Experimental Evaluation of GeoJute Reinforced Sand Beds under Repetitive Loading

by

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Approval Sheet

This thesis entitled "*Experimental Evaluation of Reinforced Sand Beds under Repetitive Loading*" by Suraj D. Vedpathak is approved for the degree of Master of Technology from IIT Hyderabad.

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I would not have accomplished many things without continual care from my loveable sisters whose unconditional love and constant encouragement kept me moving in life.

Dedicated

to

My Parents

Abstract

In this research, a series of large scale dynamic model tests were carried out on geojute and jute-geocell reinforced sand subgrade in controlled laboratory condition. The tests are conducted on geojute and jute-geocell (made from waste jute bags) reinforced and unreinforced sand subgrade under repeated loading to simulate traffic conditions. The placement density of sand in all the tests was maintained at 70% (stiffer subgrade) and 30% (weaker subgrade). A constant area of geojute and jute-geocell reinforcement was maintained throughout the test series. Cyclic behavior was investigated through varying the density, number of geojute layers and geojute arrangement. The influence of the width and height of the jute-geocell reinforcement on the cyclic behavior of the loading system was studied and performance improvement in terms of traffic benefit ratios and cumulative plastic deformation was determined. The loading was applied through a circular steel plate which replicates the load application from a passenger car replicating a single axle wheel load. A single axle wheel load was applied through a sophisticated double acting linear dynamic actuator which is attached to a 3.5m high reaction frame.

Nomenclature

b	width of geojute / jute-geocell mattress
CPD	cumulative plastic deformation
D	width of footing
D_g	Dial gauge
D_f	embedment depth of footing
δ	surface deformation
H	thickness of overlying sand layer
H_1	height of reinforced zone with 70% relative density
H_2	height of reinforced zone with 30% relative density
I_f	bearing capacity improvement factor
h	height of geocell mattress
Δh	vertical spacing between consecutive geojute layers
MPT	Multi-Purpose Test ware
N	number of geojute layers
PRS	percentage reduction in footing settlements
Φ	angle of shearing resistance
R_D	relative density
S_r	Settlement corresponding to reinforced bed at a given number of cycles
S_u	Settlement corresponding to unreinforced bed at a given number of cycles
TBR	traffic benefit ratio
u	depth of top of reinforced zone from the base of footing

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Preamble

Time immemorial geosynthetics has been serving mankind in one or the other forms. Very first use of geosynthetics was noticed by for making sand heap. Since then geosynthetics has got over wide application in last six decades. Ground improvement techniques such as soil reinforcement are certainly a great remedy to unstable soil problems. Thus, soil reinforcement such as application of geotextiles can be fully benefited and blend in for modern construction. Due to ongoing environmental concerns all over the world ecofriendly and sustainable solutions are very much sought after. To fully explore the benefits and functional mechanism of geotextiles, their interfacial behavior with infill soil is to be understood thoroughly. The behavior is usually being investigated in terms of shear properties between the geotextiles and sand.

Government of India (GoI) spends almost more than $25 billion annually using more than 15000 tons of aggregate for mere stretch of 1km road [1]. Since, 80% of road network in India is comprised of rural roads stated by a NHDP survey [2] whose performance is always questionable which forces engineers to seek alternative designs using different materials, commercial construction aids, and innovative design practices. Among all of commercial construction aids is utilization of geosynthetics, whose increased popularity is due to their time tested versatile characteristics. Geosynthetics include a large variety of products manufactured of different polymers which are adopted in numerous geotechnical and transportation applications. Often, it is important to estimate the efficacy of such inclusions in natural ground to improve the design methodologies and construction practices prior their utilization. In this study, in particular, the natural, waste and green material obtained from used jute bags are adopted in reinforcement applications under repeated loading and for all practical purposes, the jute material used in this study is called as *geojute* material which resembles coir geotextile in nature.

Studies on the geojute/coir geotextile reinforcement are being carried out for about half a century. Geojute is a natural and biodegradable material like coir geotextile. Increased bearing capacity, stiffness, and tensioned membrane effects were identified as the major reinforcement mechanisms for geotextile reinforcement [3].

The use of geo-materials for reinforcement as a reinforced soil structures is attractive from an environment as well as economic viewpoint. Since the reinforcement forms ever used, many different kinds of geosynthetics have been used and the foremost kind of reinforcement is geotextile (fiber) reinforcement. These continuous fiber reinforcements with soil may be of synthetic or natural materials. The natural fibers like jute, coir etc. being cost effective and of environmental friendly, in contrast to that of synthetic fibers, can be effectively used for low traffic volume unpaved roads like rural roads. It has the properties of biodegradability, and is the strongest and most durable material among other natural materials [4, 5]. Figure 1.1 shows life cycle of a jute material.

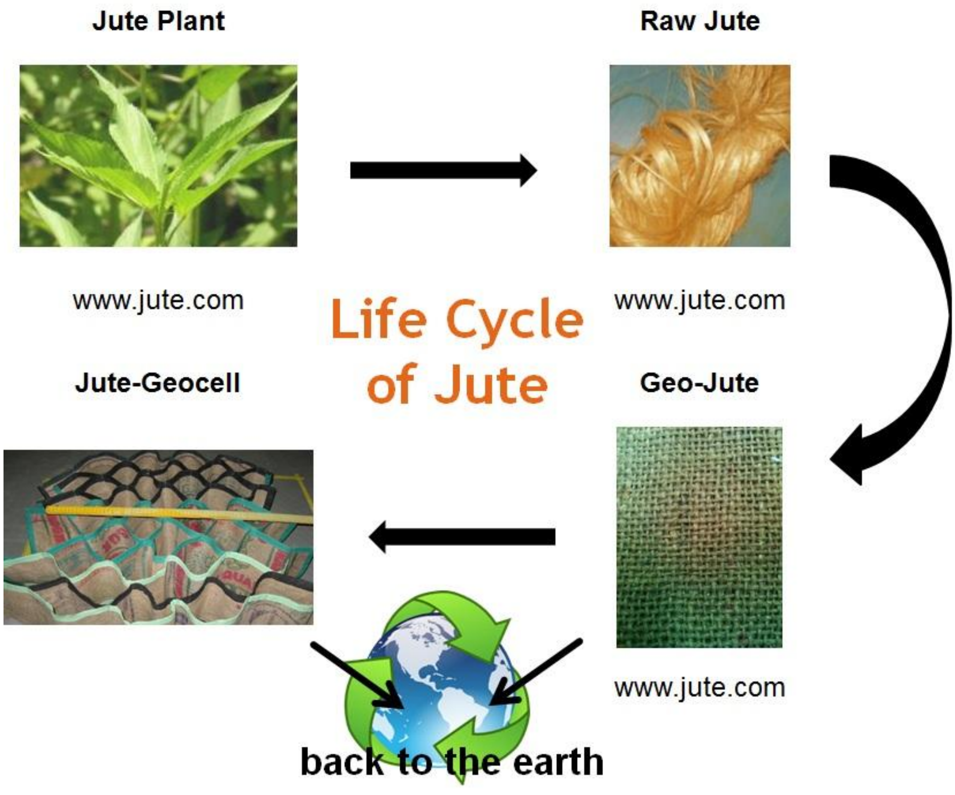

Figure 1.1 Life cycle of a jute material

In the case of geotextiles, the interface shear resistance against soil results solely from the shear resistance between the geosynthetic surfaces against soil particles. In contrary, soil particles are not interlocked with aperture openings as in case of geogrids. Cancelli et al.

[11] investigated the shear strength of soil-geogrid interfaces using direct shear tests. Similar observations were also made by Chia-Nan et al. [10]. Although coir is biodegradable, due to its high lignin content, its degradation takes place much more slowly compared to the other natural materials. Geotextiles are particularly effective in roads constructed over weak subgrade soils [9]. To quantify the benefits, from the geosynthetics especially in pavement applications, a non-dimensional parameter called traffic benefit ratio (TBR), which is defined as the ratio number of load cycles obtained in reinforced bed to unreinforced bed to obtain same amount of permanent deformation, has been introduced and is expressed in terms of extension of life or by saving in base course thickness. Several researchers worked on the cyclic behavior of geosynthetic reinforcements using geogrids observed a TBR of about 3.3 in a large test tank (Haas et al. [7]). Similarly geogrid reinforcement under a moving single wheel system observed a TBR of 1.2 (Barker et al. [8]). Similar observations were made by many other researchers where the TBR varied from 1 to 4 under single axle wheel loads (Cancelli et al. [11]). Sreerama Rao A. [6] studied the effective application of jute geotextiles over weaker pavement subgrade having lesser CBR value. Recently Senthil et al. [12] have conducted few preliminary California Bearing Ratio (CBR) tests on coir and jute geotextiles and found that the CBR values were higher for jute geotextile than non-woven coir textile. Extensive applications of jute geotextiles including rural roads were summarized by Abdullah [13] in a technical document on submitted to Jute Diversification Promotion Centre (JDPC), Dhaka, Bangladesh. It is understand from the literature study that there is a research knowledge gap in understanding the natural geojute as reinforcement under repeated traffic loading.

1.2 Mechanism of Reinforcement

The reinforcement is very well understood when the in-situ conditions are replicated with the effect provision of geotextile reinforcement within base course layer of pavements. Figure 1.2 shows geosynthetic-soil interaction in geosynthetic reinforced pavements.

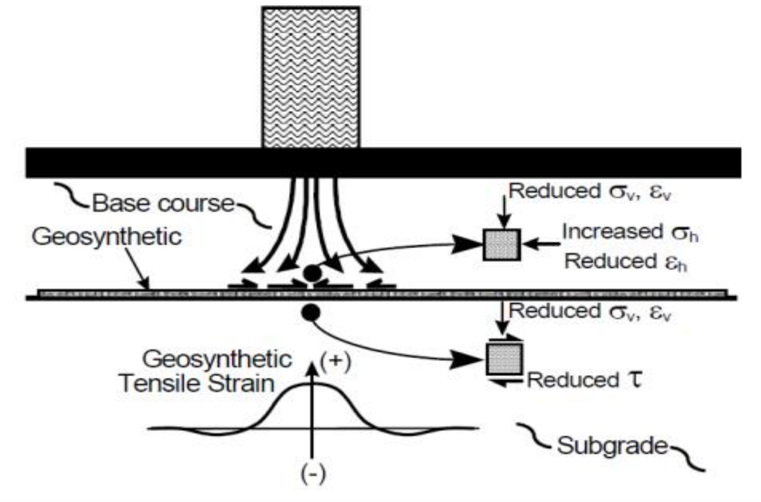

Figure 1.2 Geosynthetic-soil interaction mechanism

As shown in figure the tensile force of the geotextile and the frictional force between soil and geosynthetic reinforcement reduces the vertical and lateral deformation respectively. In case of jute-geocell, reinforcement has an additional effect due to overall confinement due to side walls of the geocell and also restrain due to vertical shear between soil and geocell wall. Figure 1.3 shows the load transfer mechanism and forces acting on due to geocell reinforcement compared to its unreinforced bed.

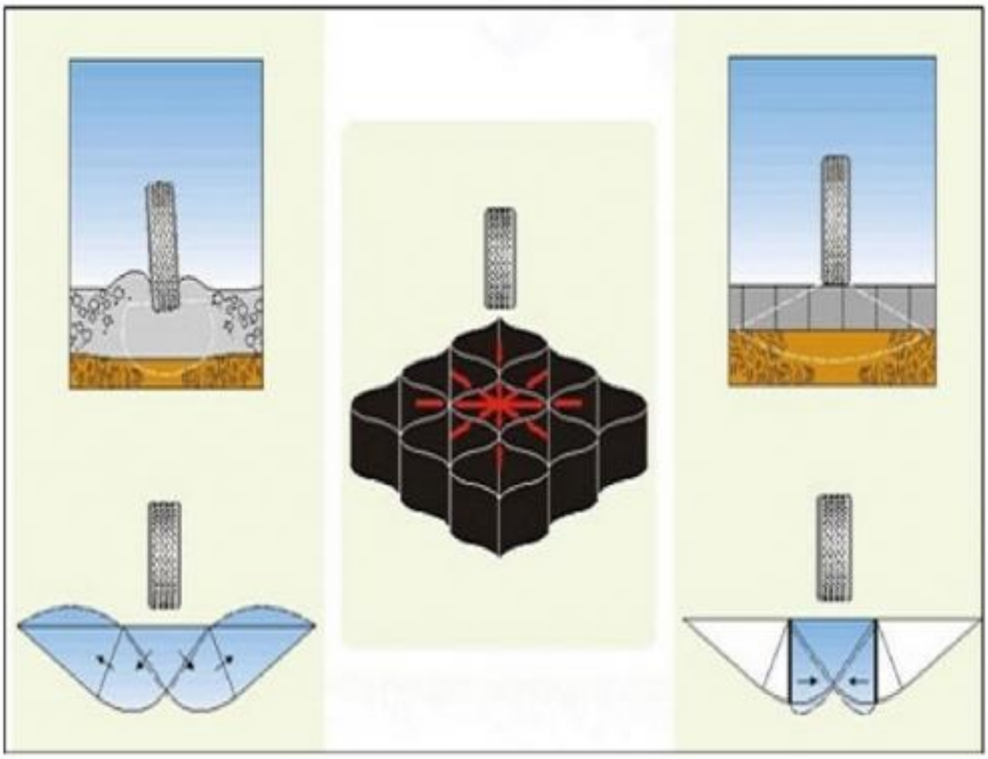

Figure 1.3 Load transfer mechanism of geocell mattress

1.3 Objective and Scope of the Study

Objective of this study is to understand efficacy of reinforced beds under repetitive loading. In the scope of the study Following aspects are given priority:

- To understand the resilient behavior of geo-jute and jute-geocell reinforced sand beds, sand beds overlying soft soil beds and stiffer beds/aggregate infill overlying soft beds under repeated traffic loading conditions which can be preferably used in increasing the life cycle of the unpaved roads.
- To know the behavior of geosynthetic reinforcement and factors affecting the performance of the geosynthetics under repeated loading.
- Performance studies in terms of non-dimensional factors like TBR (Traffic Benefit Ratio), CPD (Cumulative Plastic Deformation) to evaluate efficacy of the reinforcement material in reinforced beds.
- Comparison of various forms of reinforcement on sand beds and their effects on settlements and heave of the footing.

1.4 Thesis Organization

In ***Chapter 2*** provides the results of an extensive literature work of various factors influencing reinforced sand beds. In addition, various studies on the soft beds and stiffer beds/granular infill overlying soft beds for various forms of reinforcements have been discussed in brief.

Chapter 3 describes the laboratory equipment used to test the sand, aggregate and reinforcing material. Besides, in this section detailed discussion is done on loading pattern and test methodology carried during testing.

In ***Chapter 4*** detailed discussion is carried on to understand the influence of geojute reinforcement on sand subgrade. Various parameters like width of reinforcing material, number of reinforcing layers, and placement of reinforcing layer are studied to estimate the benefit and optimality of the reinforced material.

Chapter 5 evaluates the influence of cellular geojute reinforcement (also known as jute-geocell) on sand subgrade. Apart from some of the parameters discussed above, influence of height of geocell and infill material is also studied to check the optimality of the material under repetitive loading.

Conclusion is drawn in ***Chapter 6*** based on the results obtained from ***Chapter 4 and Chapter 5*** and Future work is predicted from the present research.

Chapter 2

Literature Review

2.1 Introduction

Roads are the arteries of communication and transportation, and are intended to provide a level of serviceability with regard to safety and comfort compatible with the volumes, loads, and speeds of the traffic for which they are intended. Road transport is vital to India's economy with annual expenditure of rupees 2,000-3,000 billion. India's road network is gigantic and is said to be only after the United States of America. Despite phenomenal industrial progress, India continues to be mainly a rural country with only a meager 20% of its total population residing in the cities. The importance of adequately constructed and maintained rural roads in the context of national economy is self-evident. But one of the striking underlying facts is the conditions of the roads. In view of massive rural population, most of the rural areas do not have all weather roads and hence have tough time during monsoons. According to 11th 5 year plan, INR 15,000 Cr. spent on maintenance of roads. The amount of expenditure spent in order to repair roads is alarming and stress is given to improve quality of road. Since roads directly contribute to the economic growth of the country it is extremely essential that the roads are well laid out and strong. Thus, design of pavement becomes a herculean task, considering importance of 'stability' in road and accelerated rate at which road network is increasing in India. Thus, it is desirable that the base of road network lies on subgrade should possess sufficient bearing capacity and should be good enough for carrying safe carriage of goods and passenger traffic at desired speed level. Here the term 'good' refers to a subgrade which possesses sufficient bearing capacity, undergoing less settlement due to load or with time, not comprised of expansive soils, and which is fairly leveled to avoid undulations or potholing in the road. However, it is understandable that such a terrain and subgrade conditions are highly ideal which generally does not exist. But, with the help of innovative techniques like geosynthetic reinforcement the subsidence effects in pavement layers are minimized. An extensive research has been carried out to understand the behavior of geosynthetic reinforcement in geotechnical applications like separation, reinforcement, filtration, drainage and confinement.

This chapter deals with the work carried out by various practitioners and researchers on ***geojute and geotextile reinforced earth and pavement structures***. However, there are several research studies available on especially geogrid, only those important studies on geogrids are included as the key focus of this study is on biodegradable geosynthetics. Primarily this chapter is subdivided into following sections based on literature studies on reinforced earth.

- Studies on Sand beds
- Studies on Soft soil beds
- Studies on Stiffer sand / granular infill overlying soft soil beds

The literature work related to *planar* reinforcement and *geocell* reinforcement made of geotextiles or geojute is discussed in detail in each of the above mentioned sections.

2.2 Studies on Sand Beds

2.2.1 Planar Reinforcement

The concept of reinforced soil was introduced way back in late 1960s by Henry Vidal with the heap of sand reinforced with pine needles. Soon after systematic approach was carried by Binquet and Lee [14, 15] by performing series of tests on strip footing supported on homogeneous sand and sand overlying deep soft soil. In their study, they have observed that pressure-settlement behavior become stiffer and ultimate bearing capacity increases by varying number of reinforcement layers and depth of placement of layers from ground surface. They introduced a non-dimensional term Bearing Capacity Ratio (BCR). BCR is defined as the ratio of footing pressure of reinforced bed to the ultimate footing pressure on unreinforced bed at particular given settlement.

A series of laboratory model tests carried out by Guido et al. [16] on rectangular and square footing showed that bearing capacity ratio at a settlement of 0.1B (B= width of footing plate) increases rapidly with increasing strip length up to a length of about 0.7B after which it remains relatively constant. Thus, better results can be obtained for a foundation on weaker soil strata.

Laboratory model tests have been carried out by Omer et.al [17, 18] for determining the ultimate bearing capacity of strip and square foundations on sand reinforced with geogrid layers. Based on the test, the critical depth of reinforcement and dimensions of the geogrid layers for mobilizing the maximum bearing capacity ratio have been determined and compared. From observation they have drawn conclusion that for development of maximum bearing capacity, the effective reinforcement is 2B (B= width of footing plate) for strip footings and 1.4B for square footings. Further they have observed that maximum width of reinforcement layers for optimum mobilization of maximum bearing capacity ratio is 8B for strip and 4.5B for square footings.

Michael et al. [19] have attempted to find out the potential benefits of geogrid reinforced sand beds supporting large scale model spread footing. An effect of planar geogrid and geocell reinforcement on performance improvement was studied. Several parameters such as number of layers of reinforcement, area of reinforcement, depth of initial layer of reinforcement, vertical spacing between consecutive layers of reinforcement and relative density of sand bed within soil mass were varied to analyze the performance of maximum benefit ratio. Maximum benefits ratio occurs when depth of top layer of reinforcement is within the one fourth width of model footing. In case of single reinforcement performance improvement depends on higher placement of density. In addition to achieve maximum improvement out of single layer of reinforcement, depth should be within 0.4B (B= width of footing) from the bottom of footing.

Michalowski [20] suggested a kinematic approach of limit analysis for evaluating bearing capacity of strip footings resting on foundation soils reinforced with horizontal layers of geosynthetics. He suggested that optimum reinforcement length is four times the width of footing in an improvement of load bearing capacity beyond which marginal effect was observed. In his study two mode of soil and reinforcement failure were considered viz. slip and rupture. Optimum depth of reinforcement was found to be 0.35B for clay and silts and as high as 0.8B for sands with angle of shearing resistance as 40°. To achieve maximum benefits in multilayer reinforcement (3 layers in this case) effective spacing between consecutive layers of reinforcement in sands is found to be 0.6 times width of footing while, it is 0.2 times width of footing in clays.

Basudhar et al. [21] carried out detailed study on geotextile reinforced sand beds. A square test tank of dimension 440 x 440 x 210mm was used in the study with different combination of footing sizes as 30, 45 and 60 mm. From results it was noted that with increase in number of layer and reduction in footing size, improves equivalent secant modulus. Experimental results were also compared with FLAC results and found to be well within the acceptable range.

Busudhar et al. [22] further studied the FEM analysis of geotextile reinforced sand bed subjected to strip loading. A brief discussion on the theory of string effect and confining effect is done in their study. They considered the effect of embedment depth ratio (d/B) variation from 0.2-1.2 on reinforced sand settlement ratio and examined that maximum settlement reduction with respect to unreinforced soil occurs when embedment depth ratio (d/B) is at 0.6. Besides they have resulted that the effect of modular ratio on settlement reduction of soil is minimal when $E_g/E_s>200$ (E_g= Modulus of elasticity of geotextile and E_s= Modulus of elasticity of soil) and found that settlement reduction is 12% at modular ratio=200.

A series of laboratory test were carried out by Sadoglu et al. [23] on reinforced sand to evaluate ultimate loads for eccentric loaded model shallow strip footings. The tests were conducted in a test tank of inner dimensions 0.9 x 0.1 x 0.65 m (length x breadth x height) with model strip footing of 8mm thick rigid steel plate with V shaped groves at particular interval for application of eccentric loading. They analyzed that vertical displacement at failure decrease with increase in eccentricity and reinforced tests show higher bearing capacity than unreinforced tests for same eccentricity.

Vinod et al. [24] investigated the effectiveness of horizontally placed braided coir rope reinforcement on the strength improvement and settlement reduction of loose sand. The tests were carried out in a fixed tank with square shape of 900 x900mm in plan and 750mm in depth with model footing of 25mm thick and 150 x150mm in size. On observation it was noticed that provision of braided reinforcement improves substantially at all level of normalized settlement. To achieve maximum benefit, location of reinforcement beneath the base of footing should be at 0.4 times the width of footing. Strength improvement ratio increases with increase in length ratio of 3 beyond which strength improvement is substantial. They proposed that almost 6 fold strength improvement and 90% settlement reduction can be achieved through coir reinforcement.

Puri et al. [25] investigated the settlement of reinforced subgrade under dynamic loading. Tests were conducted in a rigid steel tank measuring 760mm from all sides and a square shaped rigid footing of side 76.2mm. It was noticed that ultimate bearing capacity increases with increasing number of reinforcement layers. Depth of placement of initial reinforcement and spacing between consecutive layers were kept constant (u/D=h/D=0.33) for all tests. Also, width of geosynthetic reinforcement was maintained four times width of model footing. It was observed that increase in reinforcement layer (beyond N=4) does not enhance the improvement in bearing capacity. Dynamic load tests were conducted based on the optimum configuration obtained from static load test. Dynamic load was applied using a rectangular shaped waveform and frequency of 1 Hz.

Lovisa et al. [26] studied the beneficial effects of prestressing the geosynthetic in reinforced soil foundations supporting a loaded circular footing by performing a laboratory model study and finite element analysis. Tests were conducted in large test tank with inside dimensions of 800mm x 800mm in plan and 600mm in elevation with model footing of 100mm diameter and 20mm thickness. They found that load bearing capacity is doubled for prestressed (with prestress equal to 2% of the allowable tensile strength of geotextile) reinforced bed as compared to reinforced bed without prestress at 5mm of settlement. Performance in prestressed reinforced configuration is more effective for greater depth as compared to the unreinforced and reinforced (without prestress) case.

Discrete element approach was used by Bhandari and Han [27] to understand geotextile-soil interaction under cyclic vertical load. Micro-parametric study of soil and geotextiles were determined using biaxial and a tensile test. Sand used in the study was maintained at 70% relative density. Asphalt Pavement Analyzer (APA) which is used in the study to understand rut and fatigue behavior of hot mix asphalt samples was modified to simulate soil-interaction behavior with the help of an aluminium box measuring 0.38 x 0.45 x 0.1m. A rut test was carried out by applying 88kN load on a pressurized hose of diameter 25 mm for 16000 cycles (1 cycle= 1 pass). Geotextile sheet was kept at 12.5 and 25mm below the surface. Large triaxial test, pullout test and plate load test was carried out to understand geosynthetic-soil interaction. From the tests it was observed that deformation due to unloading was constant after 25 cycles. They also concluded that geotextile yielded minimal surface deformation when placed at 12.5mm below the surface when compared to placement at 25mm under cyclic vertical loading.

An experimental evaluation of the behavior of footings on geosynthetic-reinforced sand was carried out by Farsakh et al. [28]. Factors affecting the benefit improvement like depth of placement of initial reinforcement layer, ratio of width of reinforcement layer to the width of footing plate, vertical spacing between reinforcement layers, tensile modulus, type of reinforcement were studied. It is inferred from the results that reinforcement layout has a very important role in behavior of reinforced sand foundations. Results depicted that with two or more layer of reinforcement, the settlement is reduced almost by 20% at all footing pressure. It is also presented that combined behavior of geogrid and geotextile show more performance in improvement than those reinforced with geogrid or geotextile alone.

2.2.2 Geocell Reinforcement

Rea and Mitchell [29] performed laboratory tests to study the influence of the interconnected paper cells filled with sand as reinforced layer for application of economical highway construction. They studied various modes of failure viz. cell penetration, cell bursting, cell wall buckling, bearing capacity failure, bending failure and excessive rutting. The square shape cell was made of 0.203mm thick paper by keeping constant width of 51cm. The effects of ratio of radius of loaded area to cell width, ratio of the cell width to the cell height, subgrade stiffness and repeated loading were examined. Results showed that under static load ratio of loaded area to the cell width establish well within the range of 0.75-1.0 and ratio of cell width to the cell height was around 2.25. Besides cell reinforced sand showed better resistance to repeated loading. It was noticed that tension in the reinforcement yield compression on the sand encapsulated in the cell, by giving increase in stiffness beyond edges of the loaded area and sand gets confined and restricted against lateral movement, till strength of the cell reaches ultimate value.

