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INVESTIGATIONS OF BURIED STRUCTURE ENHANCED BY GEOSYNTHETIC PRODUCTS: A REVIEW

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ABSTRACT

Protecting existing utility lines in densely populated metropolitan areas is a significant concern, particularly when new roadways or bridges are constructed over these vital infrastructures. Various accidents or natural disasters may damage them. As a result of the pipe's wall full force and non-uniform load, shallowly buried pipes exposed to surface loads experience greater bending strains and are susceptible to failure. The reduced confinement of the soil backfill exacerbates these issues as well. Different geosynthetic products have demonstrated that they can be utilized to protect buried structures. To better comprehend the effects of different geosynthetic products on soil-buried structure interaction, this research performed a review investigation series for experimental, numerical, and field tests under repeated loads to evaluate the behavior of buried structures, soil responses, and geosynthetic mechanisms. A recap of previous study results and a discussion of the subject's research gaps are offered. Based on previous research, it is intelligible that geosynthetics are becoming a viable and sustainable approach for ground reinforcement. In addition, the findings demonstrated many parameters affect the degree of protection by geosynthetics, including the geogrid or geocell width, geogrid or geocell installation depth, geofoam height, the effectiveness of granular backfill stiffness and increased embedment depth.

***KEYWORDS*:** Arching in soil; Buried structures; Geosynthetics; Induced trench; Stress distribution

INTRODUCTION

One of the urban underground structure's most prevalent and critical parts is buried pipelines. Proper design considering diverse loading circumstances, especially those linked to overburden stresses and traffic loads, is crucial for these facilities' functioning[1]. In complicated metropolitan networks, building over existing utility pipes or underground conduits is often necessary, particularly in crowded urban areas. The existing underground pipes might be subject to considerable stress from these new constructions since they were not designed to resist them[2]. The resistance system of buried structures to loading is highly dependent to pipe rigidity and surrounding soil. Stresses analysis has proven that only 5% of the overall resistance to deformation is generally supplied by the pipe's stiffness, where the earth provides the remaining 95% of the deformation resistance. Because of this, the bedding and backfill materials are very important for the structural integrity and deformation of underground pipes[3].

Besides, Al-Naddaf, et al. [4] confirmed that the geometry of the buried structure and relative soil stiffness affect the size and distribution of the vertical loads above it. They disclosed also that the settlement of the surrounding soil is greater than that of the central soil column above the buried structure, because the stiffness of the buried structure is often higher than that of the surrounding soil. The relative settlement produces vertical stresses above the buried structure by creating shear forces between the soil around it, and the soil column above it. Consequently, the weight of the dirt prism is outweighed by the stress on the pipe (negative soil arching). All patterns are inverted with an embedded flexible pipe in the soil. Therefore, the load on the flexible pipe will be less than the dirt prism's weight (positive soil arching) [5, 6], as shown in **Error! Reference source not found.**. Typically, soil arching is occurred by a relative displacement between yielding and stable soil mass. The degree of soil arching varies with the relative displacement [7].

practically, unfavorable buried pipe conditions are commonly existed, such as low

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cover or low-quality backfill, or an existing buried conduit may need to be restored or reconditioned. Minimizing deflections (in buried structures/pipes, methods for alleviating stress and strain, and decreasing surface deflection) involve induced trenches, casings, relieving slabs, and, more recently is the protection via geosynthetics. Geosynthetics provide various innovative and cost-effective ways to improve the execution of pipe-soil systems[8].

Noticeably, using geosynthetics applications is growing rapidly, which has driven many researchers and industrial to summarize past findings and analyze the prospects of geosynthetics technology. This paper is an attempt to offer a comprehensive review for the literature on protecting buried structures by geosynthetic. The emphasis is given to the recent literature to highlight the latest development in geosynthetic behavior, and its effect on soil settlement, further to buried structures displacement. The goal is to present a summary of the past studies and the scope of future research directions.

