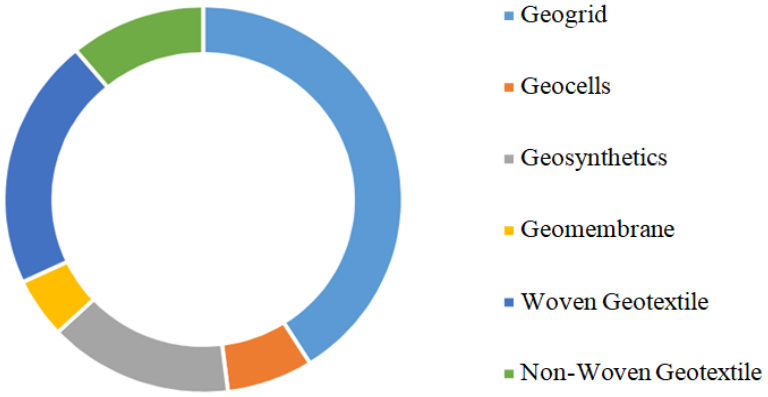

Figure 2. Donut plot for Geosynthetic usage

Lately researchers have started using the industrial waste such as rubber and tires as reinforcing materials. These newly developed reinforcing systems made of waste materials have shown promising results in boosting the load carrying capability of the footing. Figure 3 presents bearing pressure and settlement relation observed in the literature. Figure 4 highlights the observed settlement by various researchers with the application of geosynthetics in a format of box plot. Naeini et al. (2012) exhibits the least settlement out of the considered researchers work. Figure 5 presents the various ranges of relative density, angle of shearing resistance and average settlement observed by researchers. The following table 2 presents the soil compactness based on relative density and angle of shearing resistance, which clarify that the friction angle increases with the increase of the relative density, and the reason to that is when the relative density value raises, the spaces between the particles will decrease which leads to rise in the contact between them and boost in the friction angle and the bearing capacity.

Relative Density (%)	**Degree of Soil Compaction**	**Internal Angle of Friction (^{0})**
0-15	Very loose	<28
15-35	Loose	28-30
35-65	Medium	30-36
65-85	Dense	36-41
85-100	Very Dense	>41

Table 2. Relation between soil compactness, angle of shearing resistance and relative density.

Such materials not only provide a cheap ground improvement alternative in fact they also contribute in a sustainable construction practice. The reuse of such waste also contributes to the environmental stability by minimizing industrial waste up to a considerable extent. The present study also highlights two different methodologies observed in the literature i.e., experimental investigation and numerical investigation. Certain researchers have focused on experimental procedure to study the behavior of soil reinforced with different kind of geosynthetics. Test performed in the lab helps in understanding the effects of several contributing parameters such as depth of geosynthetics, their respective width, relative density of sand or other geo-parameters and number of geosynthetic layers. Contrary to experimental investigation, numerical investigations are quite convenient to perform and provide better understanding about the distribution and displacements of stresses below the reinforced footing. Although most of the researchers have adopted experimental investigation to study the

response of geosynthetics or soil reinforcements yet the combination of numerical and experimental study seemed to be more productive