Mitchell et al. [30] conducted model tests on geogrid cell reinforced sand beds. The grid cell reinforced sand layer was placed directly on the rigid concrete for calculation of the equivalent elastic modulus (E_r) for the reinforced layer with the help of elastic theory solutions for homogeneous elastic layers overlying rigid base. Some parameters were varied viz. ratio of radius of loaded area to the cell height and ratio of loaded area to cell width to study its impact on performance. They proposed an approximate formula to find out the equivalent elastic modulus (E_r) of the reinforced layer.

$$E_r = E_u f_1\left(\frac{E_g}{E_m}\right) f_2\left(\frac{a}{B}\right) f_3\left(\frac{h}{B}\right) f_4\left(\frac{a}{h}\right) f_5(N_j) f_6(E_s) \quad \text{.....................................(1)}$$

Where, a/B is loaded area to grid geometry ratio; h/B, grid geometry ratio; a/h, layer geometry ratio; E_g/E_m, modular ratio between grid material and cell fill material; E_s, modulus of the subgrade; E_u, modulus of the unreinforced sand layer and N_j is the number of grid joints per unit area.

Performed test results point out that bearing capacity increases with size of loaded area and thickness of grid layer. Effective moduli of sand layer improve substantially with grid cell reinforcement.

Large scale field tests were conducted by De Garidel and Morel [31] on continuous filaments, micro-geogrids and geotextiles cells filled soils. They compared the stability of each reinforcement form for road construction by varying geocell width to height ratio as 0.5 and 1.0 and concluded that the reinforced structures showed remarkable strengthening effects in terms of increased rigidity.

Khay et al. [32] carried out an experimental study to understand the efficacy of numerous geotextile structures in the benefit improvement of sand subgrades. The geotextiles were comprised of cell, fiber and prefab sheets. Geocell used in the study had cell to depth ratio as 0.5 with varying depths of 10, 15 and 20cm. Substantial performance of geocell was noticed with appreciable settlement reduction behaving like a slab.

Kazerani and Jamnejad [33] performed large scale experimental and FEM analysis on 3D grid cell confinement systems in granular subgrades. On observation it is depicted that when granular fill is subjected to cyclic loading each cell shares its load with the adjacent cells to form overall confinement effect of cell (hoop strength) wall and resistance from adjacent cell to restrict lateral movement and shear failure.

Koerner [34] noticed that in geocell reinforced foundation system failure is interrupted by shear strength (τ) between geocell wall and soil contained within a statistically loaded shallow foundation. For failure to occur the sand in a given cell must overcome the side friction, punch out of it, there by loading the sand below the level of mattress. Based on the concept of plastic limit equilibrium he proposed a maximum bearing capacity equation for statistically loaded geocell reinforced shallow foundation.

$$p = 2\tau + cN_c\zeta_c + qN_q\zeta_q + 0.5\gamma BN_\gamma\zeta_\gamma$$

Where, p is maximum bearing capacity stress, τ, shear strength between geocell wall and soil contained in it ($\tau = \sigma_h \tan\delta$, where, σ_h is average horizontal force in the geocell ($\sigma_h = \sigma_v K_a$ where, σ_v is applied vertical pressure and K_a is coefficient of active earth pressure (according to Rankine's theory)) and δ is angle of shearing resistance); c, cohesion; q, surcharge load ($q= \gamma_q D_q$, where, γ_q is unit weight of soil within geocell and D_q is depth of geocell); B, width of applied pressure system; γ, unit weight of soil in failure zone; N_c, N_q, N_γ, bearing capacity factors and ζ_c, ζ_q, ζ_γ, shape factors in accordance with geotechnical textbooks.

Mandal [35] carried out several tests on use of geocell mattress as reinforcing layer in highway construction. The geocell used for testing were fabricated by using both woven and non-woven geotextiles. On observation it was noticed that higher benefit improvement estimated with CBR of 22 for non-woven type whereas 75 for woven type geocell material. On calculation it is seen that in certain design procedure the thickness of unreinforced sand was reduced almost to half with the inclusion of geocell reducing overall cost by 35%.

Dash et al. [36] performed model tests on strip footing on geocell reinforced sand beds with additional planar reinforcement. The geocell used in the study was made from biaxial geogrid with square aperture opening of 35mm x 35mm. The longitudinal and diagonal members were jointed with the help of plastic strip of 6mm wide and 3mm thick. All tests were conducted on a single layer of reinforcement by keeping constant parameters like pocket size of geocell, width of the geocell layer and depth to the top of the geocell layer from the base of the footing and varying height of geocell layer and placement position of planar reinforcement. Improvement factor obtained from the results was defined as ratio of footing pressure with additional planar reinforcement at a given settlement to the footing pressure with geocell mattress without planar reinforcement at same settlement. From the results maximum performance improvement of geocell mattress with additional planar layer was obtained when height of geocell is twice the width of footing. Thus, further increase in height of geocell reduces overall footing performance on combined geocell-planar mattress since; increase in rigidity takes place leading to uniform settlement at base whilst obtaining minimal contribution from base reinforcement layer. It is also deduced that overall performance was negligible when planar layer was placed above the geocell layer. It is because of the very small overburden pressure on the reinforcement layer generating meager frictional resistance against tie pullout due to downward penetration of footing.

Dash, Sitharam and Sireesh [37] discussed the performance improvement of circular footing supported by geocell reinforced sand beds. Several parameters like footing-settlement response, surface deformations, strains in geocell wall, and pressure distribution below geocell wall were measured by conducting tests in test tank with inside dimensions of 900 x 900 x 600mm attached with loading frame assembly. Results indicate that substantial benefits in terms of stiffness and ultimate load carrying capacity are achieved with the inclusion of geocell reinforcement. It is seen that ultimate bearing capacity increases with increase in area of geocell layer as high as 3.5 times the unreinforced case when width of geocell layer is equal to four times the width of footing. Surface deformations and footing settlements were measured in non-dimensional terms as δ/D (%) and s/D (%) respectively. Appreciable reduction in surface heaving was noticed as since load is distributed to the uniformly the tensile property of geocell wall confines lateral movement of soil and also adjacent cells oppose movement with back pressure from soil contained in the cell pockets.

Further Dash et al. [38] performed model tests to evaluate performance of different geosynthetic reinforcement materials in sand foundations. The geocell mattress was made-up of cutting geogrids of required length and height and placing them in transverse and diagonal directions connected with bodkin joints. Diamond and chevron pattern were used to form geocell mattress. The patterns used in the construction of geocell are shown in Figure 14. The hatched portion depicts the typical geocell pocket opening.

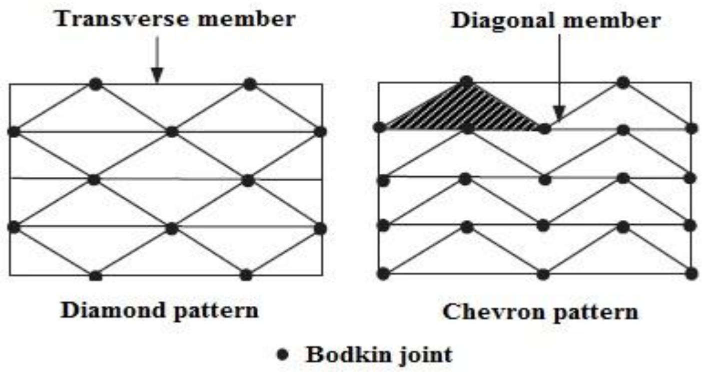

Figure 2.1 Patterns used for construction of Geocell

On observation it is noticed that geocell mattress as a the total reinforcing system acts as an interconnected cage derived anchorage from both side of loaded area owing to frictional and passive resistance developed at soil/ geocell interfaces. Because of the shear and bending rigidity, geocell layer supports the footing even after shear failure of sand inside geocell pockets.

Influence of static and cyclic loading condition on resilient response of geocell reinforced sand was presented by Tafreshi and Dawson [39]. Results demonstrated that adequate mass of geocell causes remarkable decrease in soil surface deformation and subsequently in footing settlement due to reinforcement action. Whereas, when height to width of footing ratio increase from 0.33 to 1.33 the footing behavior changes from unstable response due to excessive footing settlement to stable response. Also the geocell reinforced bed shows linear variation when applied stress is slow whereas, disproportionate behavior was noticed under quick loading condition.

Yang et al. [40] used an effective method of Accelerated Pavement Testing (APT) in evaluation of pavement performance by applying wheel load under controlled environmental conditions. In their study ATP test was performed for four unpaved road sections. The results proved that geocell used in the study has significant role in improving the stability and reducing permanent deformations in unpaved roads with sand bases. In one of the thinner geocell reinforced section was noticed with excessive rutting. On subsurface exploration it was brought to notice that geocell reinforced sand experienced “cell bursting” a failure caused due to excessive loading on the reinforced base. This failure can be overcome by providing higher geocell and/ or geocell with higher weld strength.

Shear strength of granular soil is improved significantly due to confinement effect of geocell. Thus, to understand mechanism better, Confinement effects of geocells on sand samples under triaxial test were studied by Chen et al. [41]. Volumetric strain is affected due to variation size and shape of geocell, confining pressure and multiple cell effects. It is noticed that confinement effect provided by geocells related mainly to the mobilization of the tensile strength in the geocell which varies with induced volumetric strain. They resulted that under low confining pressure behavior of geocell reinforced soil is governed by hoop tension theory whereas under high confining pressure above theory is not applicable since behavior of reinforced soil is similar to the stiff column subjected to the axial compression.

2.3 Studies on Soft Soil Beds

2.3.1 Planar Reinforcement

Yamauchi and Kitamori [42] reported the usage of synthetic meshes in improving the soft ground bearing capacity. They explained the construction procedure of sand fill over clayey hydraulic fill with the inclusion of synthetic mesh at the interface also expressed that establishment of the sand mat is necessary to allow trafficking of the soft fill by construction plant. They carried out model tests of same geometry and observed 40% increase in bearing capacity of soft clayey hydraulic fill.

A case history of the construction of a reinforced high embankment on an extra soft ground presented by Oikawa et al. [43] showed the successful application of geotextile reinforcement on peat. Performance of geotextile showed that no evidences of rotational failure, tension cracks, and extreme large deformation were observed without any ground improvement technique even though first stage of construction conducted up to critical height without rest.

Hirao et al. [44] discussed the effect of bending stiffness of geotextiles on bearing capacity improvement of soft clay. Based on findings they reported that sand mat placed on soft clay has little influence on improvement of bearing capacity whereas placement of sand mat with geotextile covering soft clay contributes to the improvement of bearing capacity of soft clay. It is also noticed that bending stiffness owned by geotextiles has nothing to do with increase in bearing capacity of soft clay.

Palmeira et al. [45] carried out back-analysis of geosynthetic reinforced embankment on soft soils. Six case histories were considered for back-analysis. They found out that back analysis of an embankment reinforced by geosynthetic layer with significant strain rate dependency yielded satisfactory results. Also it was noticed analytical solution for factor of safety for reinforced embankments on soft soil presented accuracy comparable to the slip circle methods.

Unnikrishnan et al. [46] presented strength improvement due to reinforcement on clay bed sandwiched between sand layers. They analyzed the behavior of reinforced clay by conducting static and cyclic loading model test in triaxial compression testing equipment. Study depicted that grid type of reinforcement is much better in improving strength characteristics than sheet type of reinforcement because of the interlocking of sand particles within grid opening.

A case study on construction of a damaged road section on soft marine soil at Kakinada port area was carried out y Sreerama Rao [6] where in, a section of 360m long and 21.6m wide was chosen with 1m deep trenches were excavated to a width of 1.2m to anchor jute geotextiles. It was observed that geotextiles were effective where roads are constructed over weak subgrade soils, having CR value less than 2. It was further noticed that water content, void ratio and compression index decreased whereas, dry density and CBR increased on introduction of jute geotextiles indicating improvement in the engineering behavior which enhanced road life and even after 7 years of lapse, reinforced road section is still giving a good service.

Mustafa et al. [47] anticipated beneficial effects of reinforcing weak subgrade soil with single layer of geogrid and their behavior under static and cyclic loading. Permanent deformations measured by varying deviator stress, number of load cycles, confining pressure and reinforcement structure. They presented that with usage of geosynthetic reinforcement in cohesive soil increases effective cohesion to almost two times. They also suggested that degree of improvement in both resilient and permanent strains is mainly related to soil type and stiffness of the grid. Another observation showed almost 50% reductions in permanent strains due to reinforcement.

Hufenus et al. [48] discussed membrane and confining effect of geosynthetic reinforced unpaved road on soft subgrade. Full scale field test was carried out, including compaction and trafficking, to investigate the bearing capacity and its performance on a soft subgrade. Due to planar reinforcement significant bearing capacity improvement was achieved on soft subgrade whereas meager improvement was noticed on stronger and stiffer subgrade. Significant decrease in case of rut deformation is seen when geotextile reinforcement is provided. Efficacy of geosynthetic reinforcement shows almost 30% reductions in thickness of fill layer. In case of same rut depth, geosynthetic reinforcement can sustain maximum number of vehicle passes when compared to unreinforced. Such type of practice is beneficial in both economic and ecological aspects.

Tang et al. [49] studied the effect of geogrid properties including aperture size, wide width tensile strength, and weld/junction strength on pavement stabilization on weaker subgrade having low California Bearing Ratio (CBR). Properties were evaluated with the help of interface test, direct test, pullout and Accelerated Pavement Testing (ATP). Study indicates coefficient of interaction between geogrid and surrounding material play an important role in pavement stabilization.

Jadhav and Damgir [50] studied the use of geotextile in improvement of bearing capacity of subgrade. They performed laboratory California Bearing Ratio (CBR) with different soil (B.C. Soil, Murum and both) types and reinforcement (thick and thin netted woven jute geotextiles) types. Placement of geotextiles were kept at 1/3, 2/3 and half distance. Results showed that inclusion of geotextiles improved subgrade strength and improvement was appreciable (in terms of CBR) when the thick reinforcement was placed at 1/3 distance from top surface for soil sample of 50% B.C. soil and 50% murum.

Choudhary et al. [51] carried out the field construction study on Andulia-Boyratala road under PMGSY scheme which starts from Lauhati-Haroa state highway and ends at Boyalghata. Since, soil condition were very weak (organic silt clay with occasional brown clay mixed with little sand having soaked CBR value of 3.16%) entire stretch of road was covered with Jute geotextile. The Figure 2.2 shows the layout of geotextile before and after completion of road. It is seen from the study that with the help of Jute Geo-Textile (JGT) pavement thickness got reduced by 85mm from conventional method of design saving up to 75mm thickness of brick aggregates. Further whopping cost reduction of Rs. 60,672.00 per km stretch of road construction. They concluded that brief effective life of JGT is not a discouraging factor as soil gets consolidated to its maximum within year arresting movement of particle on top.

JGT LAID ON SUBGRADE

FINISHED ROAD

Figure 2.2 Section of road prior and after construction

Noorzad and Manavirad [52] discussed beneficial effects of using reinforcement to improve bearing capacity of strip footing on soft clay. A series of finite element analysis was carried out on footing using two dimensional plane strain model in Plaxis. They reported that bearing capacity was found to increase with increasing number of reinforcement layers if reinforcement layers were placed within the range of effective depths. Further it was noticed from the results that additional increase in reinforcement beyond threshold value does not benefit in improvement of bearing capacity.

2.3.2 Geocell Reinforcement

Performance studies of road embankment on soft clay supported on a geocell mattress foundation was completed by Cowland and Wong [53] in territories of Hong Kong. Geocell mattress was laid to support embankment which has soft clay deposits underneath. Performance was monitored using pneumatic piezometers, inclinometers, hydrostatic profile gauges, surface settlement markers and lateral movement blocks. Appreciable improvement was noticed with geocell reinforced embankment even though at one section excess pore pressure was identified.

Influence of geocell configuration viz. geocell opening size and height on bearing capacity and failure mechanism of geocell reinforced soil structure was investigated through controlled laboratory experiments by Mandal and Gupta [54]. On observation of the results showed significant improvement in the overall performance in load carrying capacity and settlement reduction when geocell reinforcement was used.

Mhaiskar and Mandal [55] studied the influence of geocell reinforcement in strengthening of soft soil subgrade. They conducted the laboratory tests done in mild steel tanks of dimensions 0.85 x 0.75 x 0.6m and 1.15 x 1.05 x 0.75m (length x breadth x height). Required density was maintained using standard proctor hammer compaction. The tank was filled with marine clay up to 0.48m and the geocell mattress was overlaid on it. It was noticed that because of higher modulus woven geocell offered higher load bearing capacity when compared to non-woven geocell even though the former has less seam strength. Thus, indicating crucial role of modulus of reinforcement in strengthening of soft subgrade.

A series of model tests were conducted by Sireesh et al. [56] to assess potential benefits of geocell sand mattress over clay subgrade bed with void. The model tests were carried out in a test tank measuring 0.9m from all sides with footing thickness and diameter of 30mm and 150mm respectively. Influence of width and height of geocell along with relative density and additional planar base layer on performance of bearing capacity and settlement reduction was studied. They promoted that to quantify benefits, additional planar base layer to be laid below the geocell mattress which performs more than 3 times in soft subgrade with void. Results also pointed that load bearing capacity of footing increases as high as 40 times when coupled with improvement due to sand layer.

2.4 Studies on Stiff Sand/Granular Infill Overlying Soft Soil Beds

2.4.1 Planar Reinforcement

Love et al. [57] has systematically presented effectiveness of geosynthetic reinforcement in soft soil beds. Model and analytical tests were conducted on granular infill soft soil beds have shown significant shear stress reduction to the clay subgrade due to provision of geogrid reinforcement. Also it is noticed that amount of reduction is a function of strength of soft soil and thickness and stiffness of granular layer. They suggested that proper design approach is necessary for reinforced fill since slight modification in the unreinforced road design does not give optimum results.

Ochiai et al. [58] discussed different practice methods carried out in Japan for fill over soft ground. They emphasized on use of geosynthetic material on soft soil having high water content and low shear strength improved bearing capacity. Several studies like bearing capacity theory, cable theory combined with modulus of subgrade reaction theory and plate theory were useful in designing embankments on soft ground. They recommended multilayer reinforcement since single layer does not withstand the external forces. Also, it is suggested to provide an appropriate spacing to ensure proper bonding between soil mass and reinforcement which acts as a single mass system.

Strength behavior of geogrid reinforced lithomargic clay soil subgrade which is frequently available in Konkan region was studied in detail by Ravi Shankar and Subba Suresha [59].

They conducted plate load tests on soaked and un-soaked condition for aggregate base, reinforced and unreinforced subgrade. On observation it is noticed that Lithomargic clay loses its strength under high moisture content giving rise to differential settlement which can be arrested with the help of geogrid reinforcement. Also results predicted that with the placement of geogrid reinforcement in subgrade at depth half the width of footing settlement reduction was almost 45-71% in case of un-soaked condition and 20-51% for soaked condition.

Role of geotextile reinforcement underneath the embankment built on soft clay is explained by Sarsby [60] through a parametric study. Based on results it is noticed that reinforcement force required to maintain given factor of safety against rotational failure falls rapidly with time due to consolidation of the foundation and greater stability is achieved through use of geotextiles as basal reinforcement.

Krystyna [61] discussed the influence of geosynthetic reinforcement on load-settlement of reinforced bed by conducting laboratory experiments on two layered soft subgrade and comparing results with analytical modeling. Since, it is difficult to obtain naturally occurring homogeneous bed, they proposed that geosynthetic reinforcement provided at interface of two layer subgrade show higher benefit load capacity ratio and settlement reduction. The results from analytical modeling were in accordance with the experimental results.

Subaida et al. [62] have reported use of coir geotextiles as aggregate reinforcement in unpaved road sections. Monotonic and repetitive loading tests were conducted in a large concrete steel tank of 1.5m x 1m x 1m (length x width x height) using with 200mm diameter and 25mm thick circular plate with a groove at center. Load transfer arrangement is through load assembly prefabricated using steel channels and plates. To maintain verticality during test, load is transferred on to the footing with screw and jack arrangement through a steel ball kept in a groove of the footing plate. Construction of bed was done in two stages viz. required thickness of clay subgrade overlying with reinforced base using aggregate infill by compaction. Results reported that for 20mm of footing settlement under monotonic loading load carrying capacity ratio increased almost to 35% and settlement reduction went down by as much as 50% when reinforcement was kept at mid depth of the base instead at base-subgrade interface.

Al Qadi et al. [63] provided a new insight into effectiveness of geogrids on the performance of low volume flexible pavements. A full scale, highly instrumented (170 sensors) low volume flexible pavement road sections were constructed on weak subgrade (CBR =4%) for monitoring pavement performances and measuring pavement responses. The tests were performed with several variables like tyre configuration, loading, inflation pressure, speed and travelling offset using Accelerated Transportation Loading Assembly (ATLAS) test program. They reported that for relatively thick granular base layer, geogrid placement at upper 1/3 of the base reduces the shear strain in both longitudinal and transverse direction whereas for weak pavement base-subgrade interface reduces vertical deflections. Overall performance in reducing rutting, cracking and lateral deformations was shown by inclusion of geogrid reinforcement.

2.4.2 Geocell Reinforcement

Bush et al. [64] carried work on design and construction of geocell foundation mattress supporting embankments over soft grounds. They concluded that differential and total settlements were reduced due to load distribution through geocell mattress. Also cost saving up to 30% can be achieved as by constructing geocell reinforced embankment over soft soil as compared to conventional methods.

Mandal and Gupta [54] executed laboratory tests to analyze the performance of geocell reinforcement in improvement of bearing capacity on marine clay overlain by sand layer. In their study the determined the use of geocell with smaller opening size is appropriate for paved roads where very low settlements are permissible whereas large size geocell can be used for unpaved roads.

Dash, Sireesh and Sitharam [65] performed model studies on circular footing supported on geocell reinforced sand underlain by soft clay. The conclusions drawn from their study are provision of reinforcement in overlying sand layer improves the load bearing capacity with reduction in settlements. With appropriate dimension of geocell reinforcement seven-fold increase in bearing capacity can be achieved.

Pokharel et al. [66] conducted model tests to evaluate performance of geocell for base course for low volume unpaved roads over weak subgrade. They varied base course thickness keeping constant height of geocell (150mm) and non-woven geotextile as separator between subgrade and base layer. On observation it was noticed that life of an unpaved road can be increased up to 3.5 times depending upon aggregate used as infill.

Kumar et al. [67] studied the potential benefits of providing geocell reinforced sand mattress over clay subgrade. On observation it was noticed that bearing capacity of foundation bed increases with increase in thickness of geocell mattress. To achieve maximum benefit depth of placement of reinforcement should be 10% of footing width. Improvement factor as much as 5.5 times can be obtained with provision of geocell reinforcement two times the width of footing in sand layer reinforced over clay bed.

Summary

Initial literature study gives an outlook of the work carried out to understand various types of reinforcement and its effect on reinforced beds. Some of the important consensuses are drawn from literature review.

- Planar form of reinforcement is commonly used in the most of the geosynthetic application.
- Emphasis is given in the study of surface footing resting on reinforced beds.
- Several studies stated benefit of the use of reinforcement in improvement of bearing capacity, settlement reduction and subgrade modulus.
- Most of the studies concentrated on monotonic loading.
- Honeycomb like structure gained popularity over the period due to property of confinement effect.
- Some of the studies mentioned benefit of use of additional layer of reinforcement at the base of geocell mattress.

Though literature covers major aspect of reinforcement a very little attention is given on the environmental friendly material like geojute and jute-geocell. There is need of an hour to promote environmental sustainable solutions through green material.

In view of this, following chapters encompass experimental evaluation of reinforced sand beds, stiff beds overlying soft beds and infill material over soft bed under repetitive loading.

Chapter 3

Materials and Methods

3.1 Introduction

To understand the behavior of material on reinforced beds viz. sand beds, soft soil beds, stiff beds, granular and aggregate infill etc. it is necessary to understand the material characterization. Thus, in this chapter, the details of material and their characterization are discussed.

3.2 Characteristics of Sand

The sand used in the study is dry sand, procured from Krishna river basin, Vijayawada. It was air-dried by spreading in thin layers over a large area and sieved through 4.75mm sieve to remove gravel particles.

3.2.1 Sieve Analysis

The particle size distribution of the sand was determined by dry sieve analysis as per IS 2720 (part-IV)-1985. The sand is classified as poorly graded sand with letter symbol SP according to the Indian Standard Soil Classification System (ISSCS) since, coefficient of uniformity, C_u is equal to 2.4. Coefficient of curvature, C_c was found to be equal to 1.01. ($C_u<6$ is termed as poorly graded). The size of particle ranges from 0.15mm to 2.36mm. Effective diameter (D_{10}) of a soil sample is 0.20 and average grain size (D_{50}) of the particle is 0.50. The particle size distribution of the sand is shown in Figure 3.1.

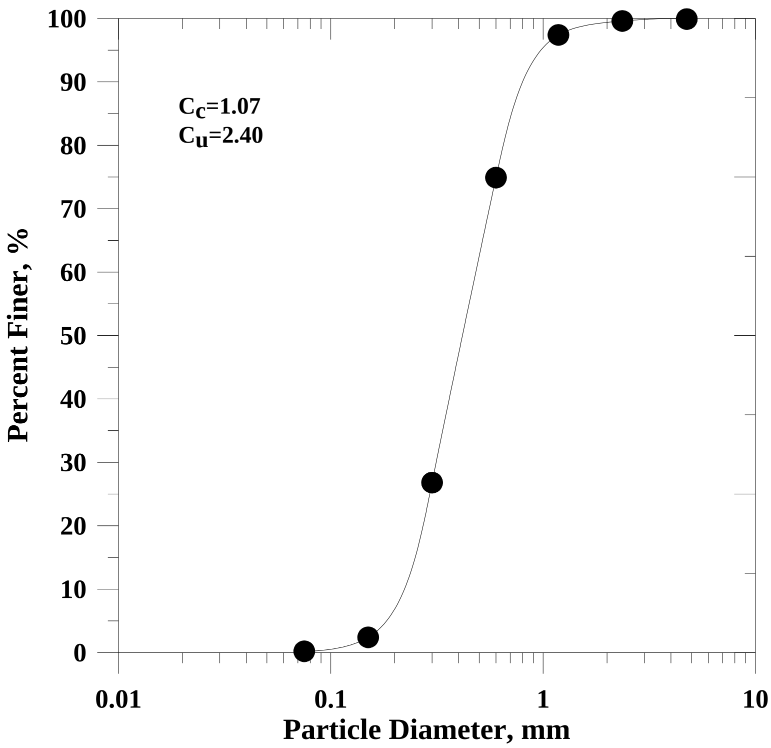

Figure 3.1 Particle size distribution curve

3.2.2 Specific Gravity

Specific gravity is conducted as per IS: 2720 (Part-III) – 1980 and a specific gravity of sand, G_s, equal to 2.63 is obtained.