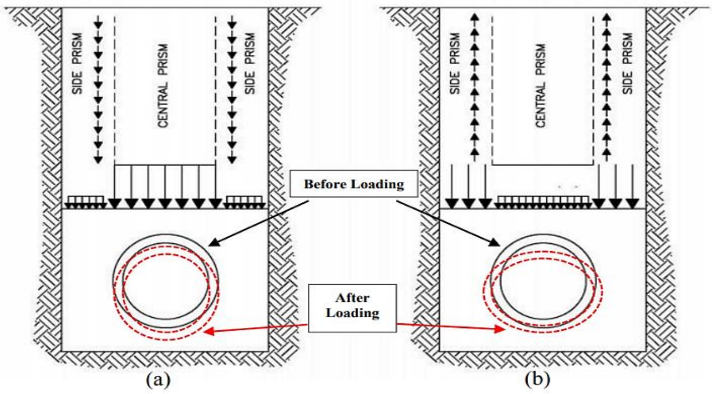


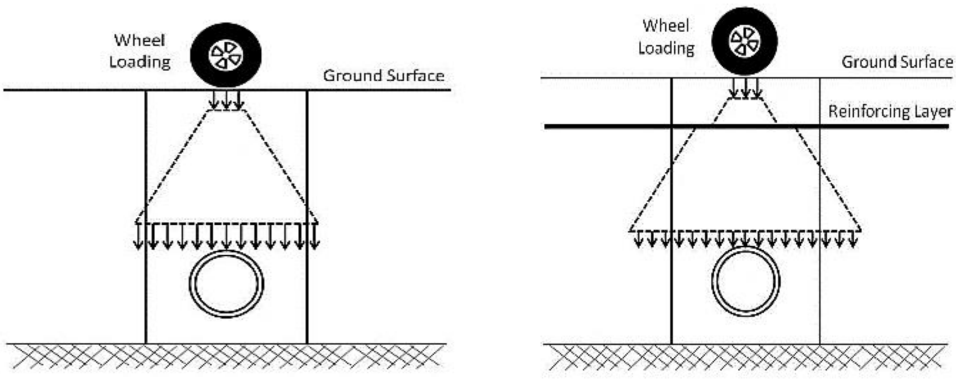
Fig.(1):- Diagram for arching soil action [6]: (a) negative soil arching (b) positive soil arching

1. GEOSYNTHETICS CHARACTERIZATION

In various methods, geosynthetics have been proposed to improve the performance of pipe-soil systems. For instance: due to its incorporation, a geosynthetic provides reinforcing function by enhancing the mechanical characteristics of a soil mass. When geosynthetic reinforcement and soil are installed, a composite material (reinforced soil) with better compressive and tensile strength (similar to reinforced concrete in theory) is produced. Any geosynthetic used as reinforcement in geotechnical constructions must primarily withstand applied stresses or avoid unacceptable deformations. Also, the potential effect of a geosynthetic applied between two materials is achieved when it reduces or distributes stresses and strains delivered to the substance to prevent damage. [9].

Geosynthetics is divided into two parts regarding protection methods for buried structures:

1. Transfer pressure to a larger soil area than would otherwise be the case [10], as shown in **Error! Reference source not found.**. Of these types, geogrid, geotextile, and geocell are in a reinforced soil foundation. The geogrids available on the market consist mostly of uniaxial, biaxial, and triaxial geogrids, while geotextiles are classified as either nonwoven or woven [11].



(a) (b)

Fig.(2):- Distribution of stresses technique above **the** buried pipe [10] : (a) without reinforcement (b) with reinforcement

2. Low stiffness with a compressible layer is embedded above a rigid structure to reverse the relative displacement in the surrounding soil such as Extruded Polystyrene (EPS) geofoam blocks have beneficial characteristics being a conducive approach to use as a stress dissipater for buried structures, as shown in **Error! Reference source not found.**. From these features, it's a lightweight material used in various geotechnical engineering implementations, such as embankment construction and bridge approaches, minimize earth loads on neighboring or underlying soils and structures. Additionally, EPS is used as a compressible material atop deeply underground culverts to encourage positive arching and lessen the load transmitted to the structure's walls [12-14].

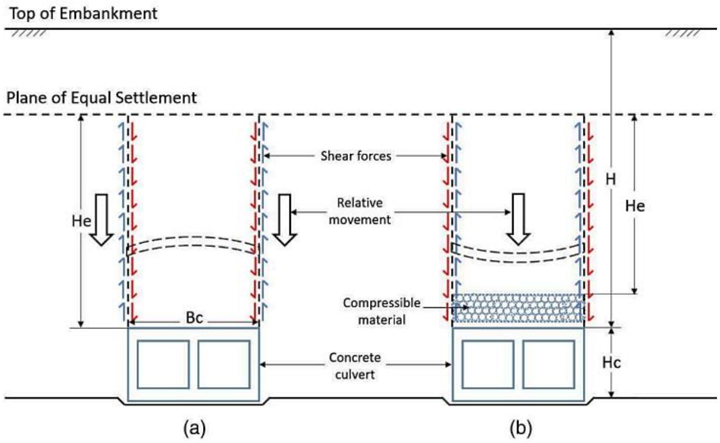


Fig.(3):- Simplified arching mechanism [14]: (a) without compressible material (b) with compressible material