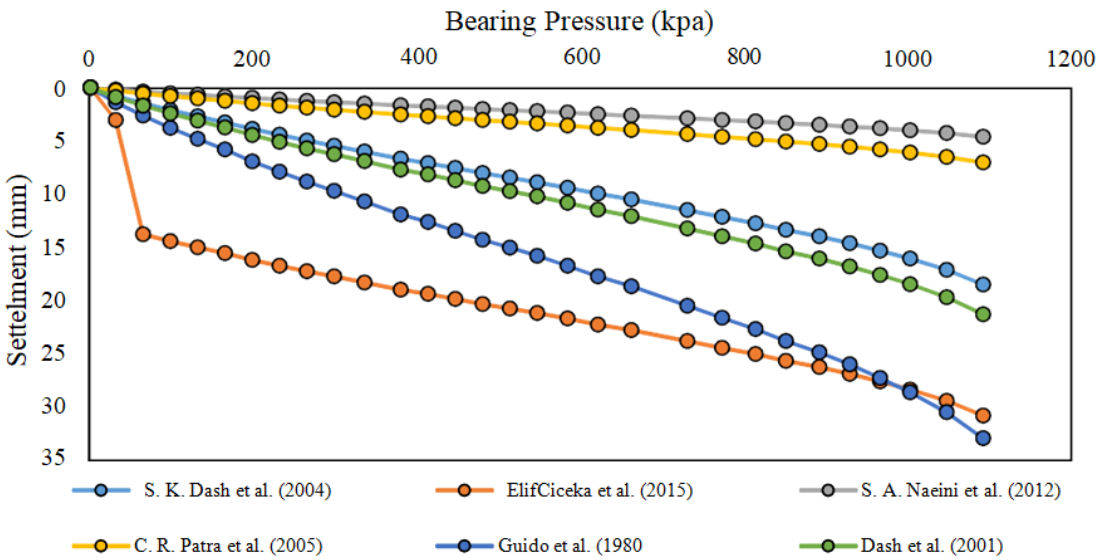

Figure 3. Bearing pressure v/s settlement for various studies

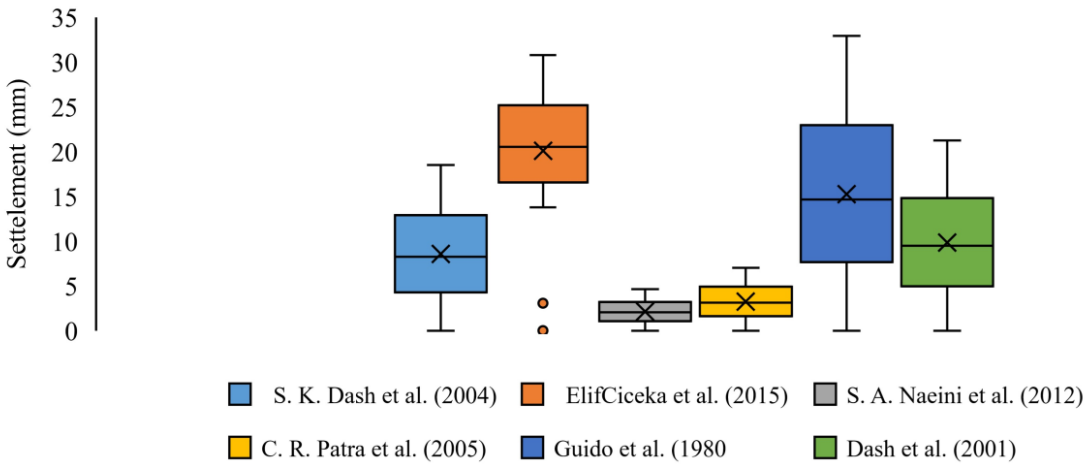

Figure 4. Box plots for settlement observed by various researchers with the application of geosynthetics

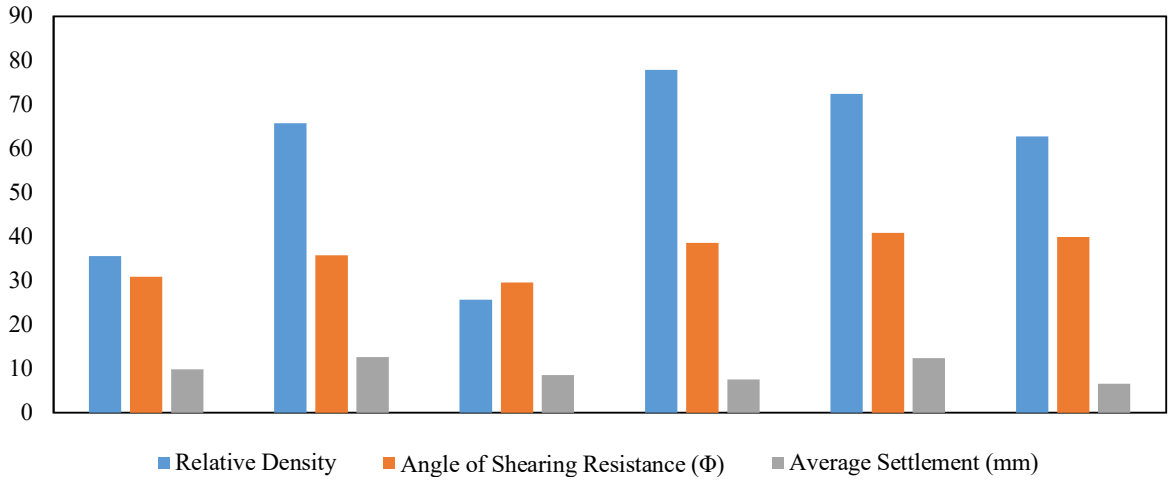

Figure 5. several values of relative density, angle of shearing resistance and average observed settlement based on various studies

4. Conclusion

The present study based on the aforementioned discussions aims to highlight the effects of soil reinforcement using various geosynthetics material on carrying capability and settlement response of various footings supported on sand beds. It also made effort to signify the effectiveness of several other parameters on the settlement and *BCR* response. The carrying capability increases because of using the geosynthetic is one of the most common findings determined in most of the studies. This section aims to combine the results of various researchers into a common band that can help the upcoming researchers to understand the work done in this field simply and effectively. Therefore, based on the above literature following conclusions are drawn:

- The use of geosynthetics droves to a substantial raise in bearing capability of the foundation. The depth of geosynthetics, their respective width, relative density of sand or other geo-parameters and number of geosynthetic layers are crucial parameters which affect the behavior of reinforcing system up to a considerable extent.
- It is also noted that the carrying capability could be improved if reinforcements are suitably located relative to the footing, which means that the configuration and layout of the layers is important as the tensile strength and the amount of them.
- Several test results established that the horizontal reinforcement is more effective as compared to the vertical reinforcement in improving the bearing capacity, though the vertical method presented a passable improvement.
- No clear failure has noticed with the using of geocells as a form of reinforcement, in spite of the settlement was reached 50% of the base diameter and the load was eight times the unreinforced sand's ultimate bearing capability.
- The implementation of geosynthetic reinforcement raises the plastic failure area in the reinforced soil structure which leads to augmentation of the load bearing capacity substantially.
- Numerical investigation of reinforcement the sand beds by geosynthetic is useful in understanding the distribution and displacements of stresses below the reinforced footing, which is difficult to study with the other methods.

- Use of recyclable materials such like waste rubber sand used tires as ground improvement technique is the new trend that should be positively explored by upcoming researchers as it provides a cheap alternative as well as promotes sustainable constriction practices.

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