3.2.3 Maximum and Minimum Dry Densities

The physical property such as maximum and minimum void ratios of sand were determined according to IS: 2720 (Part-XIV) – 1983. The maximum (γ_{dmax}) and minimum (γ_{dmin}) dry density of the sample is 16.86 kN/m^3 and 15.1 kN/m^3. Thus, maximum (e_{max}) and minimum (e_{min}) void ratio is 0.74 and 0.51 respectively.

3.2.4 Direct Shear Test

Direct shear tests conducted on unreinforced sand are performed in a small shear box of dimensions 100mm x 100mm x 30mm as shown in Figure 3.2. The sand is compacted at its 70% relative density. These tests were conducted at 40kPa, 80kPa and 120kPa of normal stresses to obtain the angle of shearing resistance of sand.

To know the shear strength parameter of the sand sample, direct shear tests are conducted as per IS 2720 (Part XXXIX/Sec. I). Shear box has in-built horizontal and vertical load cells has maximum capacity of 4.4kN and maximum allowable displacement of the box is 25mm. Linear Variable Displacement Transformers (LVDT) are attached to the horizontal and vertical dimension to measure the respective settlement of sand. The rate of displacement is maintained at 1mm/min for all the tests. Values are recorded at every 1mm of horizontal displacement. Graph is drawn to show variation between shear stress and horizontal displacement (see Figure. 3.3).

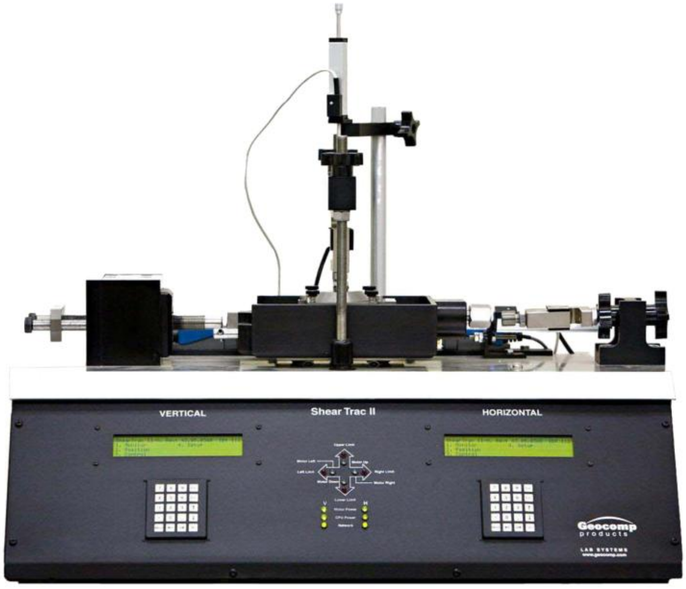

Figure 3.2 Direct shear test apparatus

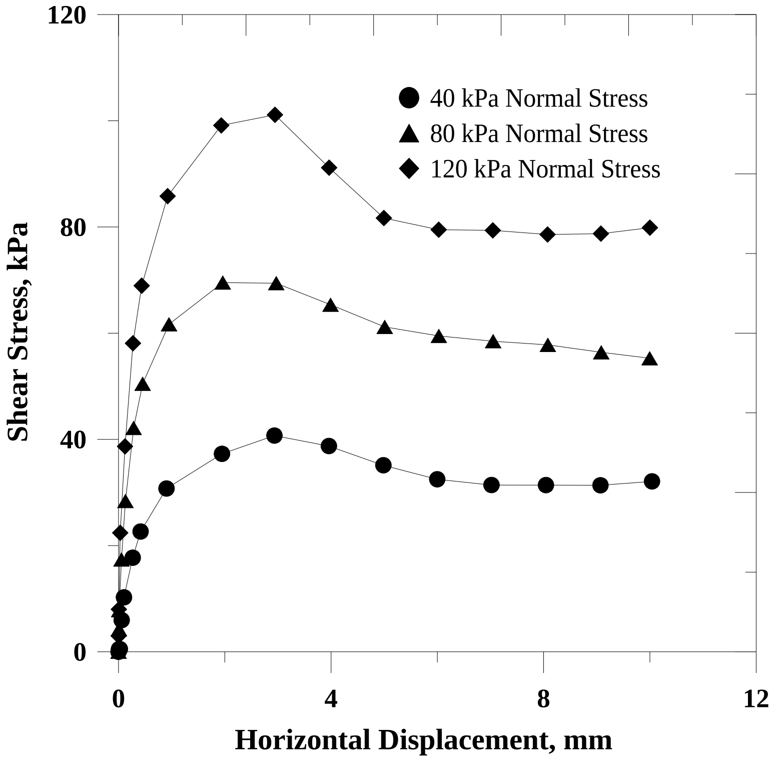

Figure 3.3 Variation between shear stress and horizontal displacement.

Shear strength parameters are obtained with calculation from variation of shear stress and horizontal displacement. Figure 3.4 shows graph between the normal v/s maximum shear stress.

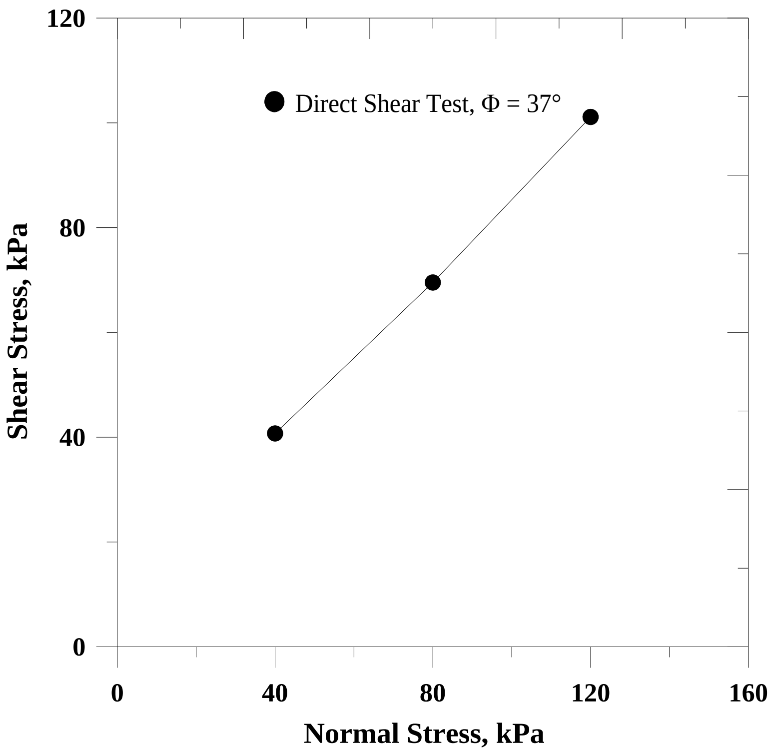

Figure 3.4 Normal stress v/s maximum shear stress

From Figure 3.4 the apparent cohesion and angle of shearing resistance is found to be 6.8 kPa and 37°, respectively.

3.2.5 Interface Direct Shear Test

In this study, large scale direct shear tests were carried out to determine the angle of shearing resistance (Φ) by shearing geojute with sand material and only with sand material. The tests were conducted under normal pressures at 40kPa, 80kPa and 120kPa respectively. The tests were ended at the horizontal displacement of 10mm.

The interface shear strength parameters are calculated using fully automated direct and residual shear tests on Shear Trac-II Systems under laboratory controlled conditions. The Shear Trac-II system consists of a Shear load frame of capacity 44kN with a computer attached network card for test control and data acquisition. Microsoft Windows application software, called SHEAR is used for running the test. The large Shear box is of dimension 300mm× 300mm×200mm as shown in the Figure 3.5. After filling lower box through required compaction technique (for maintaining 70% relative density in the box), Geojute of size 320 mm wide and 500 mm long and whose weight is 80 gms is firmly attached to the lower box. Figure 3.6 shows typical the sand specimen prepared in large scale shear box with interfaced geojute material. Upper box is placed over it and required density sand is filled. During tests, the sand is forced to slide along geojute under constant rate of displacement of 1mm/min, while a constant load is applied normal to the plane of relative movement. The normal and shear forces applied to determine the point of failure.

Figure 3.5 Large-scale direct shear apparatus

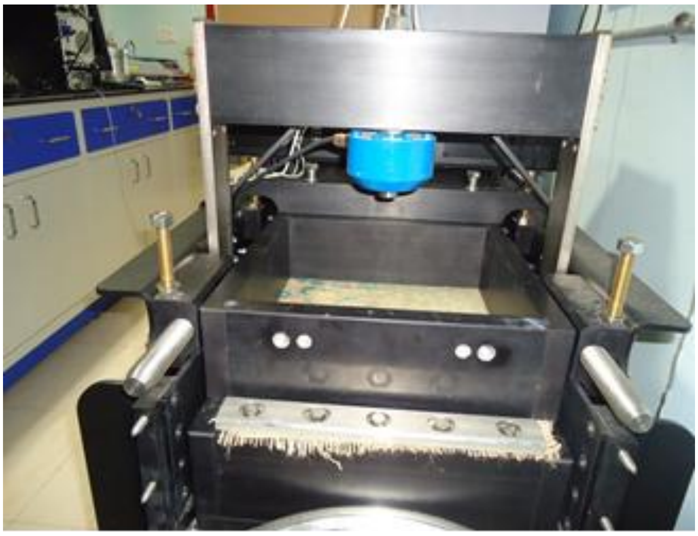

Figure 3.6 Geojute specimen under testing for interfacial shear

It can be seen from Figure 3.7 that the shear stress values have reached to its peak and then reduced to constant value for unreinforced case whereas for geojute reinforced case, the shear stress was showing increasing trend until the end of the test. From the tests it is observed that the angle of shearing resistance of the unreinforced sand is 37.0° and for the geojute reinforced sand specimen the interfacial shear angle, δ is observed to be 30.9°. The angle of shearing resistance and interfacial shear angle are presented in Figure 3.8. The interfacial shear angle is found to be well within the range of values commonly observed for geotextile materials.

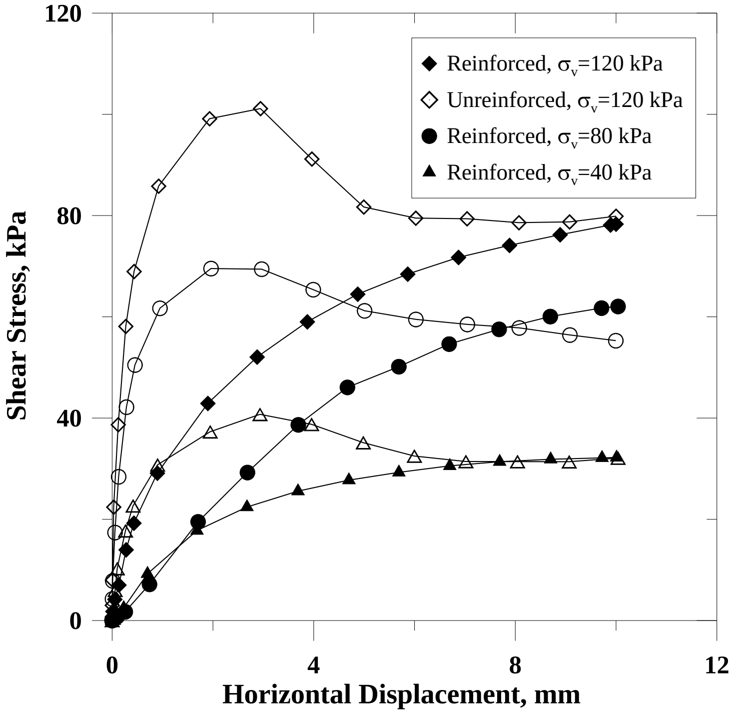

Figure 3.7 Variation of stress with horizontal displacement

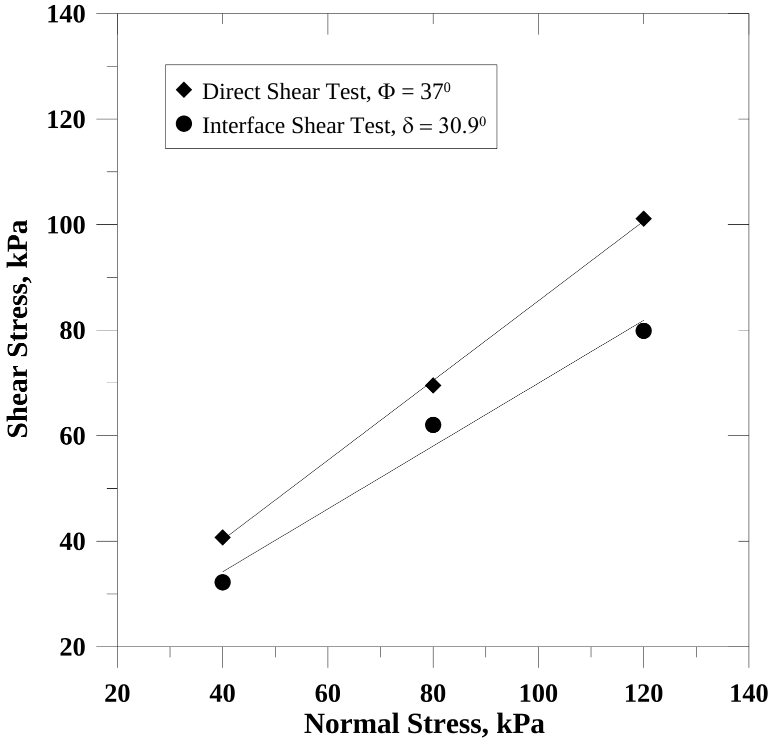

Figure 3.8 Variation of shear stress with normal stress

3.3 Characteristics of Aggregate

The material used for the study is aggregate infill material having fines obtained from the local suburban quarry site near Hyderabad. Fine contents are removed by screening it through 4.75mm sieve.

3.3.1 Sieve Analysis

Particle size distribution of aggregates is done by preforming dry sieve analysis as per IS. Based on sieve analysis aggregate is classified as poorly graded. Fig. 3.9 shows the particle size distribution curve.

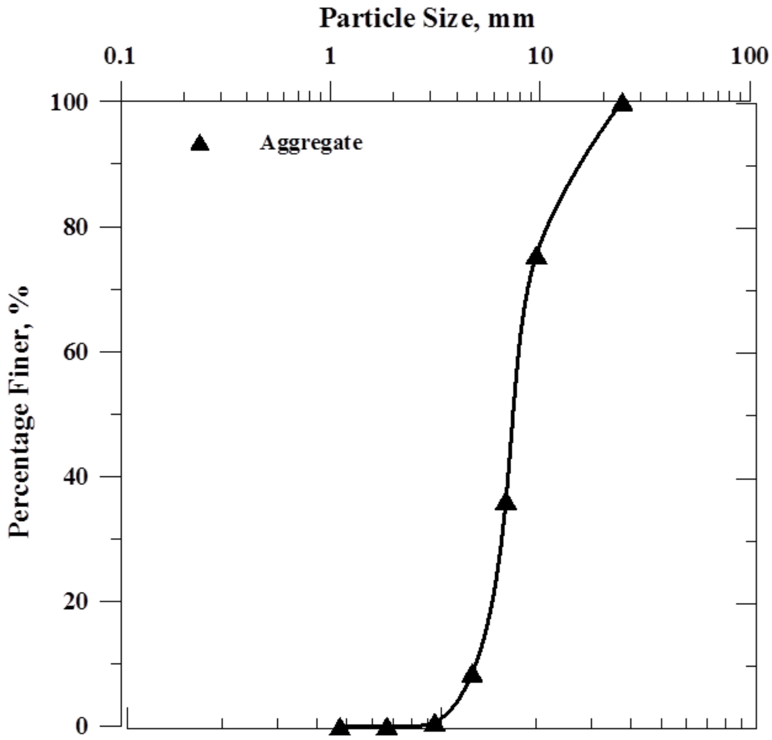

Fig. 3.9 Particle size distribution curve

3.3.2 Specific Gravity

Specific gravity test is conducted as per IS: 2386-Part-3 and specific gravity value, G_s, equal to 2.646 was obtained.

3.3.3 Water Absorption

Water absorption test was conducted according to IS: 2386-Part-3 and it was found that water absorption of aggregate in the study is 0.251%.

3.4 Characteristics of Geojute

A waste jute material, from packaged jute bags is used in the study. The jute was cut into various sizes and shapes for the testing purpose. Several tensile tests were conducted on a Tinius Olsen tensile testing apparatus (as shown in Figure 3.10) with maximum capacity of 150kN for understanding the strength-elongation behavior of geojute material.

Figure 3.10 Tensile testing apparatus

3.4.1 Wide width tensile test

A wide width tensile test conducted as per ASTM D-4595-11. Results show that a tensile strength of geojute is 4.9kN/m.

Following Table 3.1 shows the comparison of Geojute material properties with the IJIRA Jute-Geotextile. It is to be noted that the geojute used in this study is from waste gunny bags with almost half the thickness of commercially available jute-geotextiles.

Table 3.1 Properties of material

Properties	**Values (Present Study)**	**Values (IJIRA)**
Material	Woven Geojute	Jute-Geotextiles
Thickness (mm)	1.76	3.6
Mass per unit area (kg/m^2)	0.513	0.52
Aperture Size (mm)	1.65 x 1.65	2.8 x 2.8
Ultimate tensile strength (kN/m)	4.9	5.7

3.5 Test Methodology

3.5.1 Test Setup

The sand beds with 70% relative density were prepared in a test tank measuring inner dimensions of 1m × 1m x 1m (length x width x height). A rigid thin steel plate of 150 mm diameter (D) and 15 mm thickness was used to apply the repeated traffic loading. The size of the plate was chosen such a way that the area of the plate resembles the area of tire pressure. Following Table 3.2 shows properties of plate used in the study.

Table 3.2 Properties of Plate

Properties	Values
E (MPa)	2×10^5
M	0.2
K (MPa)	1.11×10^5
G (MPa)	0.83×10^5

Loading was given by graphical user interfaced MTS MPT software with the help of hydraulic power unit (HPU), hydraulic service manifold (HSM) and sophisticated double acting linear dynamic 100 kN capacity actuator which is attached to a 3.5 m high, 20ton capacity reaction frame as shown in Figure 3.11.

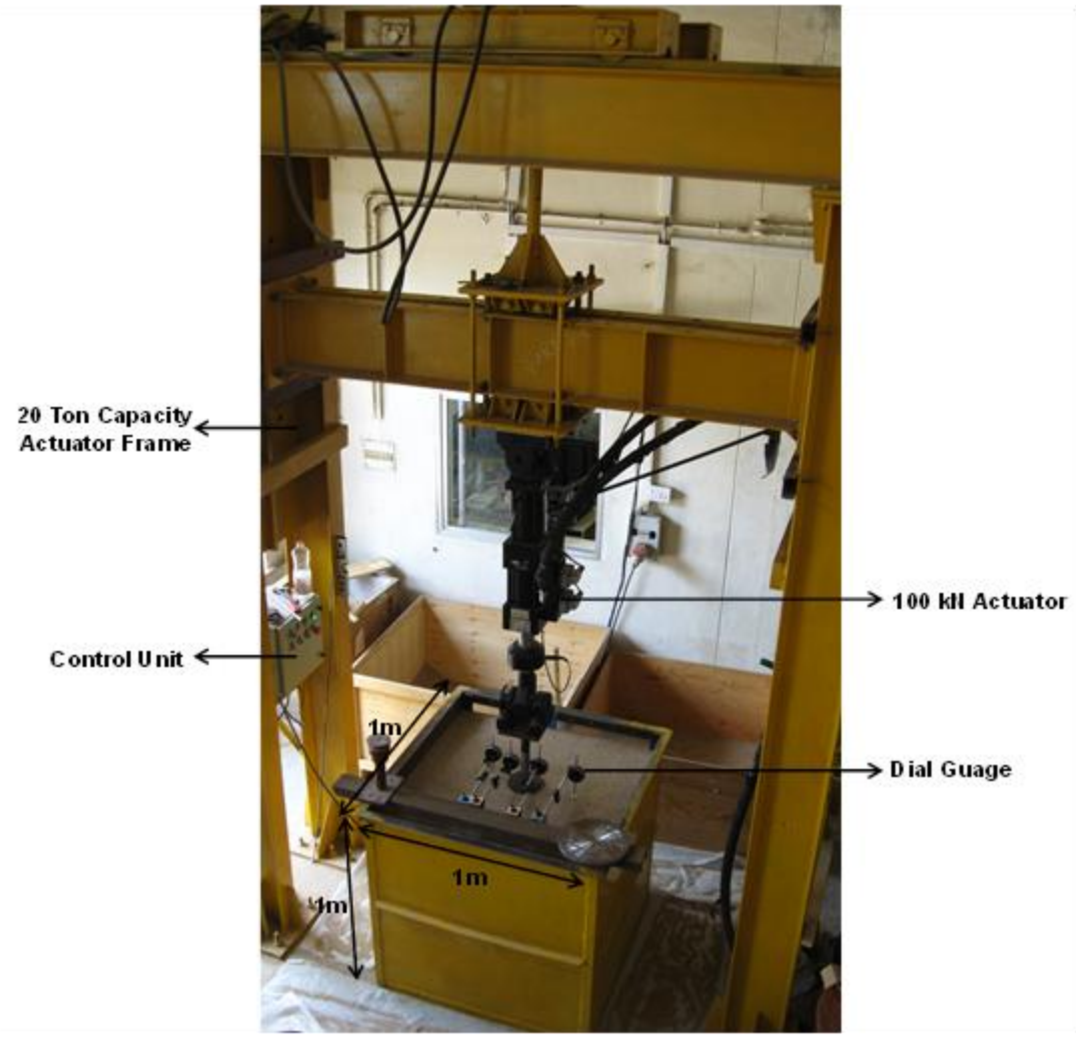

Figure 3.11 Typical Setup of loading system used in the study

3.5.2 Relative Density Calibration Chart

To determine the density with which sand is to be placed in the test tank, a special technique called sand raining or pluviation technique is used. To achieve this, a special device is designed. It consists of a long steel pipe of diameter 30mm with a cone fixed at the bottom. Apex of the cone is pointed up with cone apex angle of 60°. This pipe is fitted with a movable scale to arrange different heights. An arrangement of a typical setup is shown in Figure 3.12.

Figure 3.12 Devices used in the preparation of bed

Calibration tests were conducted to obtain a relation between relative density and height of fall as a calibration chart. Placement densities were measured physically by collecting samples in small containers whose weights and volumes were known. With the known values of the minimum and maximum void ratios of sand taken in the investigation, a calibration chart was prepared for the height of fall against the corresponding relative density. For any required relative density corresponding height of fall can be read from calibration chart shown in Figure 3.13.

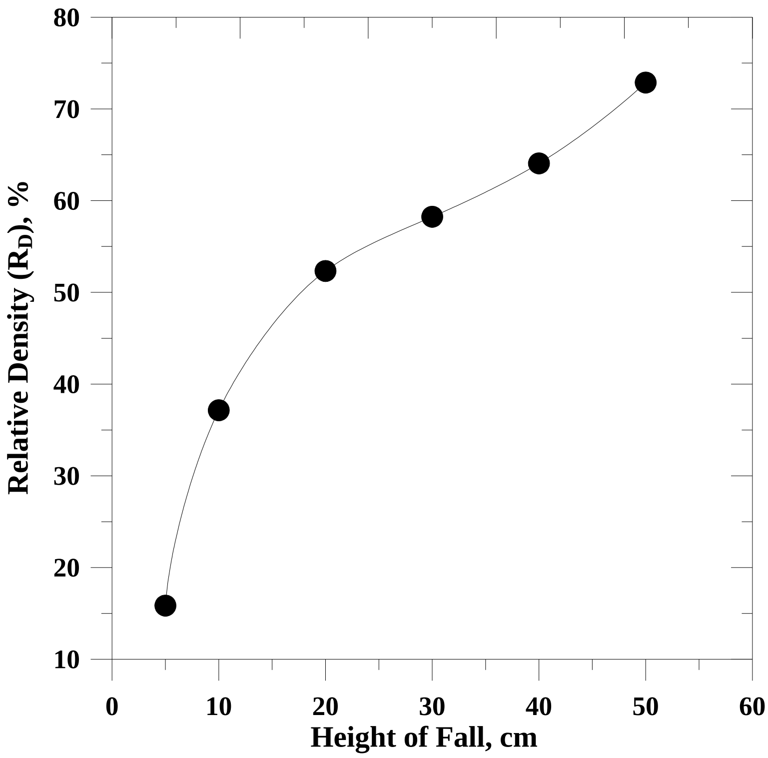

Figure 3.13 Calibration curve for the sand used in the study

3.5.3 Sand Bed Preparation

The sand was placed in the test tank using a raining technique. This device has a hopper with a pipe welded to its bottom which is 400 mm long with an inverted cone welded at its tip. The sand passes through this 30 mm internal diameter pipe and disperses at bottom by a 60° inverted cone. The height of fall to achieve the desired relative density was determined by performing a series of trials with different heights of fall earlier. In each trial, the densities were monitored by collecting samples in small cups of known volume placed at different locations in the test tank. With the known values of the minimum and maximum void ratios of sand in the study, a calibration chart was prepared for the height of fall against the corresponding relative density as shown in Figure 3.13. The height of fall can directly read from the graph corresponding to the required relative density. In all tests, the relative density of sand was kept constant at 70 % and 30% for each series of test.

3.5.4 Static and Slow Cyclic Plate Load Tests

The static and cyclic plate load test were carried to estimate the modulus of subgrade reaction, shear modulus and modulus of elasticity of unreinforced and reinforced sand subgrade. Slow incremental loading rate of 0.1kN/sec was applied up to 2kN with relieve of load at 0.5kN, 1kN and 1.5kN. A typical variation of pressure v/s settlement ratio due to slow cyclic plate load test for jute-geocell reinforced sand bed with b/D=2 and h/D=1 is as shown in Figure 3.14.