2. Field Performance

The field test is the most direct and dependable method for analyzing the load behavior of soil-reinforced foundations. Due to the difficult geological circumstances and the high expense of performing field tests, there are modicum research works on the field loading tests associated with the reinforced foundation [11]. Typically, field testing entails excavating a trench and depositing pipe samples in the field, backfilling to the appropriate cover height, or testing an existing pipe by passing or laying a weight on a pipe sample [15, 16]. Luo, et al. [17] conducted a comparative field testing to examine the reinforcing impact of geosynthetic materials in treating soft rock subgrade, offering a rationale for deploying geocell in soft rock subgrade. The reinforcing treatment tests of the soft rock subgrade was included utilizing four distinct subgrade treatment strategies. Their results indicated that the average penetration of the subgrade's reinforcing layer is reduced by 25%, the converted California Bearing Ratio is enhanced by 46%, and the dynamic deformation modulus is improved by 27% when treating soft rock subgrades with unscreened gravel and geocell. Additionally, the soil pressure is reduced by 30.1 to 37.2 %. Inside the geocell, the vehicle loads produce strain, which is linearly related to the vehicle load. The surface deflection of the subgrade treated with unscreened gravel and geocell decreased by 26.4 % to 29.2 %, according to the numerical simulation findings. Using geocell in soft rock subgrade improves the subgrade's overall stiffness and significantly lowers the surface deflection caused by the vehicle's load.

Babagiray, et al. [18] introduced the results of eight full-scale impact load tests conducted on soils reinforced with geocell, geogrid, strip geogrid, composite structures made of geogrid and strip geogrid, and geotextiles of various densities and thicknesses on 600 mm buried HDPE (high-density polyethylene) pipes diameter and 2000 mm in length. A 3125 N concrete block representing the free fall of a natural hazard, such as a rock fall or landslide, from a height of 3000 mm was used to derive the impact-type dynamic load. This research examined the energy absorption capabilities and pressure dissipation of geosynthetics used to protect buried structures under identical circumstances [18]. To assess tests responses, two pressure cells and two accelerometers were installed in the soil and pipe, respectively, to determine the geosynthetic protective layers' relative merit and pressure absorption capabilities. Regarding the reference test, it was found that geotextile (800 gr/m^2) performed the best in terms of pressure absorption (about 46.6%) and acceleration reduction capabilities (about 83.3 %). Compared to their conventional equivalents, composite structures of geogrid and strip geogrid fared better regarding acceleration and pressure absorption. The material that performed the worst was geocell, which had a pressure absorption rate of 9.5%, and an acceleration reduction rate of 33.3%.

Even with the studies that have been conducted to know the behavior of buried pipes, there are still some gaps that must be filled, including knowing the maximum extent of deformation of the structures until they reach to a stage of failure because this is not possible in field tests, to prevent damage to the truck and equipment. Besides there is no load rate can be recorded. It may be assumed that the load is being applied constantly and rapidly, as the maximum load will be applied after the weight/truck is positioned atop the pipe; laboratory and numerical tests have been conducted to get more accurate results [6]. **Error! Reference source not found.** presents an example of the loaded truck used for weight applied in a field test, where Chaallal, et al. [19] achieved the necessary truckload by loading the truck with concrete blocks of recognized weight. The primary goal of the fieldwork was to assess the short-term functionality of the flexible pipes installed at shallow depths.

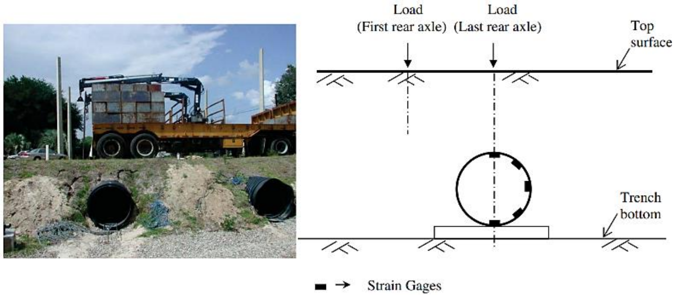


Fig.(4):- A typical load and the location of the truck's axles over the pipe [19]

4. EXPERIMENTAL AND NUMERICAL STUDIES

Most prior research works on geosynthetics' effectiveness for the behavior of underground utilities have relied on soil box model experiments. The model tests conducted in the lab are more cost-effective than field testing, which allow for more precision in the soil's placement, compaction, burial depth, and other system components. In addition, the controlled conditions of the laboratory provide for ideal environment testing (e.g., avoiding the effects of winds, rain, and temperature variation). **Error! Reference source not found.** presents an example of rigid box in experimental test, where Alotaibi, et al. [20] used a testing box to investigate the effect of geosynthetics on the behavior of buried pipes for maximum box dimensions of 2100mm long, 2000mm in height, and 3000mm in width. Six I-shaped steel beams were used at the base, sandwiched between two steel sheets size 10 mm thick, to give the steel box its rigidity. The front wall was split into four sections to facilitate soil compaction. The top of the soil model is loaded using a rigid loading frame attached to the bottom of the box. The actuator was a hydraulic jack with a 100 kN capacity that controlled by a program-operator. Besides, a numerical modeling, a finite element analysis has proved to be very useful in analyzing buried structures. It is worth mentioning that many finite element programs are available in the market, each with several advantages and disadvantages depending on the case been studied.