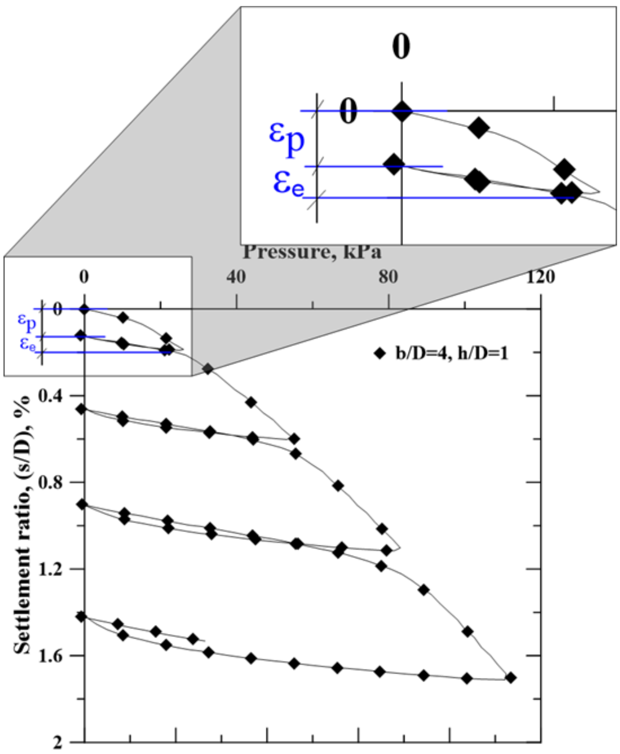

Figure 3.14 Typical Variation of Pressure v/s Settlement Ratio

3.5.5 Cyclic Load Tests

The procedure to test the beds under cyclic loads was in accordance with the Indian Standard code IS 1880: 1982 (reaffirmed 1998). Upon filling the test tank up to the desired height, the fill surface was leveled and the loading plate was placed on a predetermined alignment such that the loads from the actuator applied would be transferred concentrically to the footing to avoid eccentricity. To facilitate this, a recess was made into the footing plate at its center to accommodate a ball bearing through which vertical loads were applied to the plate. In the case of reinforced beds, upon ceasing the pluviation at predetermined depth, the geojute/jute-geocell was stretched on the leveled subgrade and continued the sand pluviation to fill the geojute/jute-geocell mattress.

The plate was located carefully at the center of the actuator against the reaction frame to avoid eccentric loading. The cyclic load was applied to a loading plate using a computer-controlled servo hydraulic actuator, with a maximum load of 7 kN and a minimum on 0.7 kN using a continuous haversine loading pattern as shown in Figure 3.15.

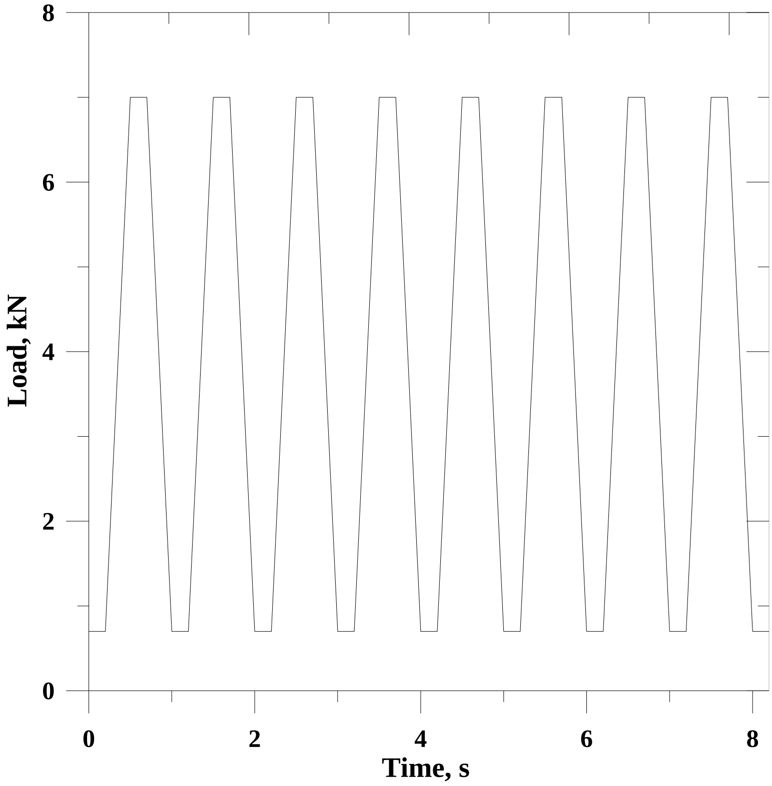

Figure 3.15 Loading pattern used in the study

The load was estimated based on the field data using a strain type total pressure cells buried under subbase layer just above the subgrade. Similar loading pattern was also adopted by Edil et al. [68] for the case of geocell reinforced granular subbase layer. Since the intermediate layers have not been simulated in this model tests, the pressure exerted on to the subgrade was directly applied through a plate. A 10% of load (0.7 kN) was constantly applied on the plate to make the cycle a closed loop. The load form was applied at a frequency of 1.0 Hz. Multi-Purpose Test Ware (MPT) software was set up to control and acquire the applied load data as well as the deformation data.

3.6 Multi-Purpose Test ware

MPT (Multi-Purpose Test ware) allows user to create complex test designs with discrete processes. Each process thus represents an individual test activity. A set of processes is grouped together in a closed loop to generate a haversine loading pattern discussed in Section 3.5.5. The tests can be done into two way viz. Force controlled method and Displacement controlled method. The tests done in the study were based on Forced controlled method in which the configuration of devices provides a means of comparing a command signal (programmer output) to generate a signal with a feedback (transducer output) signal to generate a signal that controls a servo valve. The servo valve controls hydraulic flow of the actuator which moves the actuator piston rod. The actuator piston rod is applies the force required to displace the component to be tested. Entire process is referred as "closed-loop control system" since, process of command, feedback, comparison and servo valve is a function of control circuitry and occur without operator interaction. A typical MPT close-loop control program is shown in Figure 3.16.

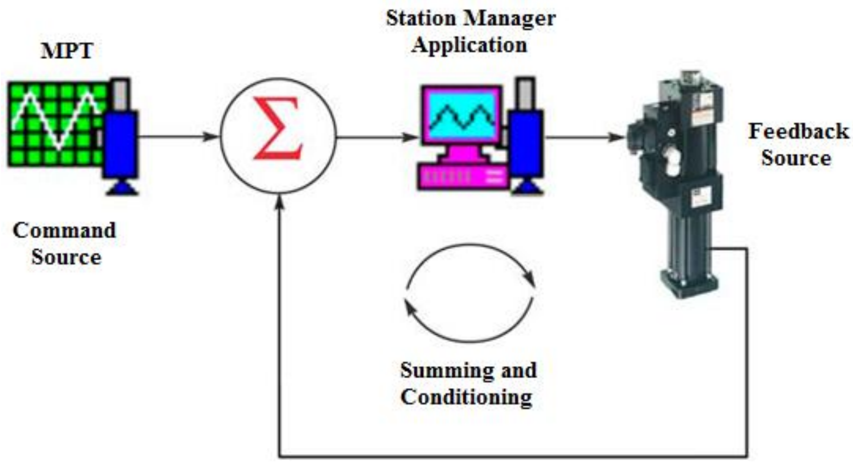

Figure 3.16 Typical close-loop control program in MPT software

3.7 General Remarks

In this chapter, a detailed characterization of each material used in this study was discussed. An elaborate discussion on the test setup and procedures followed to understand the behavior of geojute materials is presented. The MPT software is briefly discussed along with the adopted loading pattern for conducting the cyclic load testing program.

Chapter 4

Planar Geojute Reinforced Sand Subgrades

4.1 Introduction

In this chapter the behavior of the planar geojute reinforced sand subgrades subjected to cyclic loading is discussed. Influence of various parameters such as width of reinforcement layers (b), number of reinforcement layers (N) are studied to understand the efficacy of geojute material to achieve maximum performance benefits. In addition, experimental results due to variation of relative density on reinforced sand beds are presented. Performance improvement is presented in terms of non-dimensional parameters viz. Traffic Benefit Ratio (TBR), Cumulative Plastic Deformation (CPD), Improvement Factor (I_f) and Percentage Reduction in Settlements (PRS).

4.2 Experimental Programme

Figure 4.1 shows the experimental setup of geojute reinforced sand subgrades. A series of experiments were conducted with variable parameters in terms of normalized ratios (u/D, b/D, N) as described in Table 4.1. Within each series, one particular parameter was varied, while the other parameters were kept at a constant value, to understand the effect of a particular parameter on the overall behavior of the reinforced bed. Total six series of tests were conducted. In Table 4.1, the nomenclature with subscript (in column 4) defines test series and the testing scheme. In series S, static load tests were conducted on unreinforced sand beds while varying the placement density of sand where rate of loading was maintained at 1mm/min. In series A, repeated load tests are conducted on unreinforced sand beds varying the relative density of the subgrade sand. In addition, a test is also done on sand with aggregate infill material. In series B and C, tests are done on geojute reinforced sand beds by varying number of geojute layers and also varying the placement of density whereas keeping all other parameters (u/D, b/D, D) at a constant value. In series D, effect of width of reinforcement layer on efficacy of the reinforcement system was studied. Series E was carried out with the variation in relative density by keeping all other parameters (u/D, b/D, D) constant.

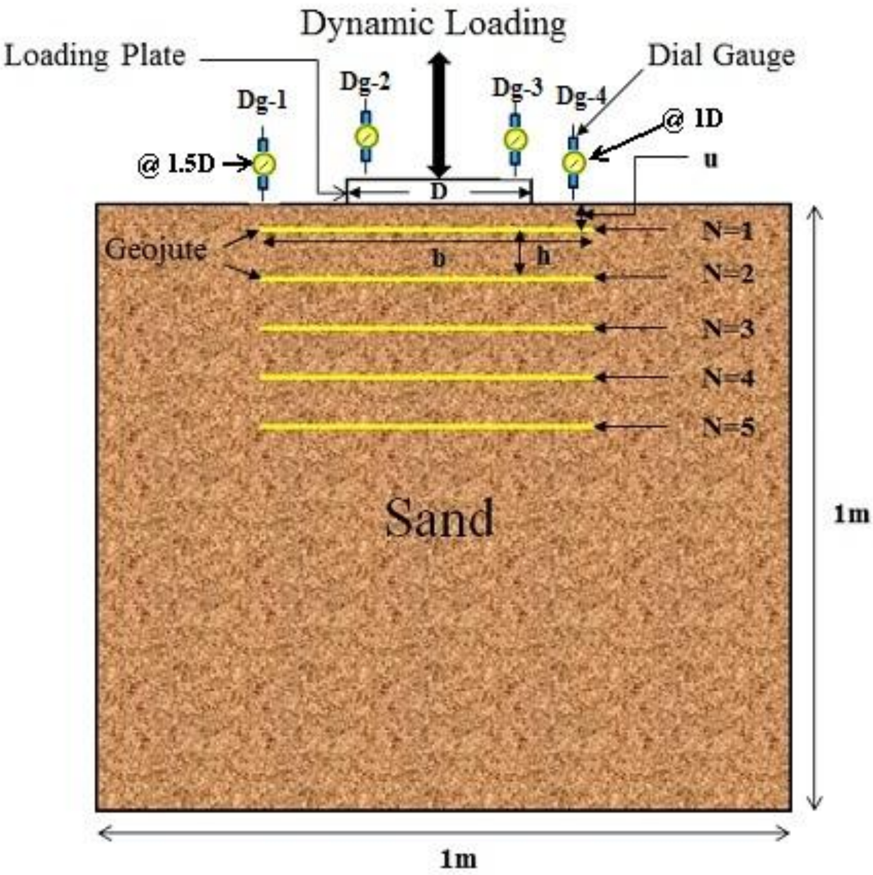

Figure 4.1 Experimental setup of geojute reinforced sand subgrade

Table 4.1 Testing scheme

Test Series	**Type of Reinforcement**	**Details of Test Parameters**	**Nomenclature**	**Testing Scheme (Subscript replicates Series)**
S	Monotonic Loading (Static)	*Constant Parameter*: Rate of loading; 1mm/min	S_1 S_2 S_3 S_4 S_5 S_6	1. R_D=30% 2. R_D=70%+30%, h1=6cm, h2=84cm 3. R_D=70%+30%, h1=10.5cm, h2=79.5cm 4. R_D=70%+30%, h1=16.5cm, h2=73.5cm 5. R_D=70%+30%, h1=21cm, h2=69cm 6. R_D=70%

A	Unreinforced (Cyclic)	*Constant Parameter*: D=150mm	A_1 A_2 A_3 A_4 A_5 A_6 A_7	1. R_D=30% 2. R_D=70%+30%, h1=6cm, h2=84cm 3. R_D=70%+30%, h1=10.5cm, h2=79.5cm 4. R_D=70%+30%, h1=16.5cm, h2=73.5cm 5. R_D=70%+30%, h1=21cm, h2=69cm 6. R_D=70% 7. R_D=30%+Aggregate Infill, h1=21cm, h2=69cm
B	Geojute Reinforced (Planar)	*Constant Parameters*: R_D=70%, u/D=0.1, b/D=4, D=150mm.	B_1 B_2 B_3 B_4 B_5	1. N=1 2. N=2 3. N=3 4. N=4 5. N=5
C	Geojute Reinforced (Planar)	*Constant Parameters*: R_D=70%+30%, u/D=0.1, b/D=4, D=150mm.	C_1 C_2 C_3 C_4	1. N=2 2. N=3 3. N=4 4. N=5
D	Geojute Reinforced (Planar)	*Constant Parameters*: R_D=70%, u/D=0.1, N=3, D=150mm.	D_1 D_2 B_3	1. b/D=2 2. b/D=3 3. b/D=4
E	Geojute Reinforced (Planar)	*Constant Parameters*: b/D=4, u/D=0.1, N=3, D=150mm.	E_1 C_2 B_3	1. R_D=30%. 2. R_D=70%-30%. 3. R_D=70%.

4.3 Test Results

4.3.1 General

The results are presented in terms of bearing pressure and settlement ratios. The settlement ratio is defined as the ratio of settlement of loading plate to the width of the plate, expressed in percentage. Typical bearing pressure-settlement ratio curve is shown in Figure 4.2. The test bed configuration schematic is shown above the Figure 4.2. It is seen from the graph that for the first few cycles (Number of cycles <10), the variation between pressure and settlement is noticeable. Further, with increase in the number of load cycles, not much variation in pressure-settlement is seen. Thus, pressure-settlement curve almost tends to vertical after it reaches a settlement ratio of about 10%. This implies that during initial load cycles, the plastic settlements are higher than the elastic settlements.

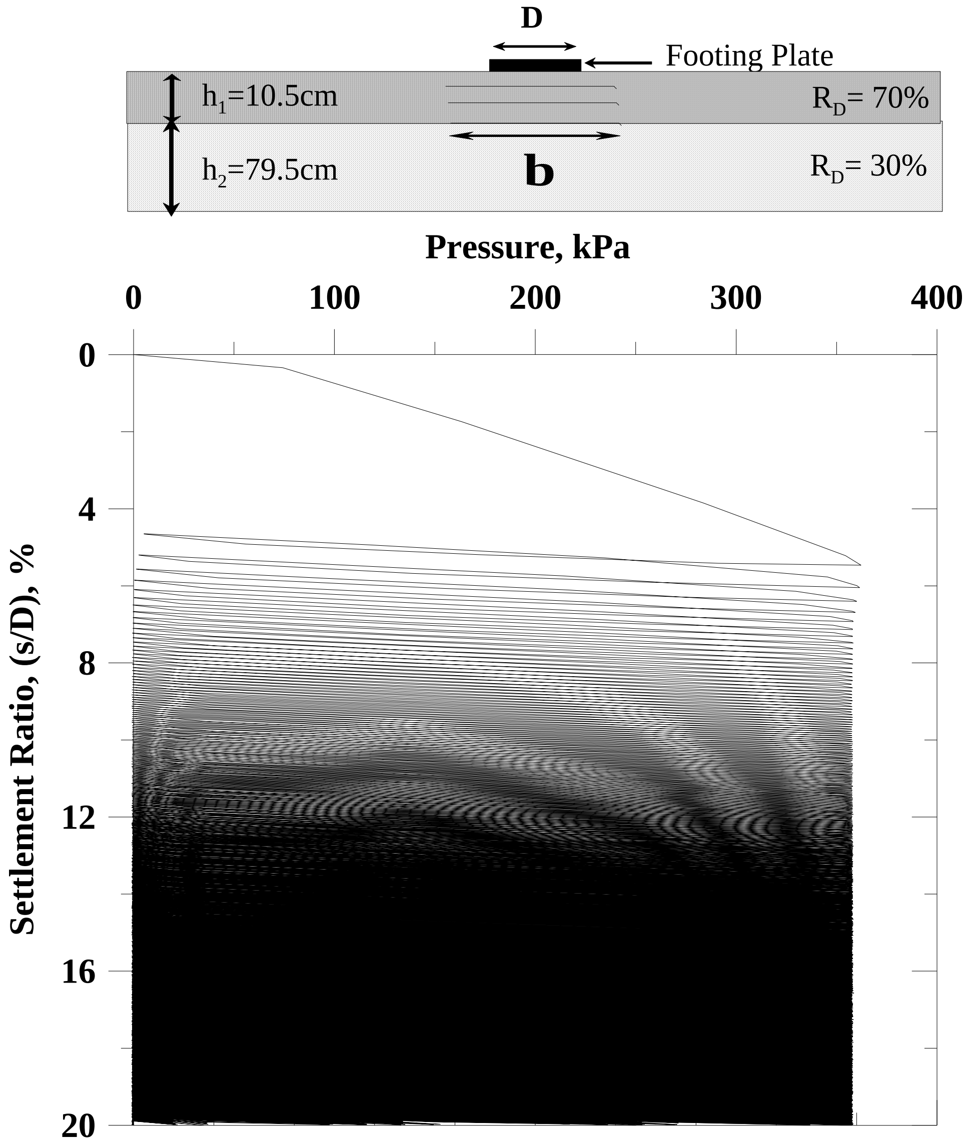

Figure 4.2 Typical pressure v/s settlement ratio curves

4.3.2 Pressure Settlements Responses

Pressure-settlement responses were monitored in order to verify the influence of placement density of the subgrade sand on overall behavior of reinforced sand beds in terms of load bearing capacity and reduction in footing settlements. The pressure settlement responses observed from series S (in this case, monotonic loading was applied at an interval of 1mm/min) are shown in Figure 4.3.

Figure 4.3 clearly shows that with increase in the placement density (relative density) of sand increases the load carrying capacity of the bed. The curves S_1 and S_6 represent the test bed with sand relative densities corresponding to 30% and 70%. The intermediate curves represent the beds with stiffer sand layer (R_D = 70%) overlaying weaker sand subgrade (R_D =30%) for different thickness of the upper layer. It is clear from these curves that the bearing capacity of the weak subgrade can be improved by placing a dense granular layer; however, the performance of the weaker subgrades may not be improved to a required degree without a proper reinforcement in the upper layer. It is noted that the bearing capacity of the weak subgrade has been increased by 1.5 times. Similar results were noticed by Sireesh [69].

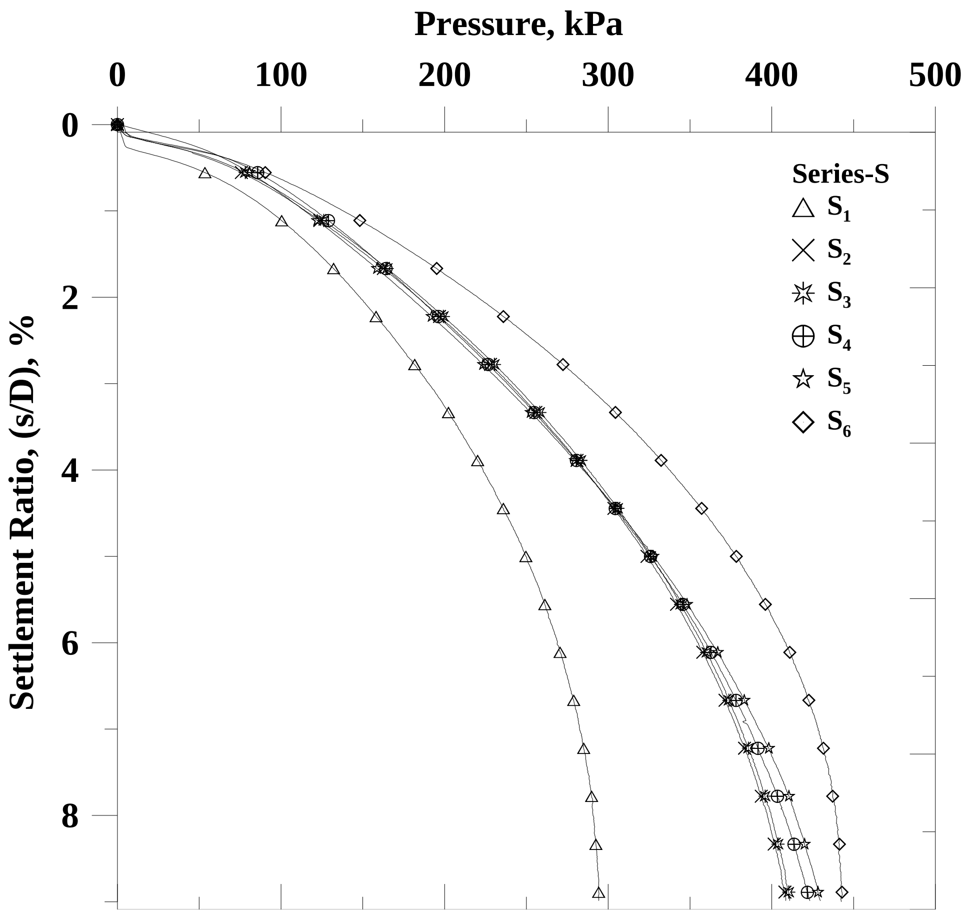

Figure 4.3 Monotonic loading on unreinforced sand (Series-S)

4.3.2.1 Unreinforced Beds and Surface Deformation Responses

Series-A shows the variation of CPD with No. of cycles under repetitive loading for different configurations of unreinforced beds, i.e., weak sand subgrades with and with out different heights of dense sand overlays. Figure 4.4 clearly shows that the failure for weaker subgrades with in first few cycles (Number of cycles <10), whereas, with increase in relative density of upper layer shows better performance in reducing the CPDs to a great extent. For sand bed with R_D equal to 70%, as much as 90 cycles are required to reach 20%

of cumulative plastic deformation, where as subgrade with R_D = 30% reached 100%CPD at 5 cycles. Hence, it is clear that with an increase in placement density, overall load bearing capacity of the sand bed increases. In case of aggregate overlying weaker sand beds shows a significant improvement with number of cycles reaching almost 2500 (Series A_7) for 20% CPD.

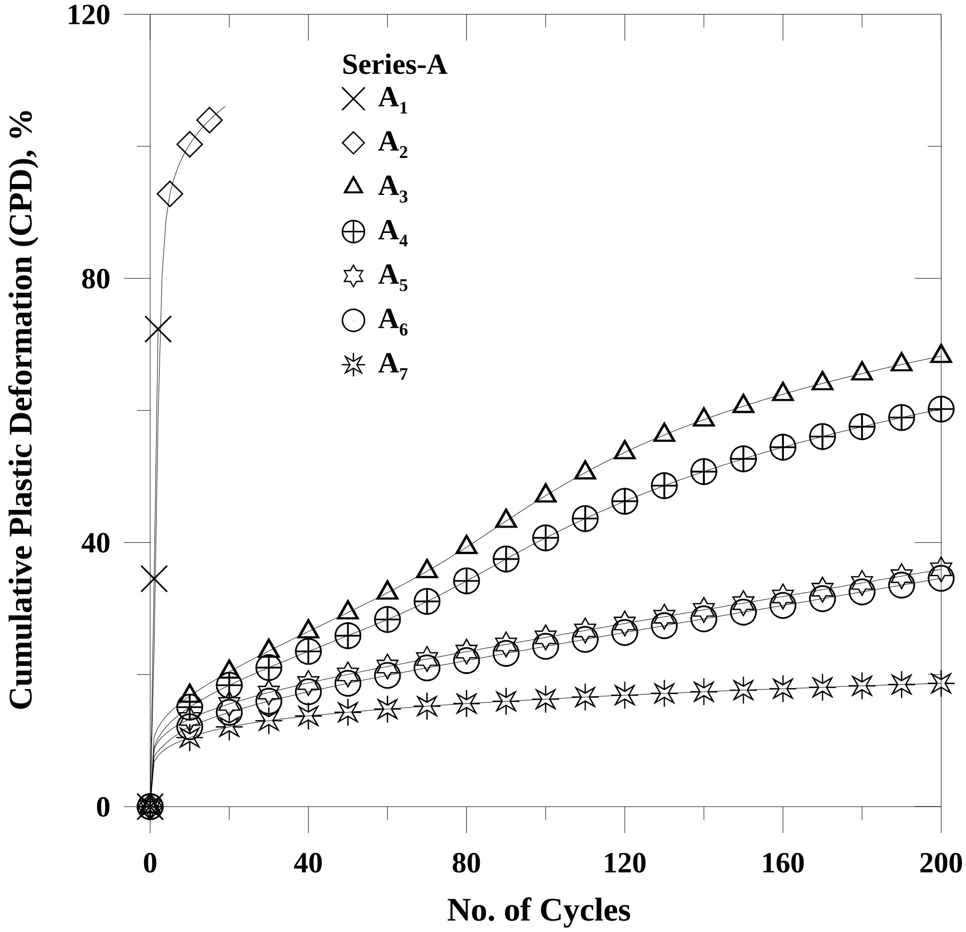

Figure 4.4 CPD v/s No. of cycles (Series-A)

The surface deformation characteristics of the reinforced beds were recorded through set of dial gauges as shown in Figure 4.1 were plotted against the footing settlement. The surface deformations were measured through four dial gauges placed on either side of plate and on the leveled surface on the test bed at a distance of 1D and 1.5D from the center of the footing (see Fig. 4.1). From Figure 4.5, it is noticed from the surface settlement plots that there is very negligible movement of the fill surface. It is also interesting to note that the surface deformations measured on either side of the loading plate are same and hence shows that the plate is settling uniformly. The place deformations were measured through two dial gauges placed on the plate and compared the data with the inline actuator LVDT. Both the measurements from the dial gauges and the LVDTs are matching and showing that there is no tilt in the loading plate movement with the application of the load. A very little change in the plate settlement is seen at a settlement ratio of 20%.

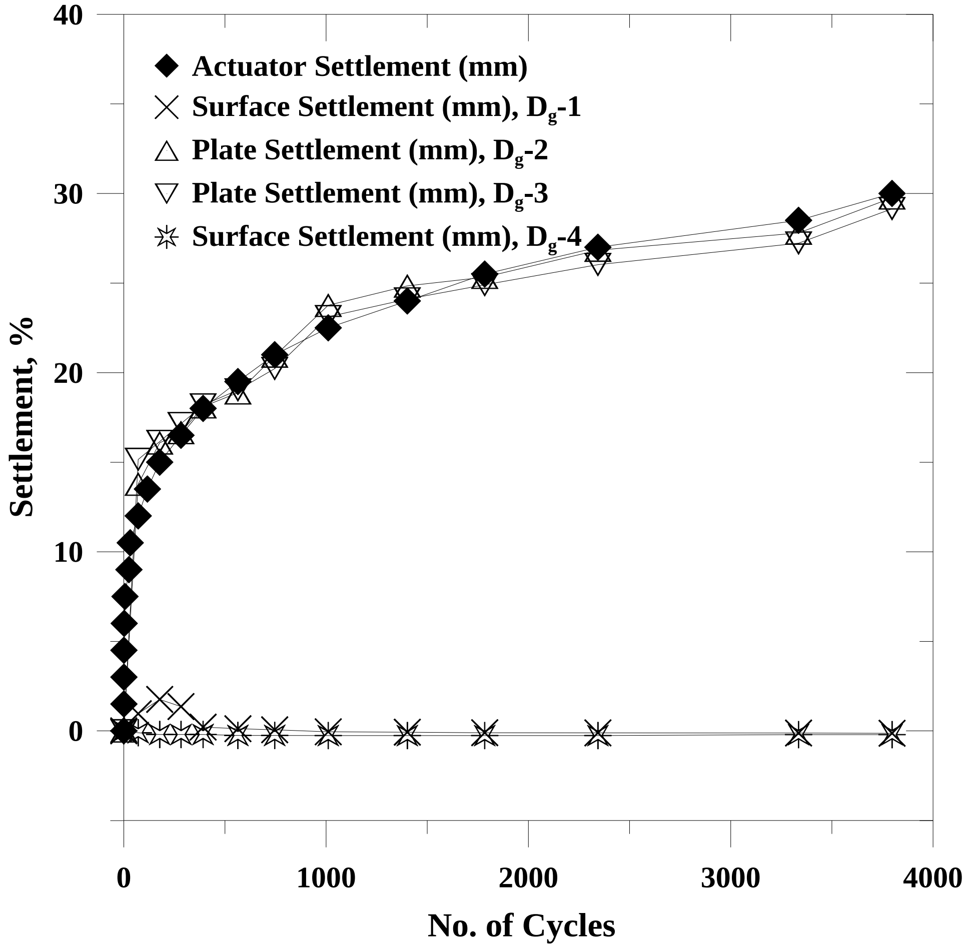

Figure 4.5 Variation of surface settlements with number of cycles

4.3.2.2 Effect of Number of Geojute Reinforced Layers in homogeneous dense sand

Figure 4.8 shows the effect of number of geojute layers on overall performance of the homogenerous reinforced sand beds wherein geojute layers are placed at succesive interval of u/D=0.1. Whereas, Figure 4.6 illustrates the placement of the geojute layer in the test tank with incorporation of preliminary checks of centering with plumb bob arrangement and Figure 4.7 displays the bed condition after the entire sand bed is prepared with required density. A proper care has been taken while leveling the surface. A stepped light weight wooden plank of 35cm x 35cm in plan and 6mm height is used for the tamping the surface, by giving a single blow of a rubber hammer from a approximate height of fall equal to 10cm.

Figure 4.6 Typical placement of geojute layer in the test tank

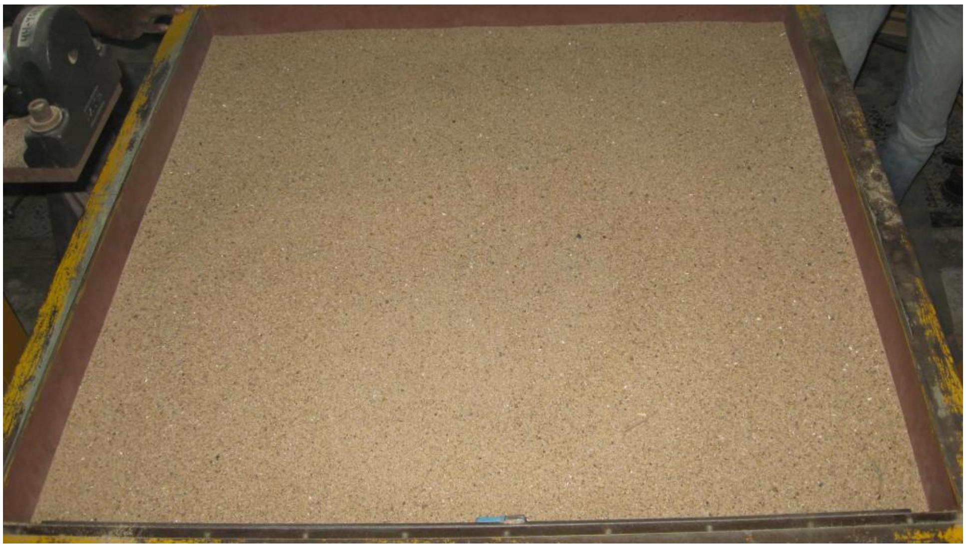

Figure 4.7 Typical leveled sand bed before the test

It is seen from Figure 4.8 that even with single layer of reinforcement appreciable performaance is achieved. An optimum number of reinforcement layers were evaluated through this test series. It is observed that with 3 geojute reinforcement layers (test-B_4) higher performance in terms of CPDs and benefit ratio is achieved. Beyond which an appreciable increase in benefit is not seen. Thus, saving the material and overall cost of construction.

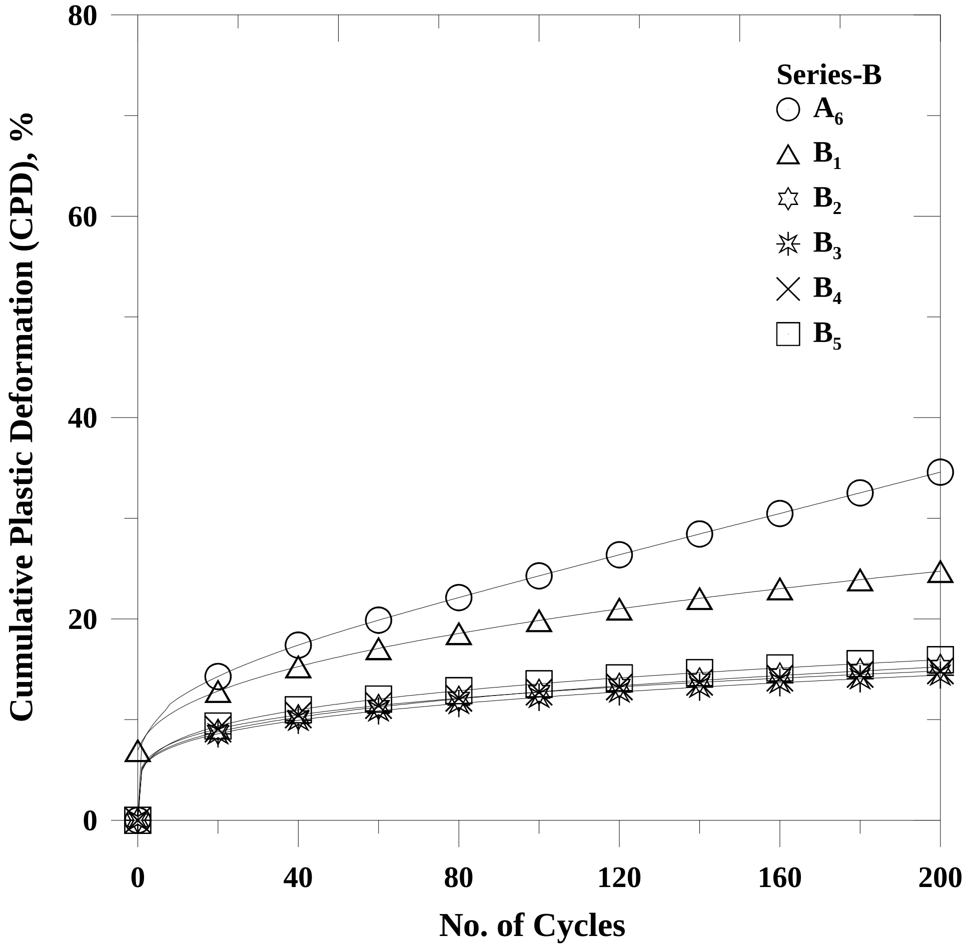

Figure 4.8 CPD v/s No. of cycles (Series-B)

Overall performance of the number of layers of geojute material in reinforced sand beds is tested through a non dimensional parameter Traffic Benefit Ratio (TBR) which is defined as a ratio of number of cycles of reinforced sand (N_r) to that of unreinforced sand (N_u) calculated at a given settlement ratio. The following is a mathematical equation for TBR evaluation.

$$TBR = \frac{N_r}{N_u}$$

Figure 4.9 shows TBR improvement with inclusion of number of layers of reinforcement. TBR increased by 4 with single layer of reinforcement to as high as 27 with inclusion of 3 layers of reinforcement at 15% of settlement ratio. Further, TBR increased to 70 @ 20% of settlement ratio showing substantial improvement for three layers of reinforcement.

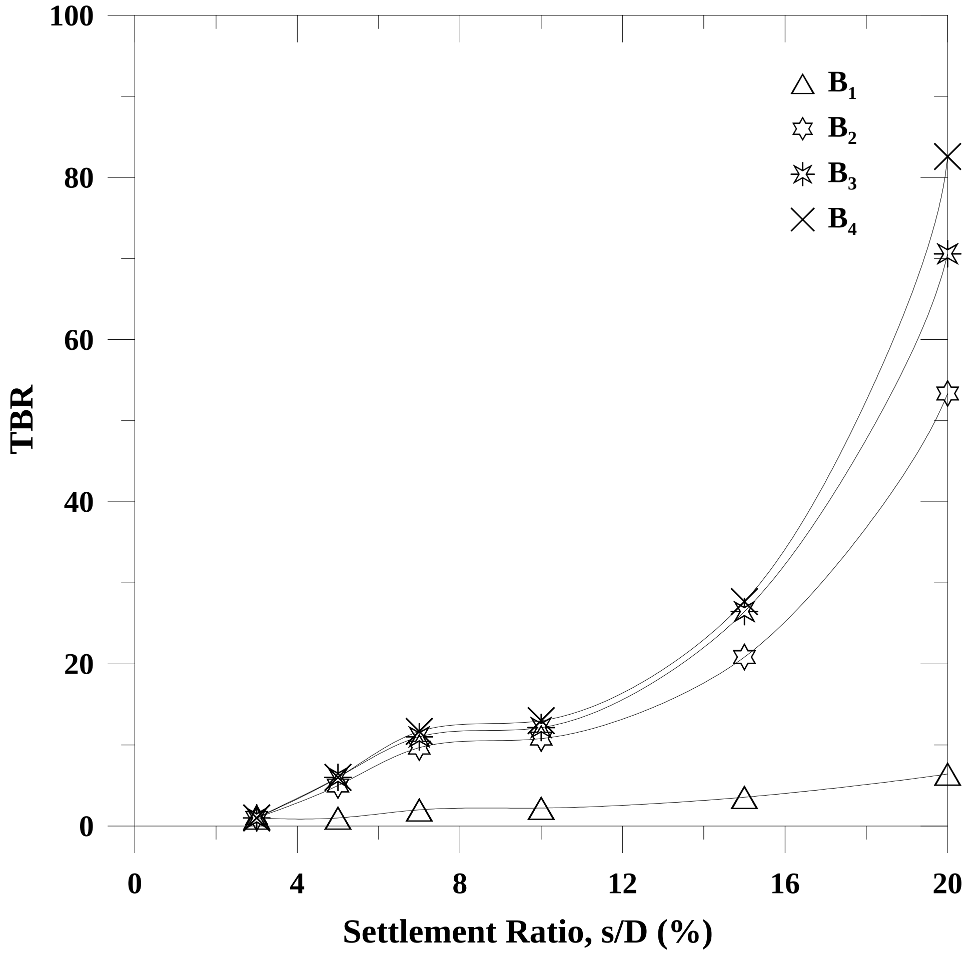

Figure 4.9 TBR v/s settlement ratio (Series-B)

The performance improvement can also be attributed by percentage reduction in footing settlements (PRS). Figure 4.10 shows the definition sketch for calculation of percentage reduction in footing settlement. It is calculated as ratio of footing settlements of reinforced beds to the settlements of unreinforced beds as shown below.

$$PRS = \frac{S_u - S_r}{S_u} \times 100$$

Where S_u and S_r are settlements corresponding to unreinforced and reinforced beds at a given number of cycle. In addition, benefit effects can also be accredited by Improvement Factor which is defined as ratio of bearing pressure corresponding to reinforced bed to the unreinforced bed at given settlement. It is denoted by I_f and formulated as follows.

$$I_f = \frac{q_r}{q_u}$$

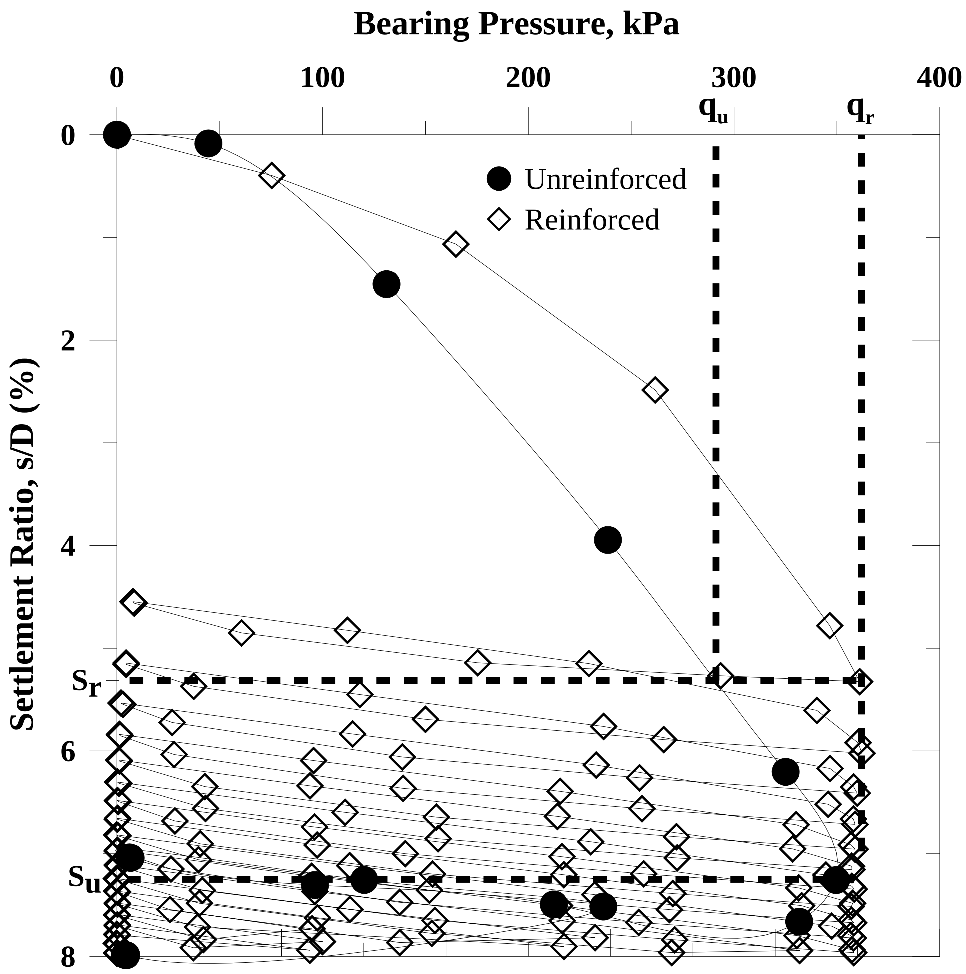

Figure 4.10 Definition sketch for PRS and I_f

In Figure 4.11 it is clearly seen that footing settlements are reduced with increase in number of reinforcement layers. Furthermore, it is also observed that the reduction in settlement ratios have increased with increase in number of loading cycles. However, the reduction in settlements can be arrested with the inclusion of at least two reinforcement layers. Further increase in reinforcement layers did not indicate much improvement in terms of reduction in the plate settlements. From surface settlement plot (see Figure 4.12) it is seen that surface settlement is minimal for 3 layers of reinforcement, whereas, for a single layer of reinforcement little heave is noticed. Also, surface settlements are almost 2% of plate settlement.

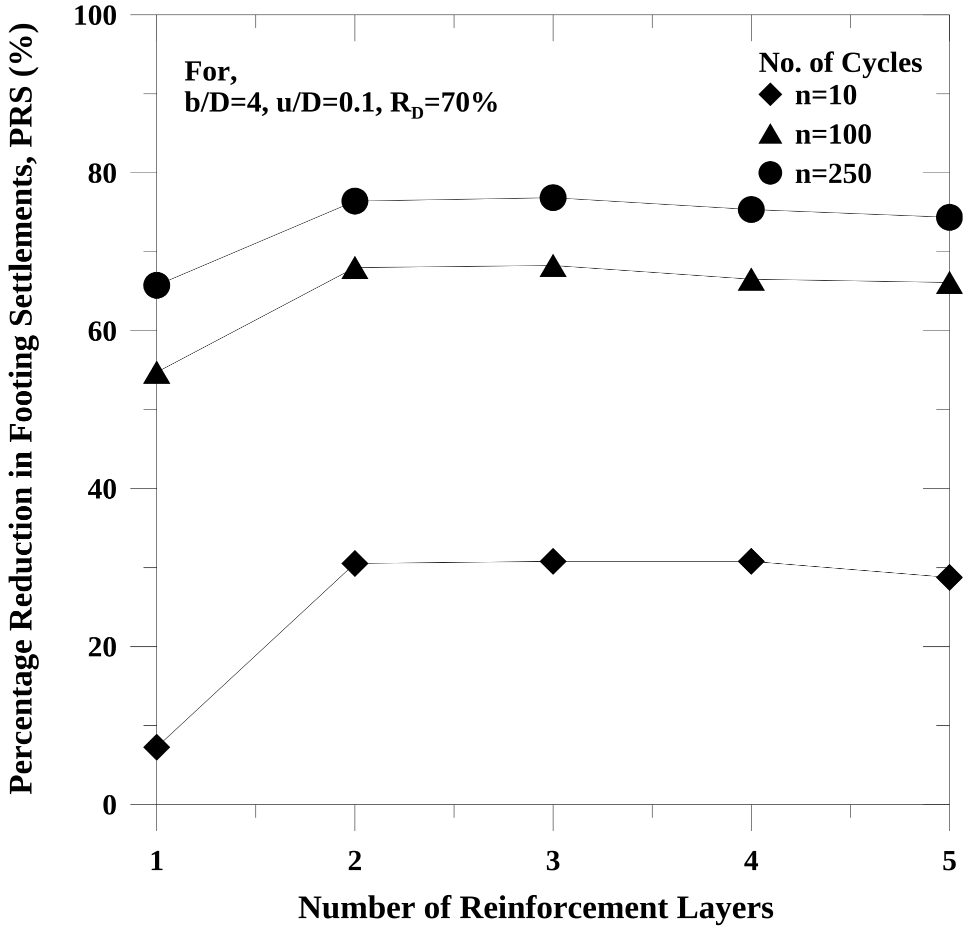

Figure 4.11 PRS v/s number of reinforcement layers (Series-B)

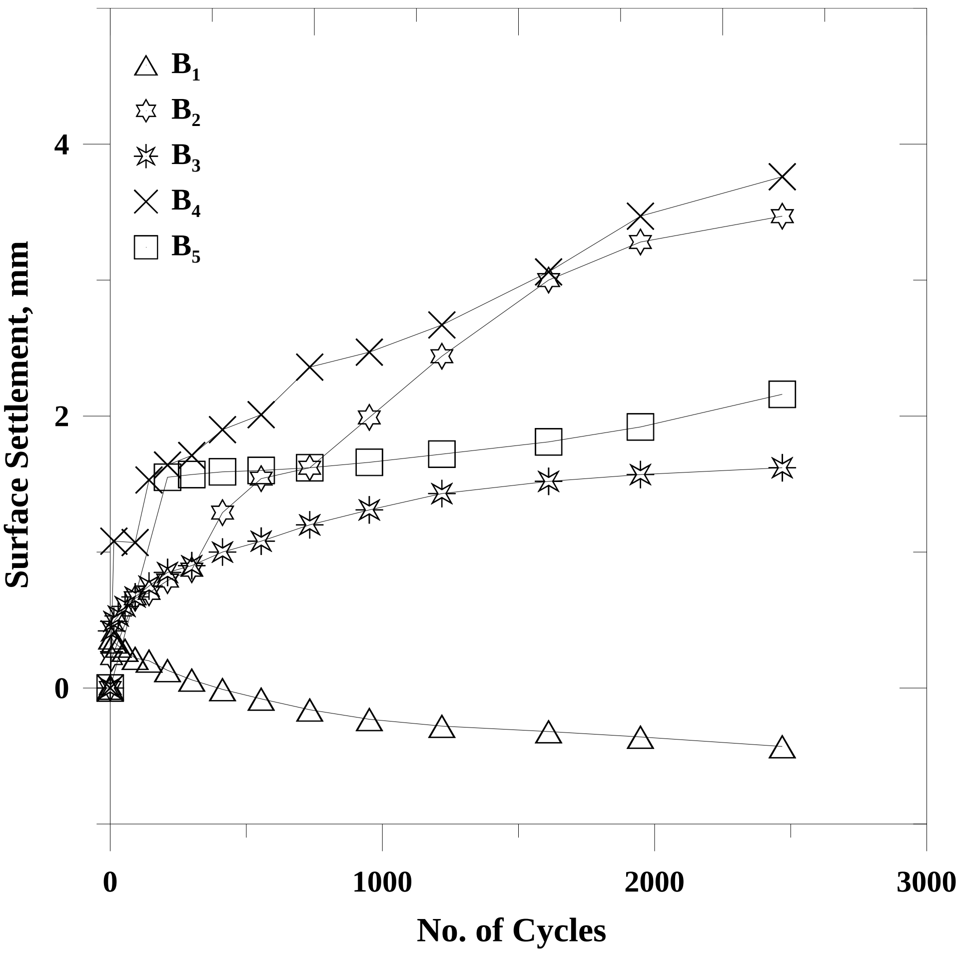

Figure 4.12 Surface settlements v/s number of cycles (Series-B)

4.3.2.3 Effect of Number of Geojute layers on Stiffer Beds overlying Weaker Beds

In Series-C (see Figure 4.13) variation of stiffer beds overlying weaker beds are studied by varying number of geojute layers in the overlaying dense sand layer. For initial cycles (<10) plastic deformations are found to be predominant, thereafter, the plastic deformations are marginal and almost constant even with increase in number of loading cycles. It is noticed that the settlements are reduced while bearing capacity is increased. Thus, it is understood that influence of geojute layers has a pivotal role in case of stiffer beds overlying weaker beds. Also, whenever a stiffer beds are laid over soft soil the load is distributed to a larger area causing failure due to excessive settlement or insufficient bearing capacity. Inclusion of geojute layers improves subgrade sterngth in such cases there by decreasing excessive settlements.

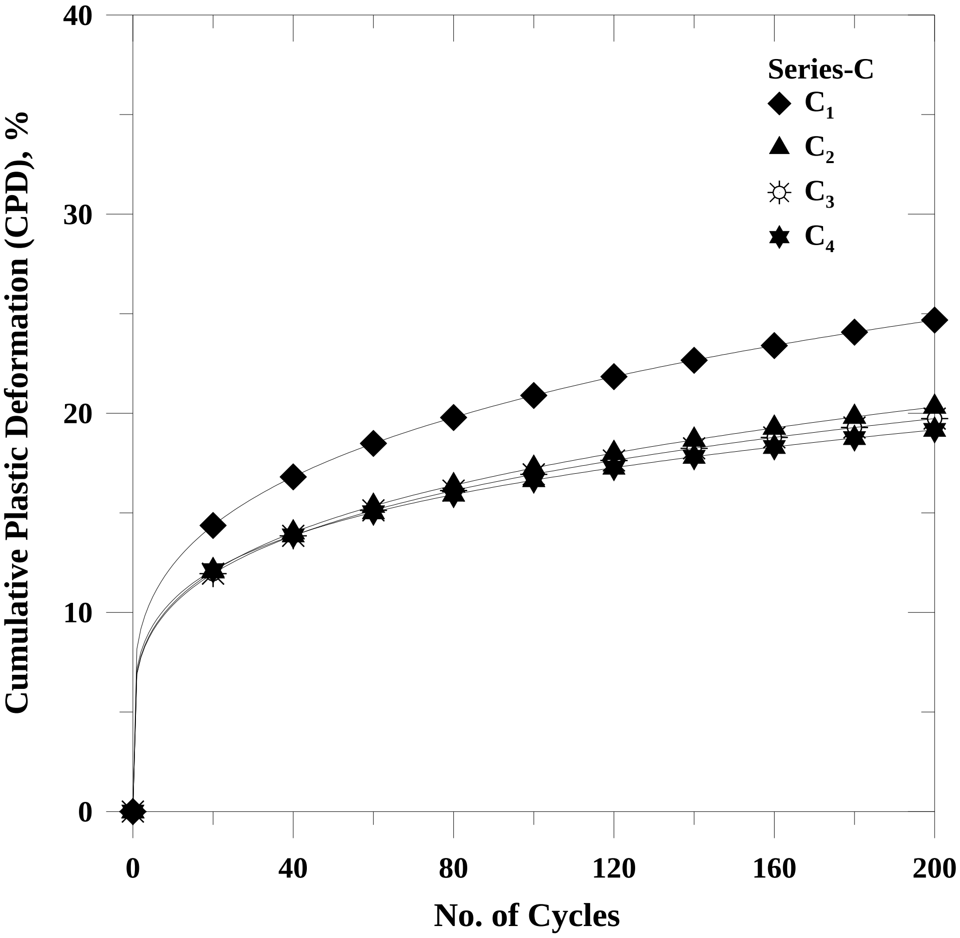

Figure 4.13 CPD v/s No. of cycles (Series-C)

In the Figure 4.14, it is seen that for the stiffer sand overlying weaker sand beds percentage reduction in footing settlements are maximum for 3 layers of reinforcement. Percentage reduction in footing settlements were as high as 50% for 3 layers of reinforcement. It is quite stimulating to note that further increase in number of layers (more than 3 number of layers) does not contribute to the performance of reduction in the footing settlements. Thus, the optimal number of layers were found to be 3 for the stiffer beds overlying weaker subgrade. From Figure 4.15 it is seen that C_1 has more surface settlements due to the thinner stiffer bed overlying larger weaker bed. Surface settlements are noticed almost upto 4% of the footing plate settlements. As the thickness of the stiffer beds increases with respect to the weaker beds surface, settlements are minimized tending to zero.