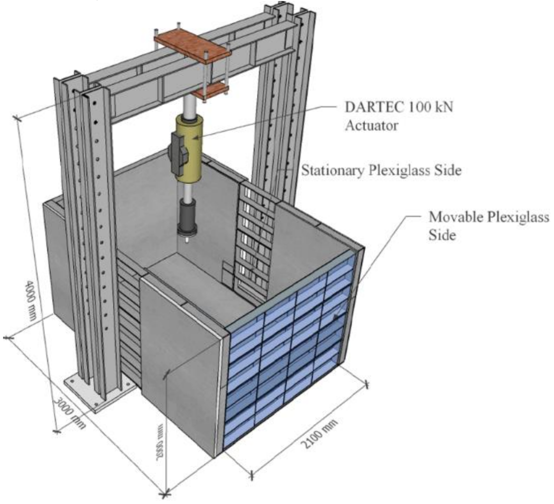


Fig.(5):- Schematic of the rigid box model [20]

4.1 Effects of Geofoam

It is well-known that soil properties, structural stiffness, and geometric features, all are affecting the earth loads operating on buried structures. The induced trench installation technique has been widely used to alleviate soil stresses on buried rigid pipes by inducing positive soil pressure above them. [21, 22]. Kılıç and Akınay [23] evaluated the effects of using EPS as a compressible inclusion above buried HDPE pipe using full-scale laboratory testing. EPS with a nominal density of 10 kg/m^3 was employed in the studies because it compresses more easily than EPS with a higher density. The effects of EPS on the behavior of a lined corrugated-wall HDPE pipe buried in a poorly graded sand were studied using a large-scale experimental setup. For this goal, five unique compressible inclusion geometries were created. To simulate the geostatic forces created by shallow and deep soil fills, vertical surcharge loads of up to 200 kPa were applied to the surface of the burial medium. Above the pipe crown, a single EPS panel is recommended for optimal performance and cost-effectiveness. This plat should be as wide as one outer pipe diameter and as thick as one-sixth of the nominal pipe diameter. It reduced stress by as much as 76% at the pipe crown and 66% along the pipe walls at the springline. Such experiment result showed that the vertical pipe deflection was reduced by 87%, and horizontal pipe deflection was reduced by 60% under a surcharge load of 200 kPa. Furthermore, with the 100-125 kPa surcharge stress range, pipe deflections were almost nonexistent under mention loading phenomenon. The findings demonstrated that the induced trench installation method may increase the positive soil arching over a buried flexible pipe and that this impact is not dependent on the vertical deflection of the pipe.

Santos, et al. [24] focused on investigating the impacts of trench installation methods using EPS geofoam for buried corrugated steel arch structure behavior. The structure was modeled and assessed using the finite element analysis program ABAQUS. This study used steel corrugated (S275) with thicknesses varying from 3 mm to 7 mm, and 152 mm × 51 mm and 400 mm ×150 mm profiles were used. Three parametric analyses were performed, one for the initial (no EPS geofoam) configuration, one for the imperfect trench installation (ITI), and other for the embedded trench installation (ETI). In each test, the shape, thickness, and corrugation profile of the steel used in the EPS geofoam were considered into account. The ETI models reduced earth pressure, deflection, and crown stress by 68%, 40%, and 39%, respectively, according to the finite element analysis. The geofoam height greatly reduces ground pressure, stress, and deflection around the arch structure in the ETI and ITI models. In contrast, other than the pressure around the spring line, the arch's behavior was mostly unaffected by the geofoam's width. **Error! Reference source not found.** presents the difference in installation between the (ETI) and (ITI) mechanisms.

Al-Naddaf, et al. [26] focused on the vertical stress response of the soil surrounding a buried steel pipe which was studied using the finite element technique under footing loading. A finite element model was developed and verified in Plaxis3D based on the results of a scaled-down physical test performed in a test box subjected to plane-strain circumstances. Next, a parametric study was carried out to examine the impacts of pipe location or embedment ratio, footing width, and loading condition. The Hardening Soil (HS) model accurately represented the backfill material's reaction to the numerical analysis' findings. The numerical study also revealed that when the embankment height doubled the pipe diameter, the pressure on the pipe dropped with increasing embedment depth. In contrast, the pressure rose with increasing footing width. When the embankment height is equal to the pipe diameter (H/D = 1), a critical footing width of 1B was shown to be responsible for the maximum pressure on the pipe. Due to the increased vertical loads on the pipe for H/D = 1, the limited footing loading condition becomes crucial.

In other study, Kılıç, et al. [27] investigated the numerical study for large-diameter thermoplastic pipes exposed to high fill stresses centered on induced trench installation (ITI) and embedded trench installation (ETI) models. The research compared the stresses and deflections caused by crushed stone, sand, and clay backfill on HDPE and PVC by accounting for pipe diameter, stiffness, and thermoplastic material type. EPS Geofoam was inserted into ITI and ETI models then subjected to several studies. Pipes with ITI or ETI models exhibit less stress and more positive arching, independent of pipe deflection. Under 30 m of fill stress, pipes having an inner diameter of 0.762 to 1.524 m bowed by around 1.5 to 3.0 %. An essentially uniform stress distribution was produced around the pipe in the ETI model, and the horizontal ground pressure in the spring line of the pipe was reduced from 65% to 40%, depending on the backfill type.