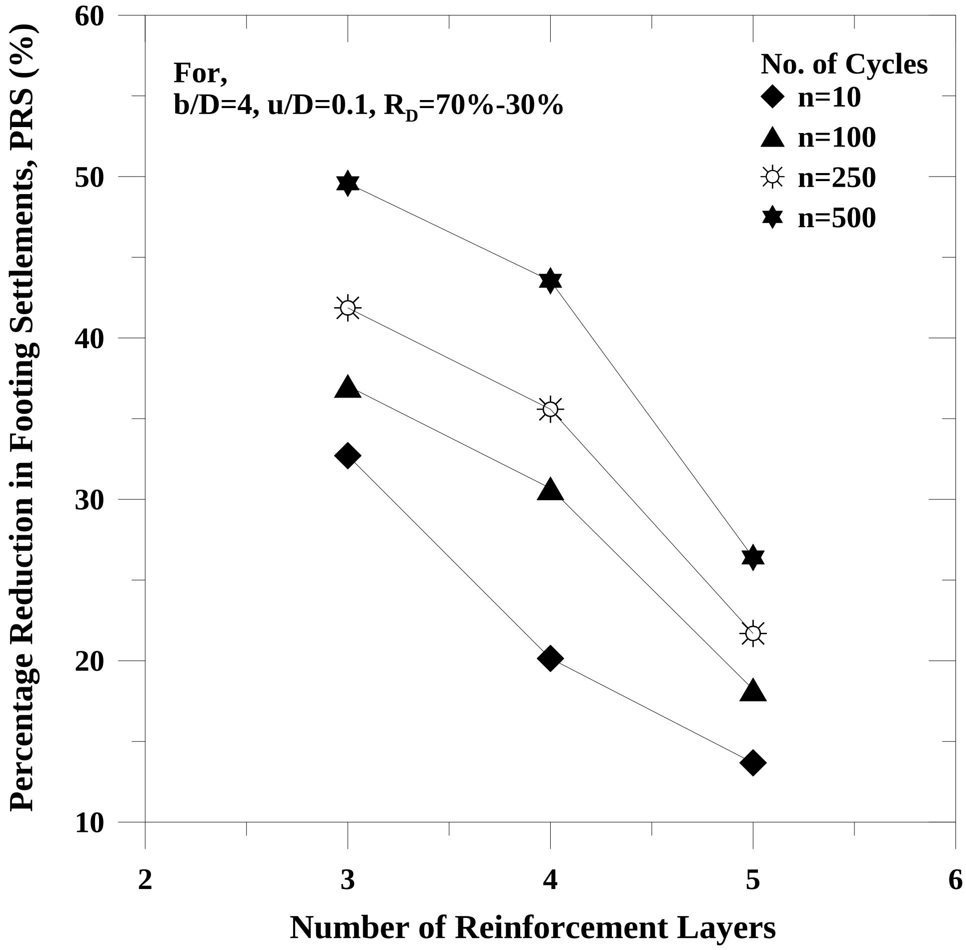

Figure 4.14 PRS v/s number of reinforcement layers (Series-C)

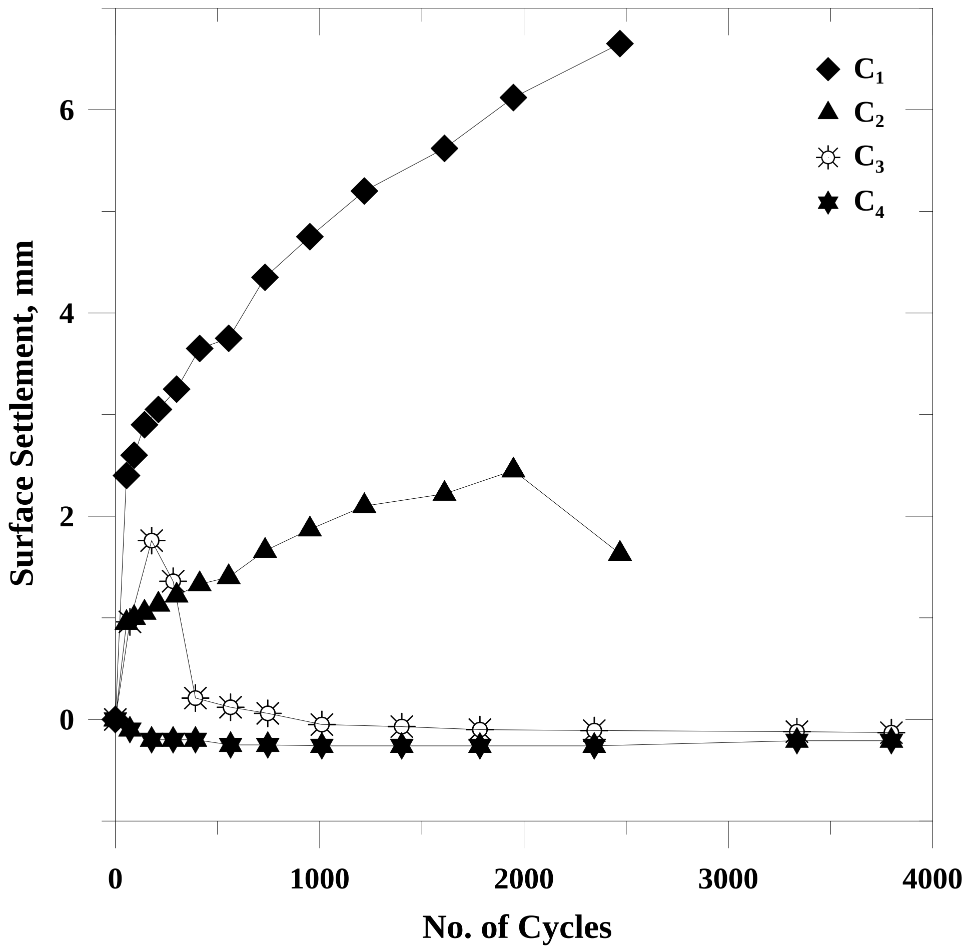

Figure 4.15 Surface settlements v/s number of cycles (Series-C)

4.3.2.4 Effect of Width of Geojute Reinforcement in homogeneous dense sand

The width of a geojute also plays a vital role in overall performance of the bed, however, it is important to determine the optimum width of the geojute layer to economise the pavement system. In this series-D, the width of the geojute has been sutdies and presented. As the width of the geojute reinforcement increases wider area of contact is created between the soil and the jute material, thus attributing to the higher lateral restraintment of the soil particles. Figure 4.16 shows that increase in width of the of geojute reinforcement increases the beaaring capacity and reduces the settlements. Since, deformations are arrested by the tensile property of the jute material and frictional restraintment due to soil-reinforcement interaction. It is seen that I_f is equal to 2 for width to footing plate ratio (b/D) equal to 2 whereas I_f is as high as four times if width to footing plate ratio is equal to 4. It is also seen that even though the material is a from the waste packaged jute bags performance is considerable.

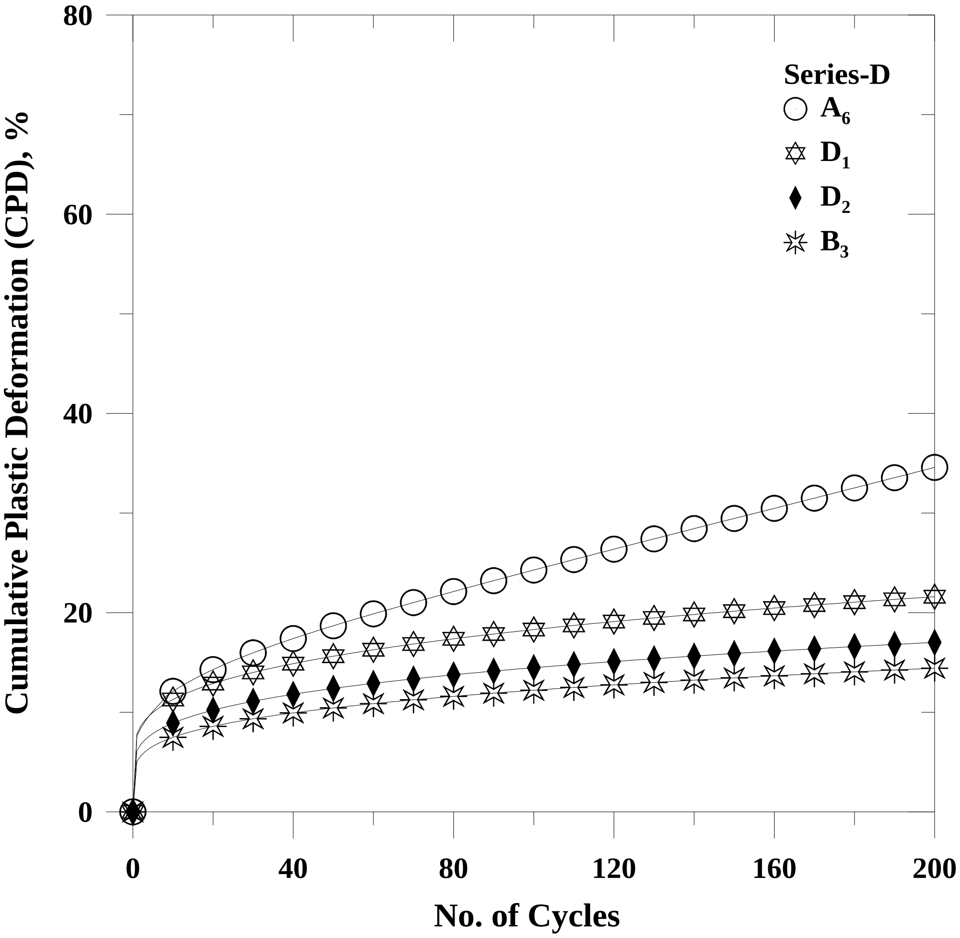

Figure 4.16 CPD v/s No. of cycles (Series-D)

It is noticed from Figure 4.17 that TBR increased as high as 70 for 4 times the width of reinforcement. Whereas, TBR of 15 is noticed for 2 times the width of reinforcement. A remarkable performance with the width of reinforcement is observed, as this can be attrebuted to higher lateral restrainment causes the performance improvement in the homogeneous reinforced sand beds. It is also noticed that (see Figure 4.18) percentage reduction in footing settlements for b/D=4 were twice as high as b/D=2 which depicts that to eliminate impact of settlement on a reinforced bed, wide width geojute reinforcement has to be provided. From Figure 4.19 surface settlements are within 2% of the plate settlement. For b/D=3 surface settlements are almost zero tending to little heave.

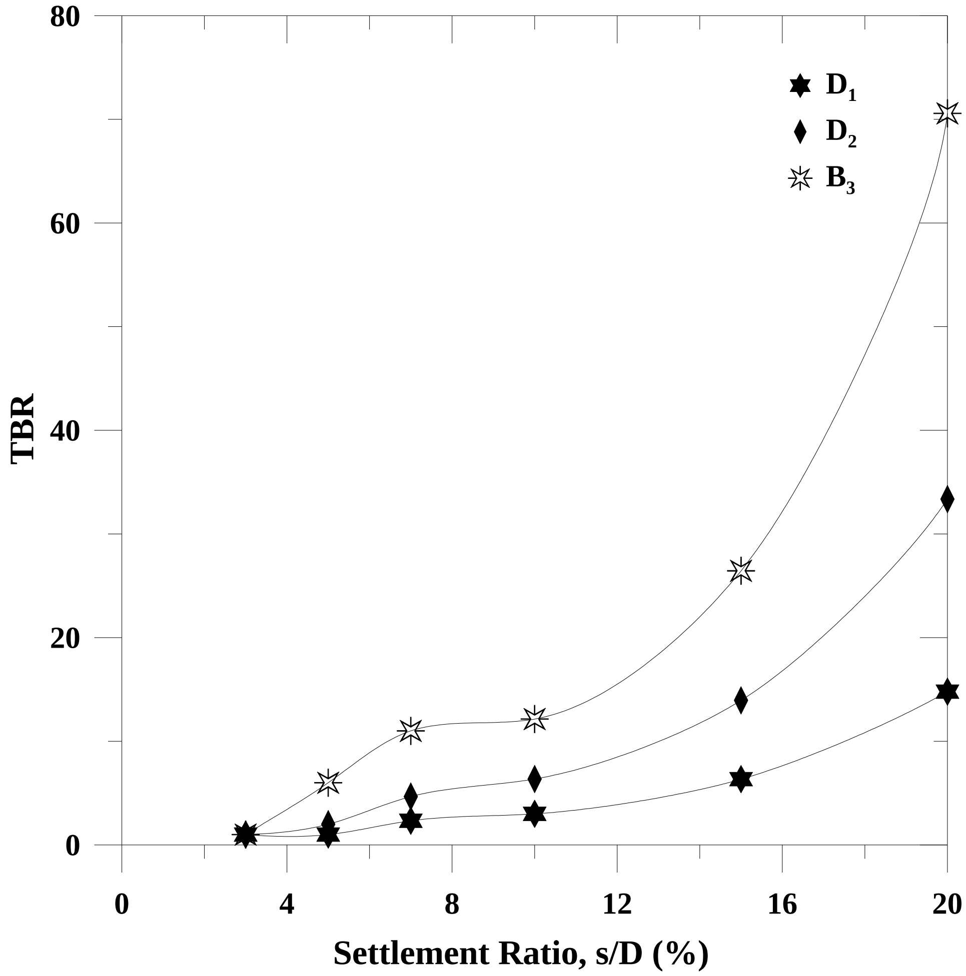

Figure 4.17 TBR v/s settlement ratio (Series-D)

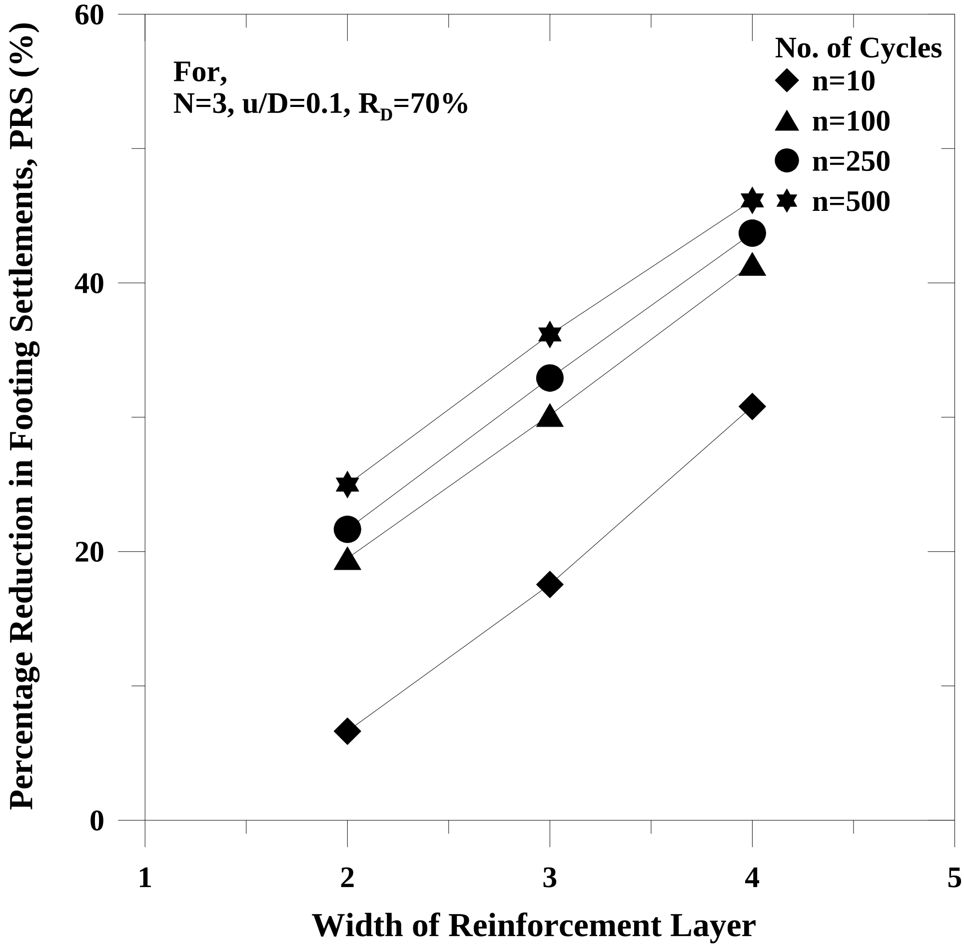

Figure 4.18 PRS v/s width of reinforcement layers (Series-D)

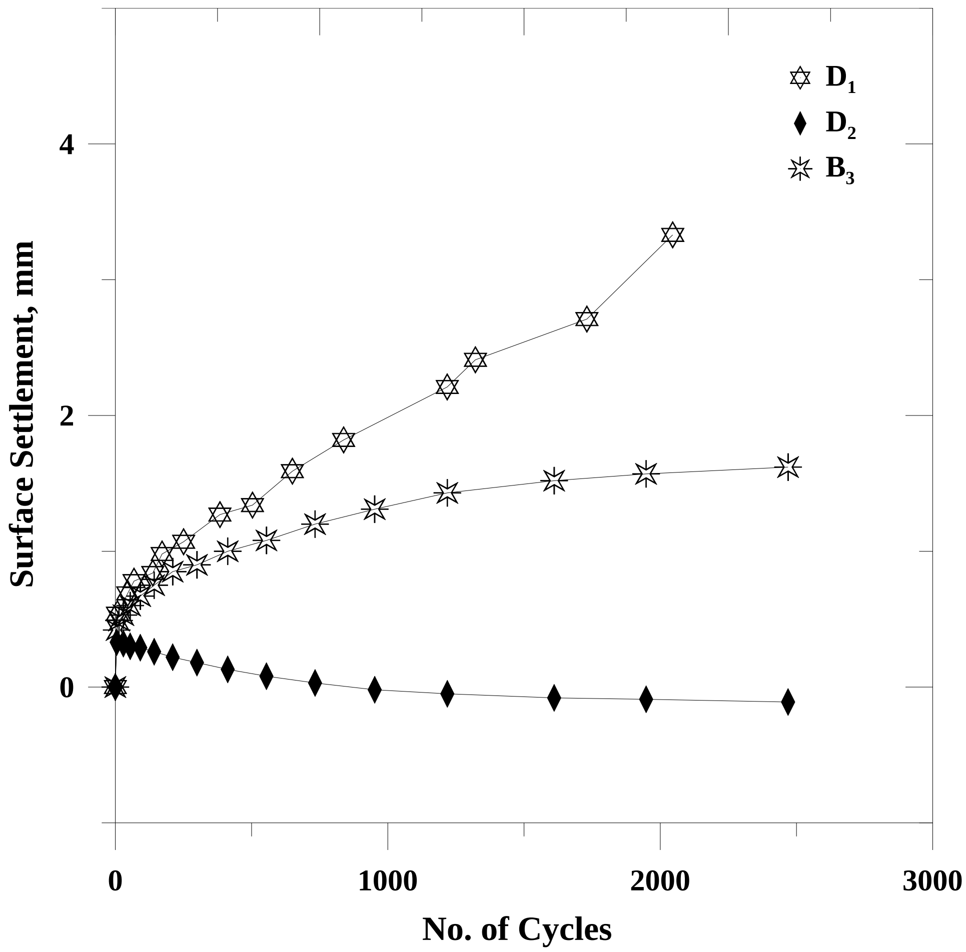

Figure 4.19 Surface settlements v/s number of cycles (Series-D)

4.3.2.5 Effect of Relative Density of Soil on Reinforced Sand Beds

The placement density has an impact on the behavior of reinforced sand under repetitive loading. Series-E as shown in Figure 4.20 depicts that with increse in placement density, plastic deformations are reduced thereby increasing overall bearing capacity of the bed. With increase in the relative density of sand, the lateral frictional resistance increases, between the soil and the jute material, with in the reinforcement layers, thereby increasing the resistance to the horizontal movement of the sand. Hence higher load carrying capacity and stiffer subgrade is achieved. Test B_3 shows appreciable performance improvement due to dense subgrade (R_D=70%) reducing deformations almost to half compared to the of weaker subgrade (R_D=30%). Even though first few cycles (cycles < 10) show major deformations, but further deformations are arrested if placement density is higher. Thus, relative density is an important factor while carrying out a construction on a reinforced sand bed. Whereas, Percentage reduction in footing settlement (see Figure 4.21) shows a marginal difference in the relative density variation from 50% to 70% since, beyond R_D=50% beds tend to become stiffer showing negligible effect on the performance.

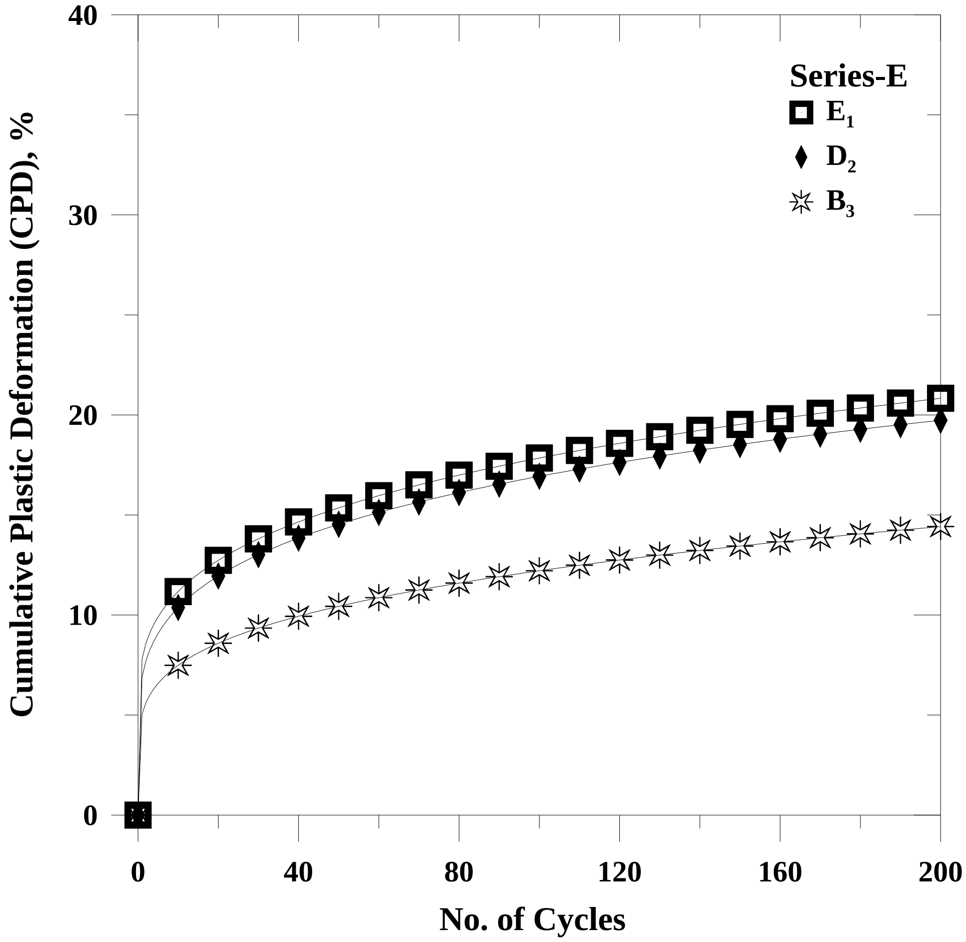

Figure 4.20 CPD v/s No. of cycles (Series-E)

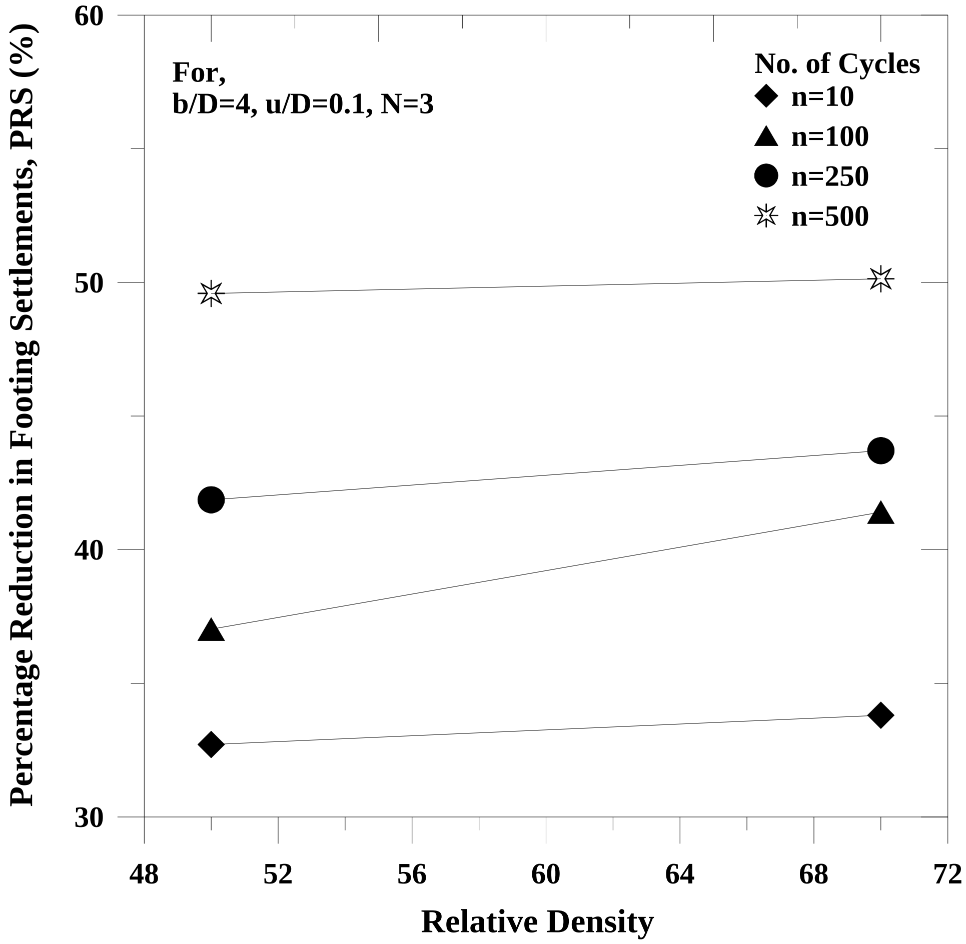

Figure 4.21 Variation of PRS with relative density (Series-E)

4.4 Concluding Remarks

Improvement factor obtained from the study is calculated in terms of equivalent single axle wheel loads (ESALs) at particular settlements. Also modulus of subgrade reactions and elastic moduli are calculated from the slope of slow cyclic tests discussed in previous section 3.5.4. Results obtained from the tests are tabularized and presented in Table 4.2.