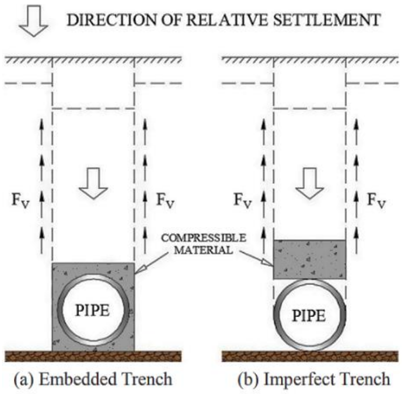


Fig.(6):- Mechanism of [24]: (a) embedded trench installation (ETI) (b) trench installation techniques (ITI).

A review of experimental and numerical tests conducted by different previous researchers could be summarized as stated by Al-Naddaf, et al. [14]. To generate positive soil arching, the layer of low stiffness compresses more than the surrounding soil, which may transmit some of the surrounding soil column's vertical loads to the nearby soil once the embankment has been constructed using a compressible material and during its service life. As a result, the culvert or pipe may be buried at a higher depth if using a compressible material.

4.2 Behavior of Geogrid Reinforcement

Many researchers investigated the influence of geogrid reinforcement on the buried pipes, bearing capacity with settlement behavior of soil, and stress distribution on geogrid [28, 29]. To clarify, Bildik and Laman [30] investigated the impacts of the reinforcement contribution that were explored by employing single and multiple layers of geogrid in the laboratory to assess the contribution of geogrids to bearing capacity and stress behavior. The geogrid's number, depth, length, spacing, and layout are significantly affected the pipes' bearing capacity, settlement, and stress distribution. Experiments were showed that the best results are achieved by installing the initial geogrid layer at a depth equal to half the width of the strip footing (u =0.50 B). Compared to an unreinforced case, the bearing capacity of this one is boosted by 1.5. Regardless of the h/B (vertical spacing between geogrid layers / footing width) ratio, the findings demonstrate that the bearing capacity ratio achieves its greatest value when the vertical spacing between geogrid layers is set to 0.50 B. The results show that the upper (first geogrid) geogrid results in greater stress than the lower geogrid (second geogrid) for both base pressure circumstances. The bearing capacity increases, and the settlement decreases when many geogrid layers are used. Nevertheless, there are no substantial impacts on behavior when the number of reinforcements is increased beyond two. The number of geogrids higher than N = 2 has no noticeable effect on the stress distribution on the pipe.

Elshesheny, et al. [31] evaluated by using a fully instrumented laboratory setup the performance of rigid pipes embedded in geogrid-reinforced soil under progressively increased cyclic loads. The impact of changing two practically relevant factors, the depth of pipe burial and the number of geogrid layers, was studied. The results showed that during the first 300 cycles, the strain created in the pipe and the geogrid layers and the rate of deformation of the footing and pipe increased significantly. Additional cycles dramatically reduced such rates. Pipe and footing deformations, pressure on pipe crown, and pipe stresses were all reduced when geogrid layers and burial depth were increased. Using reinforcing layers, stresses were redistributed to create a contained area around the pipe, giving it more lateral support. A rebound was seen at the pipe invert, which was shown to be affected by the surrounding pressure and the density of the bedding layer. Measurements of stresses in the geogrid's layers revealed that the tensile strain in the lower layer was often greater than that in the upper layer, regardless of the applied loading amount or the depth to which the pipe was buried.

Alotaibi, et al. [20] investigated the effects of sandy embankment over an already buried PVC pipe at a shallow depth and strengthened using stiff three-dimensional geogrid and exposed to strip static pressure. Twenty-eight large-scale laboratory experiments were carried out with varying geogrid geometries using single and double layers of geogrid reinforcement. A general lessening of stresses transmitted to the pipe crown below the loading center once the geogrid reinforcement was introduced. The stress sustained by the pipe, and the longitudinal stresses formed in the pipe have decreased as the geogrid width has increased for a given applied load. The geogrid reinforcement reduced the longitudinal stresses in the buried PVC pipe by as much as 80%. Finally, the findings have indicated that applying geogrid reinforcement may increase soil carrying capacity by as much as 150% and reduce surface settlement by approximately 50%.

Table(*1* highlights the key model experiments run on geogrid-reinforced foundations and the optimal layout parameters discovered for each, where the depth of the first geogrid layer (u), the length of the geogrid (L), the number of geogrid layers (N), the vertical spacing between the geogrid layers (h), and the embedded depths of the pipe were the parameters investigated. **Error! Reference source not found.** shows the geogrid-reinforced schematic diagram.

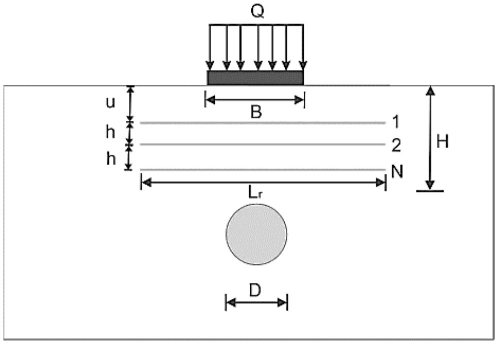


Fig.(7):- Schematic view of investigated parameters [30]

It is widely agreed that a value between 0.3 and 0.4 for the embedment depth u/B in the top layer of reinforcement is appropriate. However, if u/B is too great, the foundation will experience shallow shear failure above the top reinforcing layer, which is detrimental to enhancing bearing capacity [11]. As the reinforcing length increase, the soil's bearing capacity increases. Increasing the reinforcement length above a certain critical value will not appreciably enhance the performance of the reinforced foundation. The frictional resistance and passive force generated by reinforcement beyond the effective anchoring zone have relatively little impact on the bearing capacity improvement as reinforcement length increases beyond the anchorage zone [11].The bearing capacity of the buried pipe increases with the increase in Embedded depth.

Table(1):- Summary of the model tests of geogrid reinforcement

Authors	Geosynthetics used	Reinforcement parameters				Embedded depths
		N	L	u	h	
Tafreshi and Khalaj [28]	geogrid	5	1-5D	0.2-1.2B	0.35B	1.5-3D
Asakereh, et al. [29]	geogrid	4	6D	0.35B	0.35B	2-3D
Elshesheny, et al. [31]	geogrid	2	4.35D	0.35B	0.35B	1.5-2.5D
Bildik and Laman [30]	geogrid	3	5B	0.10-0.75B	0.25-0.75B	3D
Alotaibi, et al. [20]	geogrid	2	1-6D	0.2-0.4B	0.2-0.8B	1.5D

4.3 Behavior of Geocell Reinforcement

In recent years, geocells have shown their worth in several geotechnical engineering applications, showing promises in outperforming traditional soil reinforcing options. As shown in **Error! Reference source not found.**, when stresses are applied, the geocell-reinforcing process prevents soils from spreading laterally by confining them inside their linked cells. Geocells perform like firmer mattresses by spreading out the force of an impact over a larger surface [32, 33].

Fig.(8):- Geocell reinforcement [33]

Geocell reinforcement behavior depends on factors like geometric characteristics, the tensile strength of the material from which the geocell is made, subgrade and fills aggregate compaction, soil cover thickness, loading plate size, soil grain size, and geocell's opening size. A series of plate load tests have been conducted to investigate the sensitivity of scale geocell-reinforced soil to protect buried pipes by Khalaj, et al. [34] , who presented a full-scale, three-dimensional model testing results simulating vehicle loads on a 250-mm-diameter high-density polyethylene (HDPE) pipe buried in geocell-reinforced soil. The improvement in buried pipe behavior was studied as a function of embedment depth (1.5- and 2-times pipe diameter), geocell pocket sizes were (55×55 mm and 110×110 mm), while the geocell layers' thickness was maintained at 100 mm throughout all tests. All experiments utilized the standard height of 100 mm for the geocell. A circular loading plate with a diameter of 250 mm was subjected to repeated loads of 800 kPa. The findings reveal that geocells significantly impact pipe displacement, soil surface settlement, and transfer pressure at the pipe's crown. For instance, a geocell with a 110×110 mm pocket size may decrease vertical diametric strain (VDS) by 27%, and soil surface settlement (SSS) by 43% compared to an unreinforced soil sample. Meanwhile, a geocell of the same size, 110×110 mm, gives around a 50% decrease in SSS and VDS compared with the unreinforced soil by extending the buried depth of the pipe from 1.5D to 2D. Besides, decreased displacement of the pipe crown when geocell with 55×55 pocket size is used by 14% compared to geocell with 110×110pocket size. As an explanation, the SSS value is not significantly impacted by the geocell's pocket size. For instance, the SSS value at the last loading cycle is 29.97 and 28.34 mm for the geocell reinforcement with aperture sizes of 55×55 and 110×110, respectively.

Fattah, et al. [35] conducted a series of laboratory experiments with PVC pipes buried in a medium sand layer below a subbase layer, looked at the effect of dynamic loads (frequency and amplitude) on the performance of the reinforced and unreinforced subbase layer above the pipe. The geocell reinforcing layer’s effects on the stress transferred to the pipe crown and the pipe’s vibration were studied by subjecting the pipes to repeated dynamic loading at 0.5 and 1-ton amplitudes and loading frequencies of 0.5, 1, and 2 Hz. Additionally, the performance of the geocell atop the buried pipe was analyzed by developing a 3D computer model in the finite element software PLAXIS 3D. The experimental results backed what was hypothesized about the characteristics of the buried pipes. The results revealed that the crown vibration decreased by 35%, and vertical pressure reaching the pipe was lowered by 41% after applying geocell reinforcement. The consistency between theoretical and experimental results shows the relevance of geocell reinforcement in improving pipe safety.