Table 4.2 ESAL and Modulus values

Nomenclature	No. of Load Cycles		Modulus of Subgrade Reaction (MPa)	Modulus of Elasticity (MPa)
	@ s/D = 10% No. of Load Cycles Applied	@ s/D = 20% No. of Load Cycles Applied		
A_1	1	1	20.3	53.01
A_2	1	2	22.72	59.08

A_3	5	49	21.57	56.1
A_4	8	63	23.33	60.66
A_5	14	134	24.66	64.13
A_6	15	137	21.19	55.09
B_1	31	137	22.99	59.78
B_2	150	2401	28.67	74.54
B_3	179	3657	28.32	73.64
B_4	152	4845	28.75	74.75
B_5	111	2353	28.28	74.2
C_1	18	411	22.72	59.08
C_2	38	886	21.57	56.1
C_3	41	1292	23.33	60.66
C_4	39	1358	24.66	64.13
D_1	42	767	18.84	48.99
D_2	87	1735	19.05	48.99
E_1	33	906	20.3	53.01

Based on the results obtained from the present study on geojute reinforced sand beds, following conclusions are drawn.

- With inclusion of geojute reinforcement, there is an appreciably high performance improvement both in terms of load carrying capacity and settlement reduction
- Better performance of footing can be obtained in terms of load carrying capacity if 3 number of geojute reinforcement are provided.
- It has been ascertained beneficial to have a dense infill material to get better benefit out of reinforcement. Thus, placement of density increases the bearing capacity and reduces plastic deformation.
- Surface settlements observed from the reinforced sand are very minimal.
- Modulus of elasticity obtained from the model tests for loose-stiff sand are within the range (35-80 MPa). With maximum modulus of elasticity reaching ~ 75MPa.

- Optimum width of geojute mattress was found to be four times the width of footing. Benefit improvement due to width of geojute mattress is almost reaching TBR value equal to 70.
- TBRs and CPDs show an appreciable improvement with number of loading cycle.
- PRSs show that the reduction in settlement is higher for 3 layers of reinforcement and b/D=4 reaching as high as 50%.

Chapter 5

Behavior of Jute-Geocell Reinforced Sand/ Aggregate Beds

5.1 Introduction

In this chapter a detailed discussion is done on the jutegeocell reinforced sand subgrades subjected to the traffic loading. The influence of various parameters such as width and, height of the geocell reinforcement and provision of an additional base layer is studied to understand the efficacy of jutegeocell mattress to achieve maximum performance benefits. In addition, the behavior of jute geocell was verified with different infill materials. Performance improvement is estimated in terms of non-dimensional parameters like Traffic Benefit Ratio (TBR), Cumulative Plastic Deformation (CPD) and Percentage Reduction in Settlements (PRS) due to cellular form of reinforcement.

5.2 Experimental Programme

Figure 5.1 shows the schematic of the experimental setup of jute-geocell reinforced sand subgrades. Table 5.1 presents the series of experiments conducted on jute-geocells. The variable parameters including b/D, h/D are depicted briefly in each series. Within each series, one particular parameter was varied, while the other parameters were kept at constant, to understand the effect of the particular parameter on the overall behavior of the reinforced bed. The details of nomenclature corresponding to each test scheme are discussed in Section 4.2. In series F, cyclic load tests were conducted on jute-geocell reinforced sand beds with varying height of jutegeocell mattress and keeping other parameters at constant (b/D, u/D). In series G, repeated load tests are conducted on reinforced sand beds varying width of geocell mattress. Influence study of additional planar reinforcement at the base of geocell is done in Series-H. In addition to above series, a test is also done on sand with aggregate infill material and discussed in Series-I. Thus, Series-I discuss the influence of aggregate as infill material in geocell reinforced beds.

Table 5.1 Scheme of Experiments conducted on Jute-Geocell Reinforced Sand Beds

Test Series	Type of Reinforcement	Details of Test Parameters	Nomenclature	Testing Scheme (Subscript replicates Series)
G	Jute Geocell Reinforced Sand	*Constant Parameters*: h/D=1.33, u/D=0.1, D=150mm, R_D=70%+30%.	F_1 F_2	1. b/D=2 2. b/D=4
F	Jute Geocell Reinforced Sand	*Constant Parameters*: b/D=4, u/D=0.1, D=150mm, R_D=70%+30%.	G_1 G_2 G_3	1. h/D=0.67 2. h/D=1 3. h/D=1.33
H	Jute Geocell Reinforced Sand with Planar Geojute Base Layer	*Constant Parameters*: h/D=1.33, u/D=0.1, D=150mm, R_D=70%+30%.	H_1 H_2 H_3	1. b/D=2 2. b/D=4 3. b/D=4, with additional base planar reinforcement.
I	Jute Geocell Reinforced Aggregate	*Constant Parameters*: h/D=1.33, u/D=0.1, D=150mm, R_D=70%+30%.	I_1 I_2 I_3 I_4	1. b/D=2 2. b/D=4 3. b/D=4, with additional base planar reinforcement. 4. b/D=4, with additional base planar reinforcement and aggregate infill material.

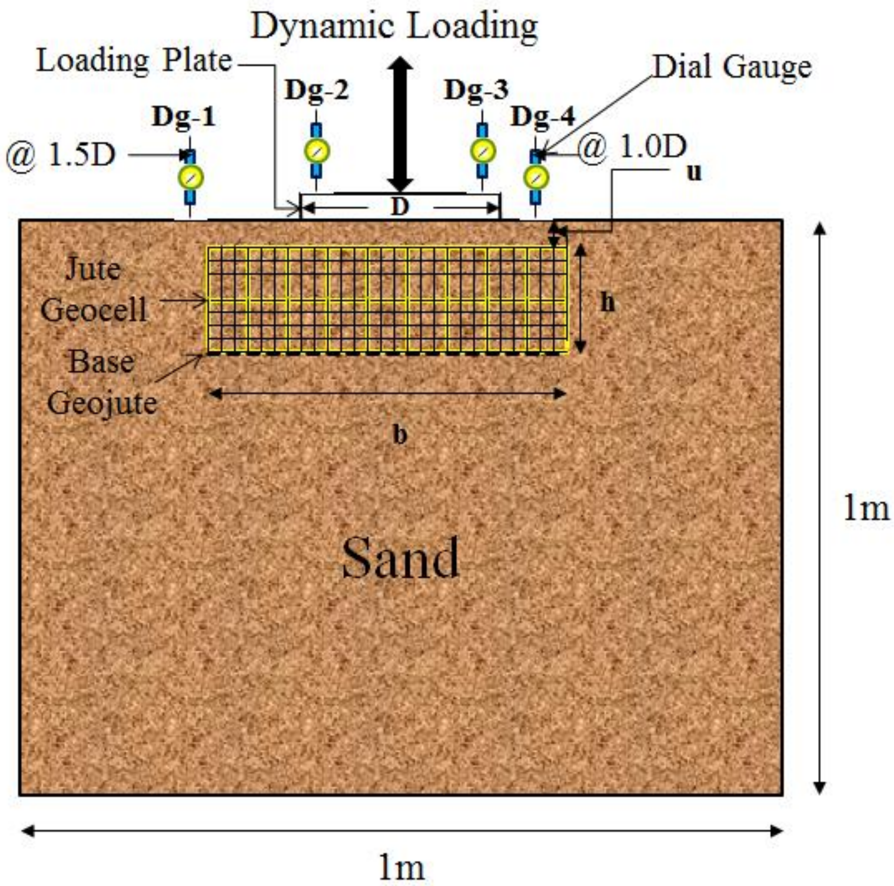

Figure 5.1 Experimental setup of jutegeocell reinforced sand subgrade

5.3 Model Tests

5.3.1 General

In this chapter, cyclic load tests conducted on jute geocell reinforced sand beds are presented. The jute geocell is hand-stitched from waste packaged jute bags threaded with a waste cloth at the borders. Figure 5.2 shows a typical hand stitched jute-geocell used in this study. The data obtained from the dynamic actuator on the sand beds are presented in terms of settlement ratio which is defined as the ratio of settlement to the plate width expressed in percentage. Typical settlement ratio v/s number of cycles is shown in Figure 5.3. The markers represent the settlement corresponding to the upper (7kN) and lower (0.7kN) limit of a haversine loading pattern that has been applied on the test bed. From Figure 5.3, it is noticed that settlement ratio increases with number of loading cycles. Gradually, the settlement ratio will almost become asymptotic to the x-axis with number of cycles. This represents that of a constant permanent deformations occur in the test bed.

Figure 5.2 Hand-made jute-geocell used in the study

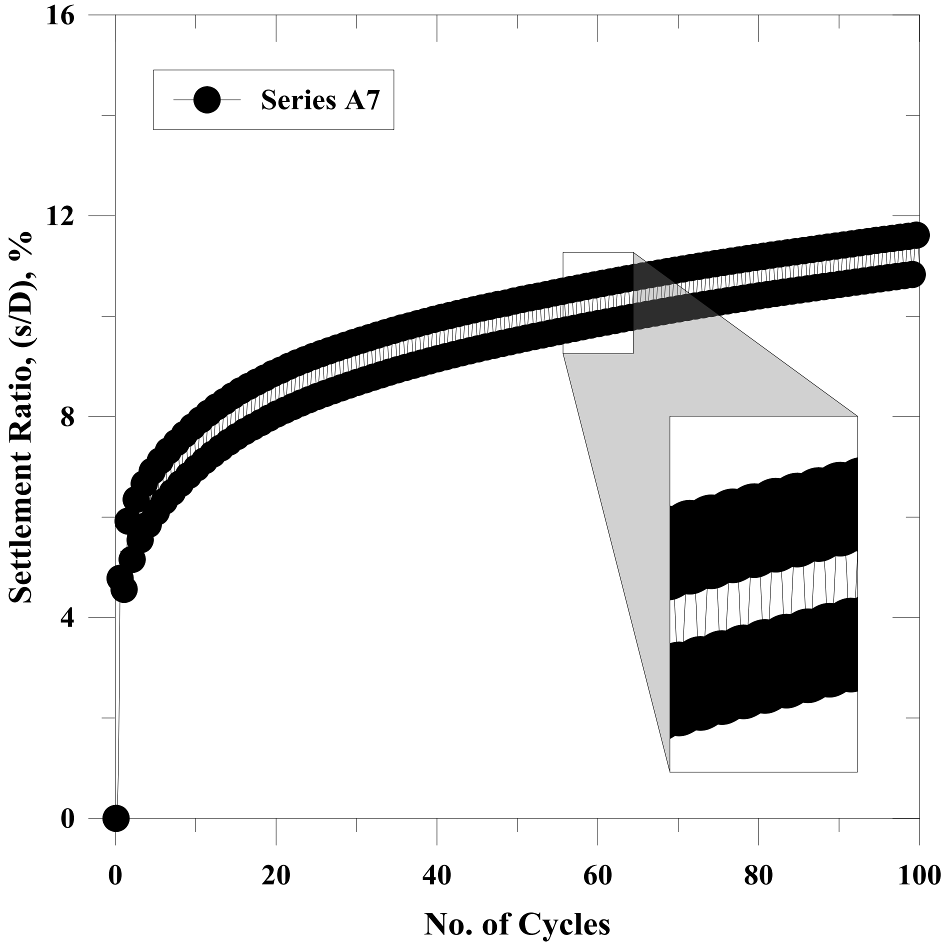

Figure 5.3 Typical settlement ratio v/s number of cycles

5.3.2 Pressure-Settlement and Surface Deformation Responses

Pressure-settlement and surface deformation responses were monitored during the cyclic load tests in order to verify the influence of placement density of the soil on overall behavior of sand beds in terms of reduction in footing settlements. The pressure settlement responses observed from series I_4, shown in Figure 5.4, depicts that initially at low number of loading cycles ($n < 10$), the total settlement ratios are higher for a given cycle and the settlements get moderated with increase in the number of loading cycles. This is more predominant in case of unreinforced case where one can expect more plastic deformations than elastic rebound. If the sand is replaced with construction aggregate as infill material, as high as 10,000 loading cycles were required to reach a settlement ratio of 12.5%.

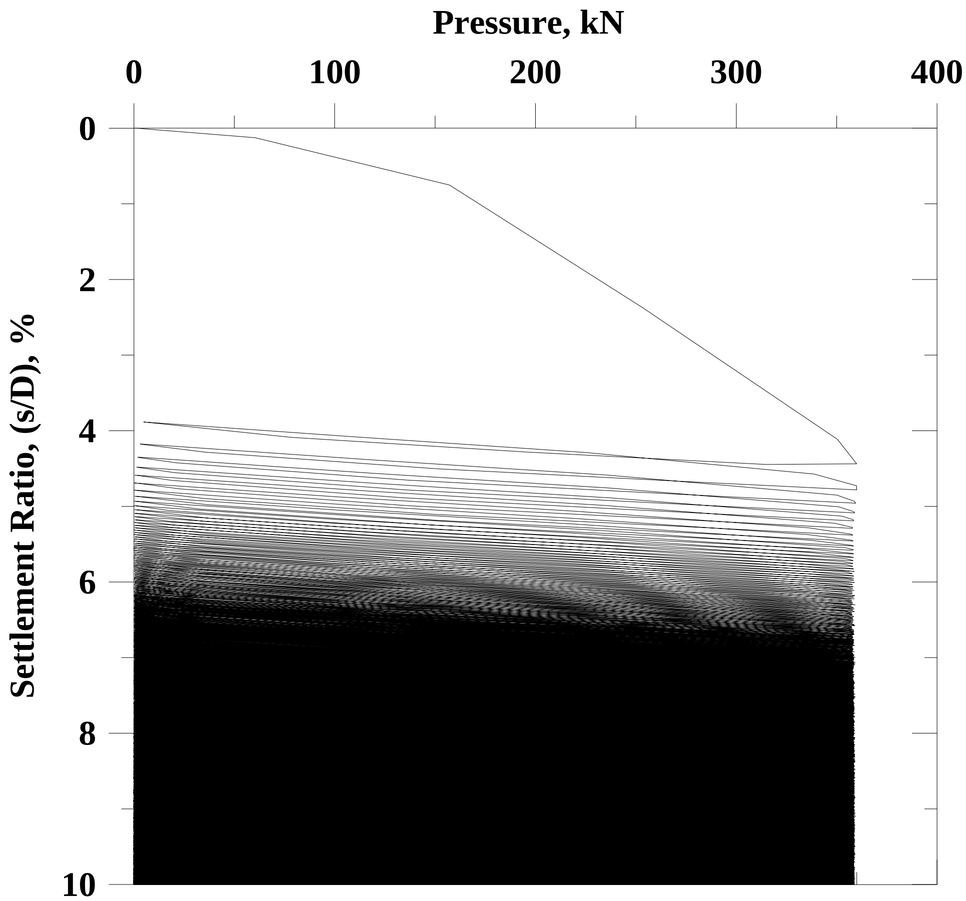

Figure 5.4 Typical pressure v/s settlement ratio curve (Series-I_4)

Typical surface deflection profiles along with plate settlements are shown in Figure 5.5. The plate deformations measured in typical test beds show that the deformations obtained from inline LVDT placed in the actuator in accordance with the externally measured plate settlements. This observation concludes that the loading plat has settled uniformly into the test beds without any tilt or inclination. Figure 5.5 also presents the surface deformation patterns with loading cycles. It is to be noted that the positive values show the settlement and the negative values represent heave of the fill surface. It is interesting to note that the unreinforced beds have shown heave of the fill surface, representing that the failure planes have reached the surface resulting the heave of the fill surface. Similar observations were observed by Chummar [70] in sand beds and also found that the heave is significant at a distance of 1 to 1.5 times the width of the loading plate (D) from center line of the plate. In this study, Dg-1 is placed at a distance of 1D and Dg4 was placed at 1.5D from the center line on either side of the plate. Both the dial gauges show a heave pattern of the surface confirming that the unreinforced beds have undergone general shear failure. In contrary, the jute geocell reinforced beds have arrested these shear planes to reach the surface owing to their three dimensional structure. Figure 5.6 shows the location of dial gauges on the fill surface and the loading plate after the failure of the test bed.

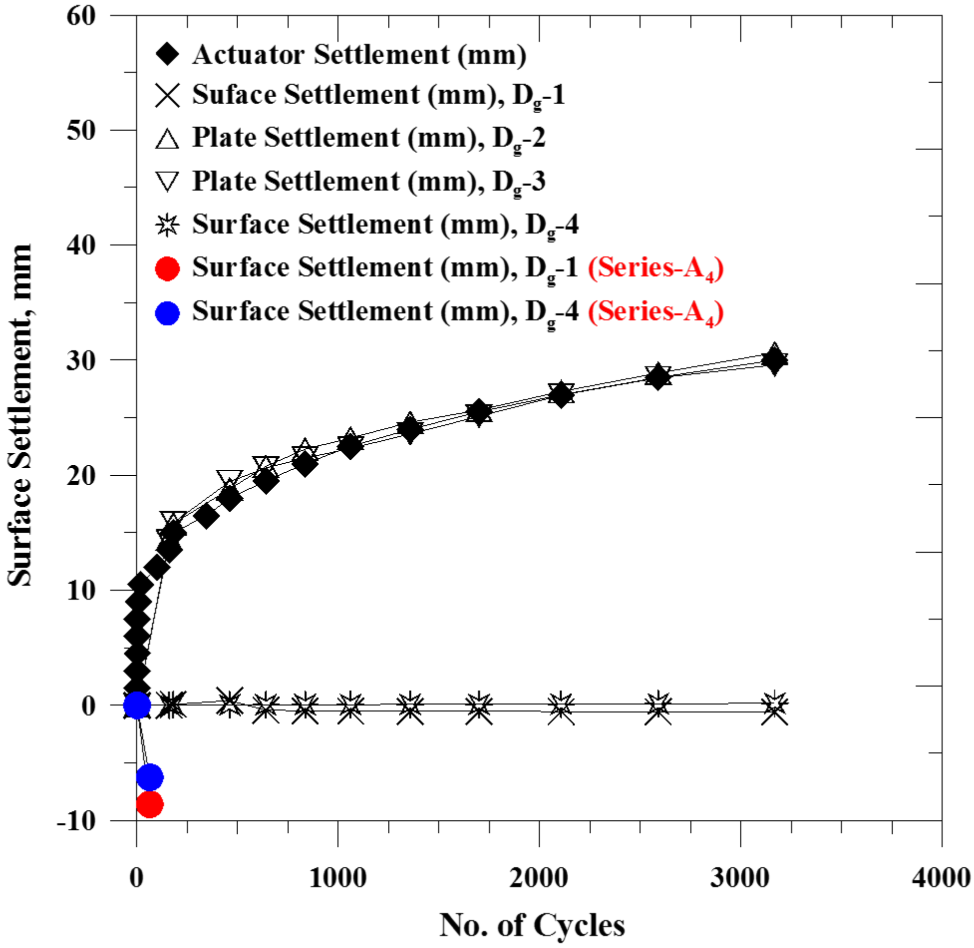

Figure 5.5 Variation of surface settlements with number of cycles (Series G2)

Figure 5.6 Plate and Surface deformations after the test

5.3.2.1 Unreinforced Beds

The tests in Series-A are conducted on unreinforced test beds with stiff sand layers overlaying weak sand layers. The test data in terms of CPDs and No. of cycle under repetitive loading are preseted in 5.7. It is interesting to note from Figure 5.7 that in case of unreinforced aggregate overlying weaker sand beds show a significant improvement in reduction of CPDs with number of cycles. Besides, aggregate overlying sand beds have sustained as high as 2500 load cycles for 20% of footing settlement. The upper aggregate layer behaves as a reinforcement layer for weaker sand subgrade and hence improves the settlement behavior of the sand subgrades. Besides, the interlocking property of aggregates with high angle of shearing resistance would increse the structural support to the cyclic loading.

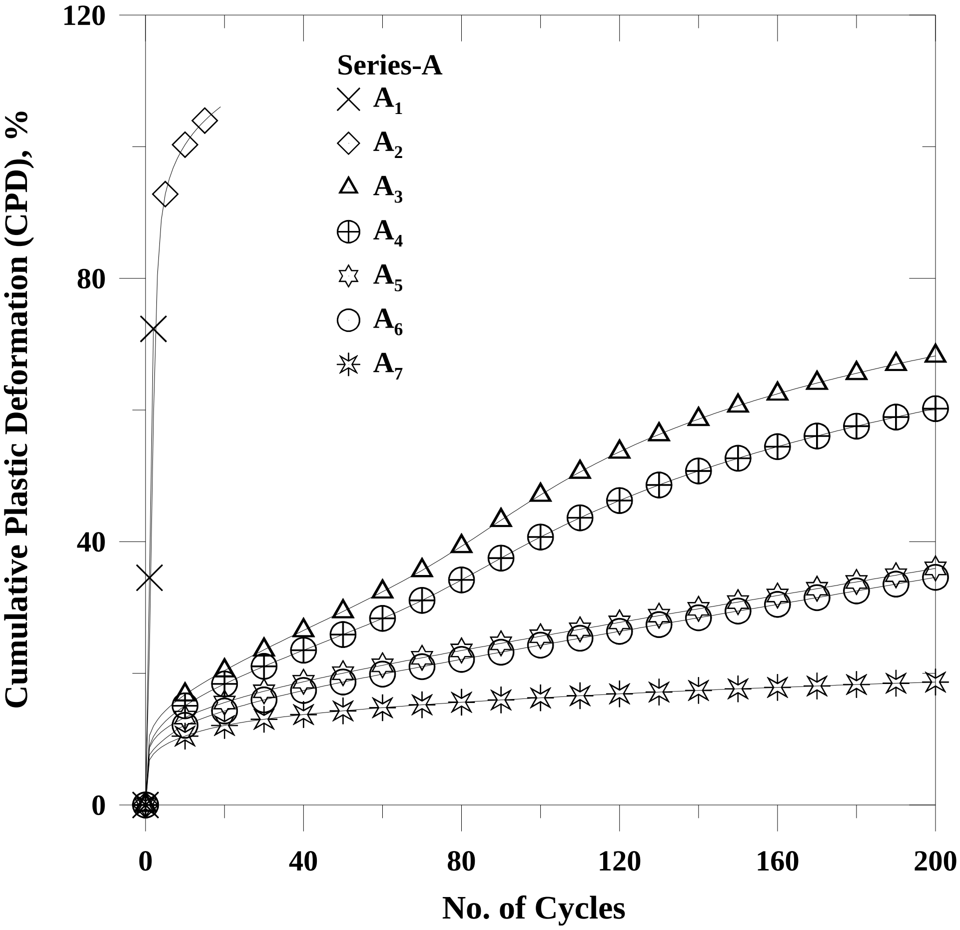

Figure 5.7 CPD v/s No. of cycles (Series-A)

5.3.2.2 Effect of Width of Jute-Geocell mattress

In Series-F, variation of width of a geocell mattress on stiffer beds overlying weaker sand beds are studied. It is seen in Figure 5.8 that when width of jutegeocell mattress increases from b/D=2 to b/D=4, an improvement is noticed in terms of percentage reduction in footing settlements. With increase in plan area, the geocell mattress redistributes the footing pressure over a wider area of stable soil mass leading to increased performance. The performance of unreinforced beds (A_5) is noticed to be high in terms of controling permanent deformations on the test bed than the jute geocell reinforced sand beds initially. These high permanent deformations in geocell reinforced beds are attributed to the lowe stiffness of the jute geocell walls under the applied loading. After certain cycles, the geocell reinfroced beds tend to show uniform deformations with increase in load cycles, but on unreinforced test beds, the permanent deformations continue to increase with number of load cycles. The initial lower performance of jute geocell could be avoided by compacting the infill material to a higher degree.

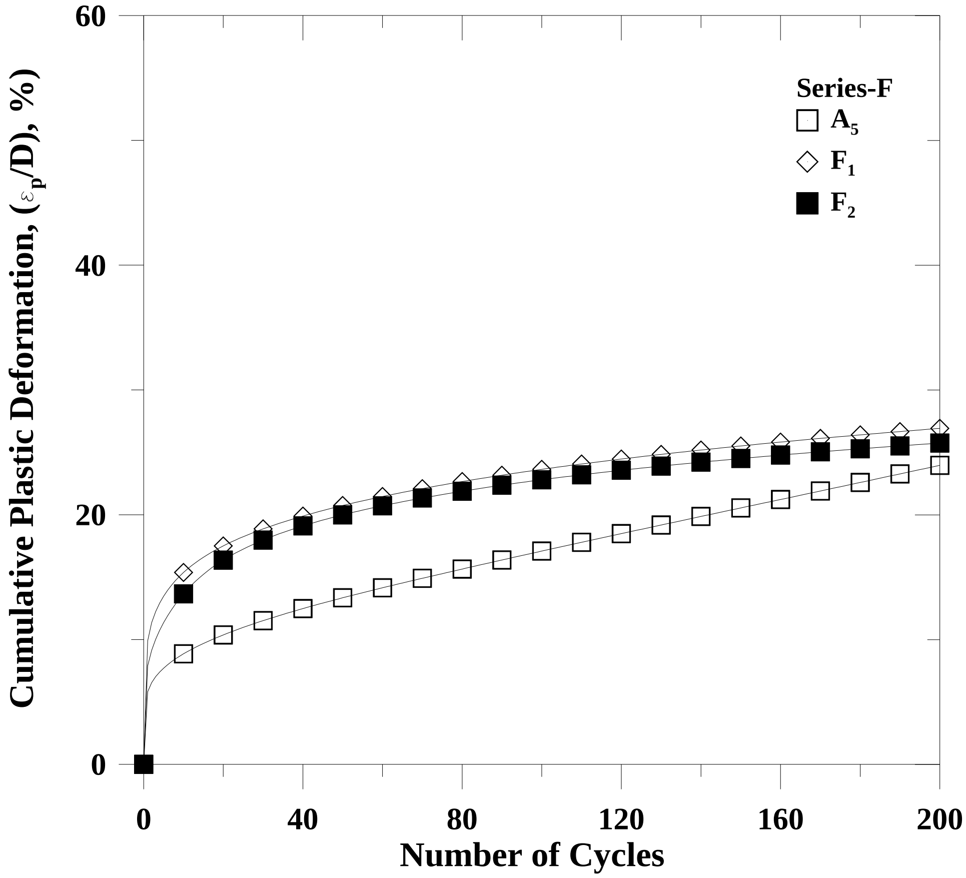

Figure 5.8 CPD v/s No. of cycles (Series-F)

5.3.2.3 Effect of Height of Jute-Geocell mattress

Figure 5.9 shows the effect of different heights of jute-geocell reinforced sand overlying weak sand subgrades on cumulative percentage deformations. It is seen that with increse in height of geocell, initial permanent settlements are higher; this could be due to the lower flexural stiffness of the jute mattress. The jute material is strong in tension and can impart higher membrane support while used as planar layer. Thus, it is noted that for height of geocell mattress equal to width of the footing plate the improvement is appreciable. It is brought to the notice that further increase in geocell height does not contribute to the performance in terms of benefit ratio and surprisingly a failure in the jute material at the seam was noticed in Series-G_3 (see Figure 5.10). The seam failures may be expected at higher loading cycles due to lower flexural strength.