Fattah and Mohammed Redha [3] investigated of pipe model made of geocell-reinforced sand. A rigid tank was installed with a 110 mm diameter by 1.4 mm wall thickness PVC pipe to simulate an underground pipe. Under varying traffic loads, several laboratory model tests were carried out. Investigations were done on how different variables affected how well backfill pipes and sand bedding worked. The characteristics comprised the bedding and back fill’s degree of compaction, the force of the surface dynamic pressure, and the frequency of the loads. The results of this investigation were expressed as the vertical transmitted pressure on the pipe’s crown, surface soil settlement, and pipe’s crown displacement amplitude. The results showed that the degree of compaction of the sand bedding and backfill affects a buried pipe’s performance. The vertical pressure on the pipe crown, surface settlement, and displacement amplitude all decrease by roughly 30%, 40%, and 15%, respectively, as the relative density of sand increases from 30% to 60%. The surface settling of the unreinforced model drops by more than 40%, as the relative density of the soil increases from 30% to 60%. For the geocell-reinforced model, this reduction is around 25%. The dynamic response (displacement amplitude, surface settlement, and transmitted dynamic pressure) for all soil states is usually reduced to variable degrees when sandy soils are reinforced with geocells. The soil becomes stronger as a result of this circumstance.

4.4 Behavior of EPS with other Geosynthetic Reinforcement

The behavior of EPS and other reinforcement (geogrid or geocell) was investigated through extensive experimental studies and 3D finite element analyses to assess the effects of several factors impact buried pipe efficiency, including embedment depth, placement of the geogrid or geocell, and the width, thickness, and density of the EPS blocks. Compressibility and low material density are two characteristics that set EPS blocks apart. As a result, its shape and location may significantly impact underlying forces. A geogrid or geocell reinforcement put above the EPS system might prevent an increase in soil surface settlement, which the compressibility of the EPS system would cause. [1]. **Error! Reference source not found.** shows the effectiveness of geocell reinforcement in improving the support of EPS geofoam blocks.

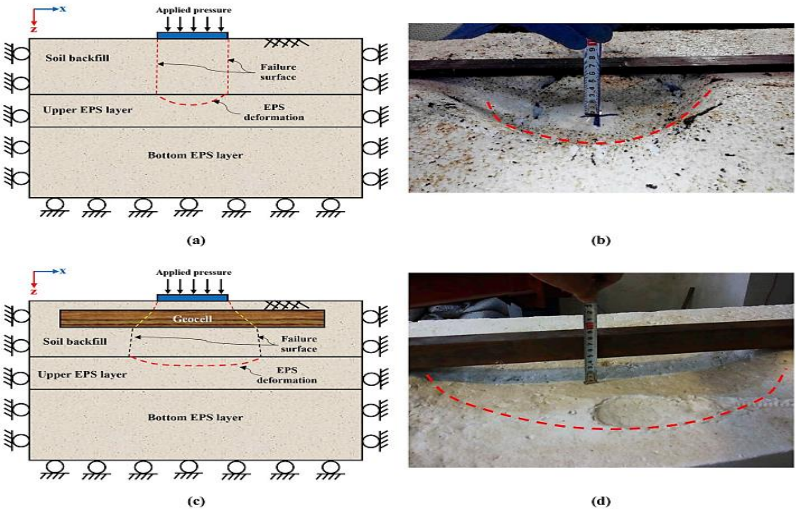


Fig.(9):- unreinforced pavement foundation failure mechanism was schematic; (b) EPS geofoam punching failure; (c) geocell reinforced pavement foundation failure mechanism schematic; and (d) EPS geofoam under geocell reinforced pavement foundation with typical broader deformation basin. [36]

To achieve these objectives, Moghaddas Tafreshi, et al. [13] investigated the full-scale prototype tests on 250 mm-diameter HDPE flexible pipes placed at shallow depths and under simulated traffic stresses, as shown in Fig.(1. This study examined the effects of repeated loads on pipe behavior with amplitudes of 400 or 800 kPa, and diameters of 0.6, 0.8, and 1. The reduction of pressure relocated to the pipe, the pipe's deformation, and the surface settlement of the backfill were tested using expanded polystyrene (EPS) geofoam blocks of different densities and geocells as a three-dimensional (3D) reinforcement. The results showed that regardless of the applied pressure, the vertical diameter strain of the pipe, the pressure delivered to the pipe, and the surface settling all increase significantly with increasing loading surface diameter. Fewer pipe deformations occur when an EPS block was placed over the pipe because it improves soil settling while lowering transmitted pipe pressure. An EPS block's responsiveness is improved by its increased density, but it wasn't enough to prevent the increase in surface deflections. The pressure applied to the pipe was reduced, its deformation is lessened, and the EPS block's potential to increase soil surface settlement was eliminated when geocell reinforcement is used under the loading surface. It was found that a pipe buried at a depth equivalent to twice the pipe diameter responded adequately and steadily with a geocell reinforcement layer placed over two EPS geofoam blocks (with a total thickness of 0.3 and a width of 1.5 pipe diameter). By putting these measures in place, the vertical pipe strain, transmitted pressure over the pipe, and soil surface settlement were reduced and are now within acceptable limits. These values were 0.45, 0.37, and 0.53 times lower than those obtained for a comparable unmodified buried pipe installation.

Khalaj, et al. [37] investigated the experimental and numerical testing that has been done on the efficiency of expanded polystyrene and geocell reinforcement in improving the behavior of unpressurized subterranean pipelines subjected to surface forces. The soil, geofoam, geocell, and pipe were modeled in ABAQUS using the finite element technique (FEM). The model was tested in the lab to ensure its accuracy. As much as 39.5% and 29.5% reductions in maximum surface settlement and pipe crown displacement were seen when geocell and geofoam were added to the soil, respectively. Because of its density, the EPS block may significantly limit the allowable range of pipe crown movement.

Azizian, et al. [1] evaluated the findings from laboratory tests conducted on buried 160 mm uPVC (unplasticized polyvinyl chloride) pipes. The buried pipe's performance in reinforced and unreinforced trenches was studied using a single layer of HDPE (high-density polyethylene) geogrid and expanded polystyrene (EPS) geofoam block. A plate was placed over the trench surface and subjected to 500 cycles of repetitive loads simulating car tire stresses, with a frequency and an amplitude of 0.33 Hz and 450 kPa, respectively. The purpose of the testing program is to determine how various factors, such as the density, breadth, and thickness of EPS blocks and the pipe's embedment depth, affect the pipe system's behavior as a whole. After initially rising rapidly at the beginning of loading, the rate of change in soil surface settlement, vertical diameter strain, and circumferential pipe strain reduced as loading proceeded. The findings demonstrate that the density, breadth, and thickness of EPS blocks affect the behavior of underground pipelines. The best compromise between pipe crown strain, vertical diameter strain, and soil surface settlement was achieved by reinforcing the geogrid with an EPS block with a density of 30 kg/m^3, a thickness of 60 mm, and a width of 1.5 times the pipe diameter.

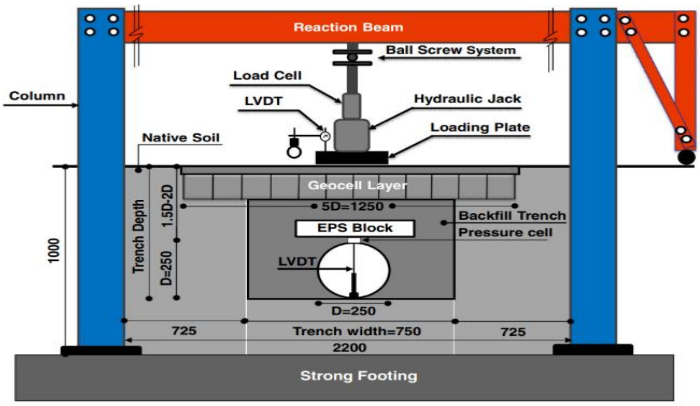


Fig.(1):- Diagram representation of the test setup [13]

5. CONCLUSION

The geosynthetic-reinforced foundations based on an experimental study, numerical modeling, and field performance are reviewed in this study's literature, along with a general overview of the reinforcing mechanisms of reinforced materials, a discussion of current research trends, and a look at future directions for reinforced foundations. The following are the most important major findings:

1. Based on the findings of several laboratory model tests, EPS is employed as a compressible material above different buried structures (mainly culverts and pipes) to inverse the relative distortion within the embankment and reduce the pressures above the buried structure due to the positive soil arching phenomenon. Also, using geogrid or geocell reduces EPS compression, besides protecting buried structures.

2. Using model experiments, the best parameters for the geosynthetic-reinforced foundations' designs are determined. For optimal performance, the top reinforcement layer's embedment depth (u) should be between 0.3 B and 0.4 B, the optimal distance (h) between reinforcing layers is between 0.2 B and 0.4 B, and the ideal reinforcing length (L) ranges from 4 to 5 B. This finding was also confirmed by several field investigations. In addition, a pipe's vulnerability to damage decreases as its embedment depth increases.

3. Relly on several experimental and numerical studies, geocells are useful in a variety of geotechnical engineering implementations and that they have the potential to outperform traditional soil reinforcing options. Geocells effectively minimize pipe deformation and soil settlement; in addition to the influence of many key factors on geocell reinforcement, comprise the geocell width, geocell installation depth, and granular backfill stiffness.

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