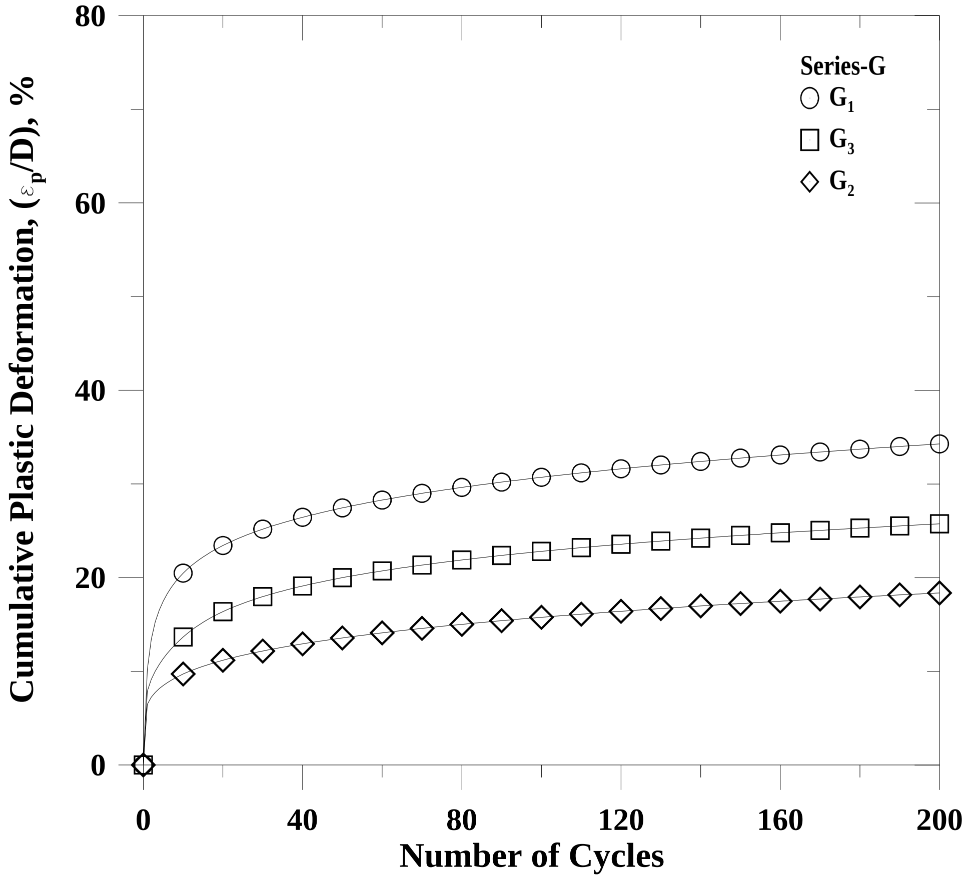

Figure 5.9 CPD v/s No. of cycles (Series-G)

Figure 5.10 Weld Failure in Jutegeocell (Series-G_3)

5.3.2.4 Effect of Additional Planar Geojute Reinforcement

An additional base layer beneath the jute-geocell mattress shows an improvement by reducing the vertical settlements. This is due to additional membrane support offerd by the planar geojute layer beneath the geocell mattress, which will arrest the movement of infill material into the weak subgrade soil. From Figure 5.11 it is seen that additional base layer helps in achieving higher stiffness in reinforced sand beds. Due to footing settlement, sand in the jutegeocell directly below the footing tends to move down. At higher settlement of the footing, this sand overcomes the frictional resistance on jutegeocell wall and punches down the sand subgrade. Thus, with provision of additional layer the vertical movements are arrested.

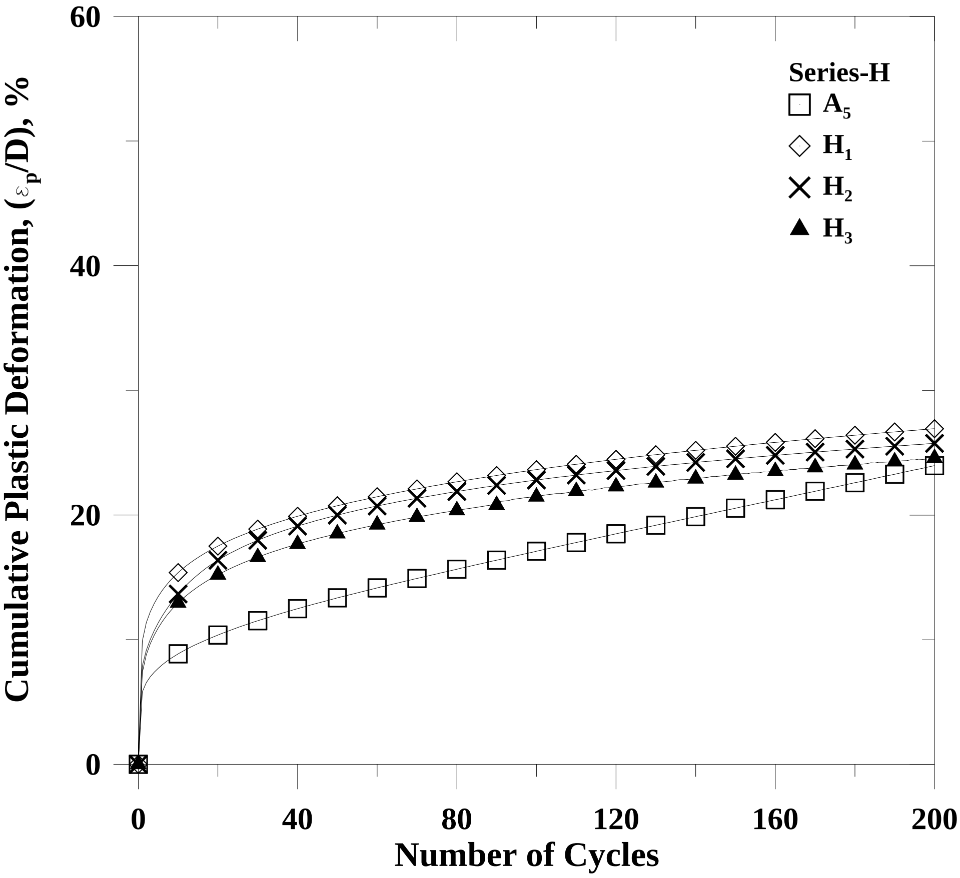

Figure 5.11 CPD v/s No. of Cycles (Series-H)

5.3.2.5 Comparative Study on Geojute and Jute-Geocell Reinformcement Forms

An attempt has been made to understand the effect of reinforcement form (in terms of planar layers and geocell) on the overall performnace of the test bed. To compare different forms of jute reinforcement, the optimum amount, in terms of total area, of reinfrocement used in planar layers which would give highest perfromance is used to prepare the geocell mattress. A total of 4 layers of reinforcement in case of geojute (area ~ 1.44m^2) and jute-geocell of h/D=1 (area ~ 1.5m^2) was compared in this study. It is noticed from the Figure 5.12 that planar geojute shows almost 1.3 times better performance compared to the jute-geocell. Percentage reduction in footing settlement was observed as 52.5% for jute-geocell whereas it is noticed as high as 62.5% for four layers of geojute reinforcement (representing same area). The traffic benefit ratios showed an appreciable performance improvement as well. Refered from Figure 5.13, TBR was noticed as 4 for jute-geocell reinforced bed while, it was as high as 20 for geojute reinforcement for the same area of reinforcement. Hence, it can be concluded that the performance of geojute (planar) is higher than the jute-geocell when made out of flexible jute materials.

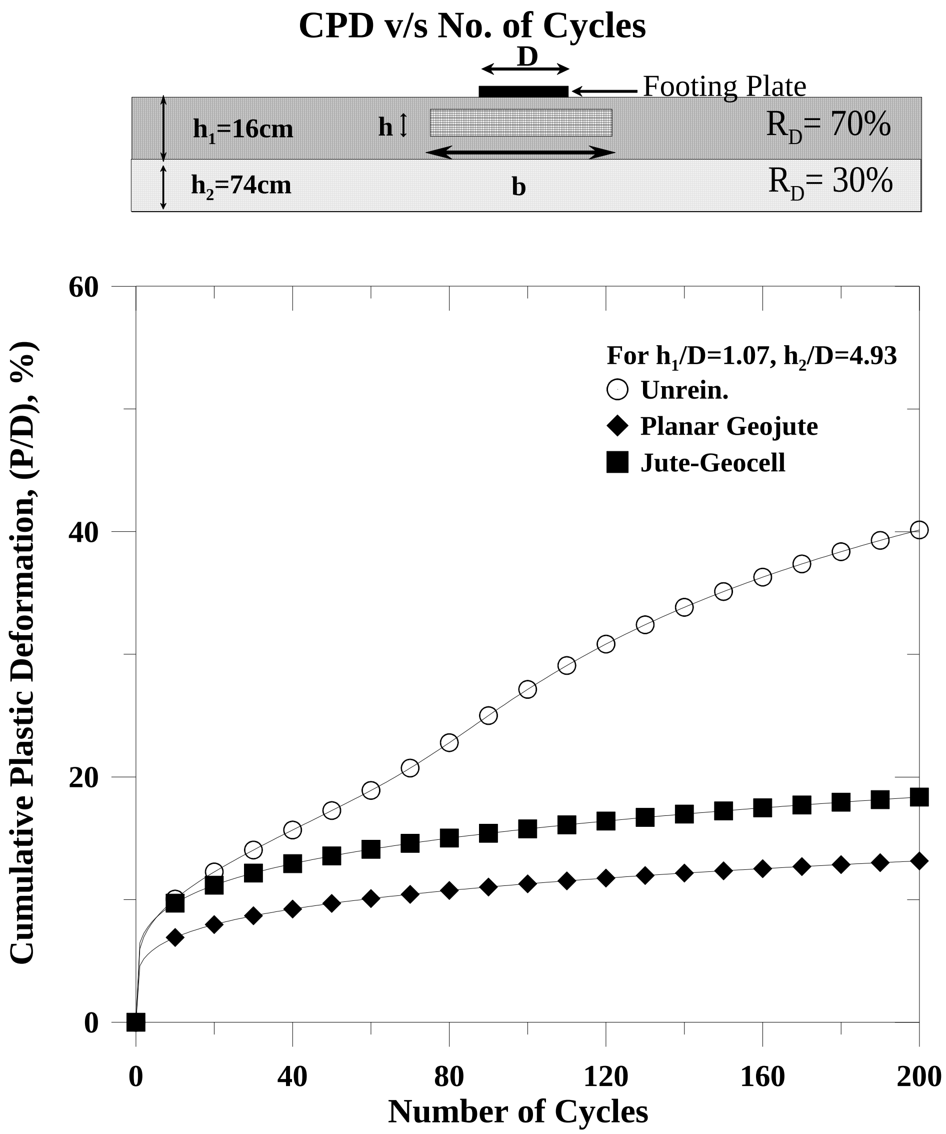

Figure 5.12 Variation of CPD v/s No. of Cycles for same area of reinforcement

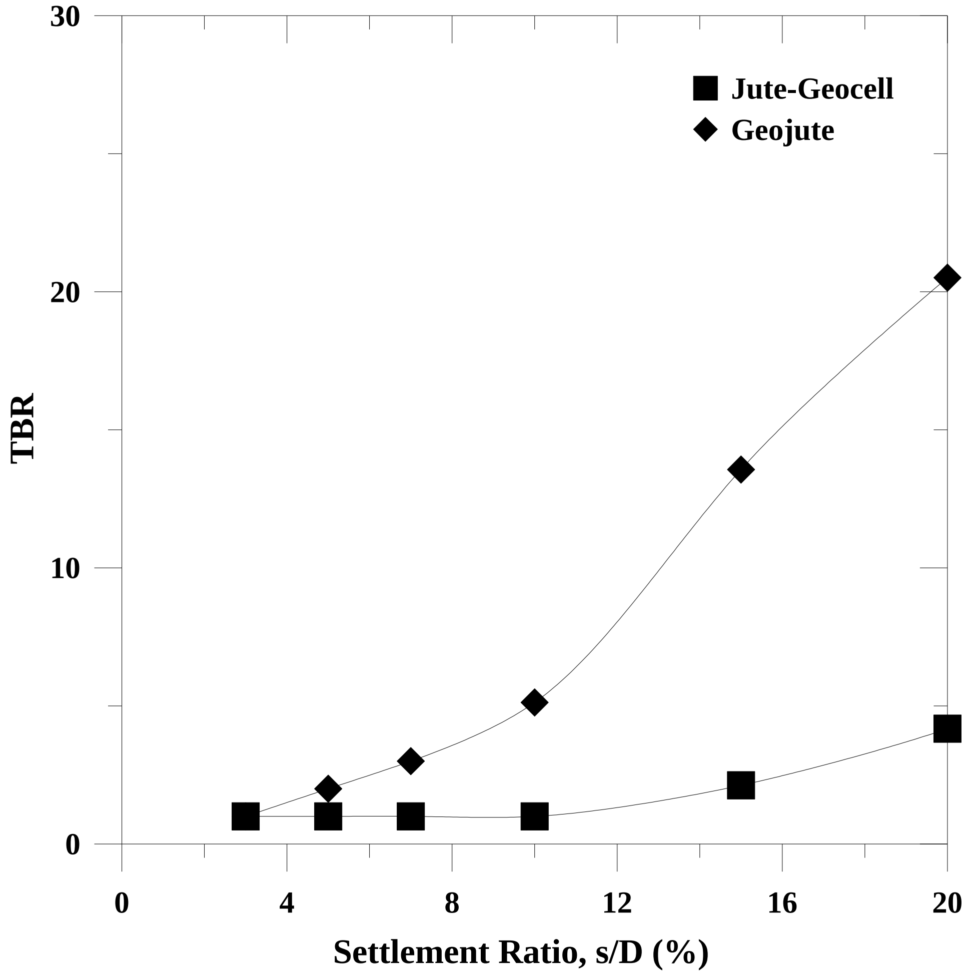

Figure 5.13 Variation of TBR v/s settlement ratio for same area of reinforcement

5.3.2.6 Effect of Aggregate In-fill Material

The partical size of an infill material has an impact on the behavior of reinforced sand under repetitive loading. Figure 5.14 presents the variation of CPDs with number of loading cycles for the test Series I. Figure 5.14 shows that with increaseing the particle size of the infill material, plastic deformations are reduced thereby increasing overall bearing capacity of the bed. With the provision of aggregate infill material, the interlocking behavior improves the frictional resistance between particles and jute-geocell walls, therey increasing the resistance to the vertical movement of material within the cell pockets. Hence higher load carrying capacity and stiffness is achieved. Figure 5.15 shows an aggregate overlying weak sand subgrade, which was compacted with a rammer of weight 35N falling from a height of 0.436m for five times imparting a compaction energy of 763N-m. Whereas Figure 5.16 shows the bed after testing. A very less deformations were noted even after applying a large number of load cycles (2500). With inclusion of jute-geocell mattress within the aggregate fill, the test bed withstood as high as 10,000 cycles for about 12.5% settlement ratio.

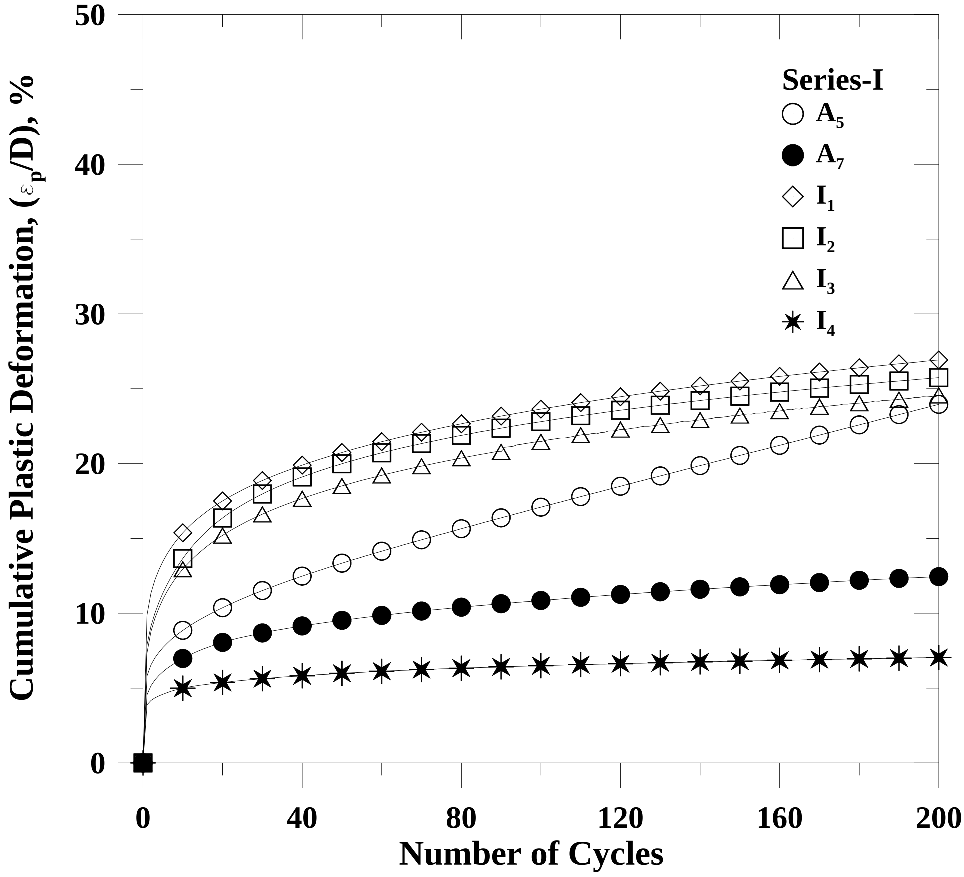

Figure 5.14 CPD v/s No. of cycles (Series-I)

Figure 5.15 Reinforced bed prior testing (Series-I_4)

Figure 5.16 Reinforced bed after test (Series-I_4)

5.4 Concluding Remarks

Improvement factor obtained from the study is calculated in terms of ESALs at a particular settlement. Also, the modulus of subgrade reaction is calculated from the slope of the slow cyclic load tests as discussed in section 3.5.4. Results obtained from the tests are tabularized in Table 5.2.

Table 5.2 Results from the test series

Nomenclature	No. of Load Cycles		Modulus of Subgrade Reaction (MPa)	Modulus of Elasticity (MPa)
	@ s/D = 10% No. of Load Cycles Applied	@ s/D = 20% No. of Load Cycles Applied		
F_1	1	8	13.08	34.01
F_2	8	263	15.41	40.08
F_3	4	42	13.93	36.24
G_1	1	34	14.02	36.46
G_2	3	42	13.93	36.24
H_3	3	62	17.34	45.09
I_4	2178	10000 (12.63%)	29.38	78.39

Based on the results obtained from the present study on jutegeocell reinforced beds, following conclusions are drawn.

- With inclusion of jute-geocell reinforcement, expected performance was NOT noticed owing to lower flexural stiffness of the flexible jute material
- Height of geocell has an impact on the performance. Better performance of footing can be obtained in terms of load carrying capacity and CPDs for h/D=1.
- Provision of an additional reinforcement layer beneath the geocell mattress helps in improvement of load bearing capacity. It helps in restraining the vertical deformation of the infill material.
- From the comparative study on the form of reinforcement, the performance due to geojute reinforcement is appreciable as compared to jute-geocell. Since, least flexural stiffness of jute-geocell mattress cause higher initial plastic deformations. Whereas, tensile property of geojute and membrane effects attributed to the lower plastic deformations on planar geojute reinforced sand beds.
- Surface settlements observed from the reinforced sand are negligible indicating that the jute geocell mattress arrested the potential failure planes.
- It has been ascertained that it is beneficial to have a dense infill material to get better benefit out of reinforcement.
- Modulus of elasticity obtained from the model tests for weak (RD = 30%) to stiffer (RD = 70%) sand beds are within the range of 35-80MPa. Aggregate infill shows an improvement as high as 79 MPa.
- Optimum width of jutegeocell mattress was found to be four times the width of footing.

CPDs show an appreciable improvement with number of loading cycle when aggregate infill is used against sand infill.

Chapter 6

Summary and Conclusions

6.1 Summary

In this research, a series of large scale dynamic model tests are conduct in a controlled laboratory environment. A total 50 experiments were carried out in a test tank of dimension 1m x 1m x 1m. Sand subgrades were prepared in the test tank using pluviation technic at 70 and 30% relative densities at different test schemes. In few series of tests, a homogeneous sand subgrades were prepared at 70% relative density to first understand the behavior of the sand beds under repeated loading, then, a weaker sand subgrades were prepared overlain by stiffer sand layers at 70% relative density. A single axle wheel load of 40 kN (per tire) was applied through a sophisticated double acting linear dynamic hydraulic actuator which is attached to a 3.5 m high reaction frame. A series of experiments were designed to improve the structural support of the weak sand subgrades by introducing waste geo-jute (planar) and jute-geocell reinforcement in the upper layers of the subgrade. In the last series of experiments, the sand infill in the geocell pockets was replaced with aggregate (± 20mm size) to see the efficacy between the fill materials on the performance of the bed. Tests are conducted on sand subgrades and granular infill beds with and without geo-jute reinforcement configurations. The number of loading cycle, the number of reinforcement layers and the width of planar jute layers on the performance of geo-jute reinforcement was also investigated. The influence of each variable is studied by keeping the other variables at a constant value.

In the jute-geocell series, the influences of height, width of the geocell on the overall performance of the bed are investigated. In addition, the geocell mattress with a base layer of geojute was also investigated. The infill material type was also investigated.

In all the tests, load-deflection profiles along with bed surface deformations are measured through instrumentation including LVDTs and load cells. The data is presented in the form of cumulative permanent deformations (CPDs) and Traffic Benefit Ratios (TBRs) and Percentage Reduction in Settlements (PSRs).

6.2 Conclusions

6.2.1 Geojute Reinforced Beds

Test results have shown that, with the provision of geojute reinforcement, there is an appreciable high performance improvement in terms of reduction in footing settlement and increase in bearing capacity of the reinforced bed. Better performance of the footing is obtained in terms of number of repetitive load cycles if geojute layers are placed at a distance of 0.1D and consecutive distance between two layers kept at 0.33D. With inclusion of geojute reinforcement, there is an appreciably high performance improvement in terms of reduction in permanent deformations and increased number of load cycles on the test bed. Better performance of footing is noticed when 3 number of geojute reinforcement layers are provided. The optimum width of geojute layer was found to be four times the width of the footing. It has also been ascertained that dense granular blanket encompassing the reinforcement layers resulted in higher benefit ratios in terms of CPD and TBRs. Surface settlements observed from the reinforced sand are very minimal. Non-dimensional factors such as TBR was achieved as high as 70 while, 50% reduction in footing settlements were noticed for 3 number of geojute layers. Modulus of elasticity obtained from the model tests was higher for stiffer homogeneous geojute reinforced beds. For weaker beds moduli values were found to be as low as 48 MPa.

6.2.2 Jute-Geocell Reinforced Beds

It is understood that with the inclusion of jute-geocell reinforcement, an appreciable performance is noted in terms of load carrying capacity and settlement reduction in a series of static tests. A series of slow cyclic tests were also conducted to determine the shear modulus and elastic modulus of the test beds with different configurations. In repeated load tests, the height of geocell has an impact on the performance of the reinforced bed. Since, walls of the geocell generate hoop stresses to avoid lateral spreading of soil and also restrain vertical movement due to friction between soil particle and wall. From results it is seen that better performance of footing can be obtained in terms of plastic deformations (rut depth) for h/D=1, further increase in height of the geocell decreased the performance owing to its lower flexural rigidity. In addition, it is observed that larger width of geocell mattress helps in spreading load over wider area, thus; improving the benefit ratios. Investigation shows that better performance is achieved for geocell mattress having width about four times that of footing plate. If additional base layer is provided below the geocell mattress, performance improvement is enhanced further. This improved performance is attributed to the membrane support provided by the additional base layer. Due to load distribution over wider area through geocells, the surface settlements observed from the reinforced beds are found to be marginal. But, negative value of settlement (as heaving) is noticed for unreinforced sand bed depicting that general shear failure occurred in unreinforced beds. In these beds, the failure planes were noticed reaching fill surface showing heave. It has been ascertained to have a dense infill material to get better benefit out of reinforcement. Modulus of elasticity obtained from the model tests for weak to stiff sand beds are within the range of 35-80 MPa. Aggregate infill shows an improvement in the modulus as high as 79 MPa. CPDs show an appreciable improvement with number of loading cycle.

However, the performance of the jute geocell reinforced sand beds is inferior to the planar geojute reinforcement system. This is mainly attributed to the density of the infill material within the cell pockets. It was anticipated that as the geocell height increases, the density in each cell pocket was reduced due to the interference of the cell walls during sand pluviation. This will result in lower placement density within the pockets leads to weak interaction between the cell walls and the infill material. Hence the performance of the jute geocell was less than that of planar geojute reinforcement system. However, if the jute geocell mattress is compacted with aggregate infill, the performance was improved drastically and the benefits were observed to be higher.

Some of excerpt from the conclusion are listed below:

- Provision of *three* layers of geojute reinforcement in sand beds performs better in achieving the maximum performance.
- Dense beds showed better performance improvement in terms of benefit ratio. Thus, Benefit ratio increases with increase in *placement density.*
- Optimum width of reinforcement was noticed *four* times that of footing plate in both the forms of reinforcement.
- In terms of Jute-Geocell expected performance was not noticed, this is due to lower flexural stiffness of the material in terms of mattress. But, potential failure planes were arrested due to confining effect of jute-geocell mattress, resulting negligible surface settlements.
- Width and height of jute-geocell showed an impact in enhancing performance. On investigation an optimum width and height of jute-geocell was noticed as *h/D=1* and *b/D=4.*
- Provision of an additional base layer and granular infill material improves bearing capacity of sand bed further by large extend. This is attributed to interlocking property

of aggregate and geocell wall arresting vertical movement of particles within cell pockets.

- Non dimensional parameters viz. TBR, CPD, PRS and I_f showed appreciable benefit in improving performance of reinforced beds. Highest benefit achieved for reinforced beds with aggregate infill against sand infill.

6.3 Future Scope of the Work

The present study has given emphasis on geojute reinforced sand beds. An attempt has been made to understand the behavior of jute material as a cellular reinforcement. Following are the recommendations for scope of future work.

1. Further studies can be carried out to completely understand the longevity of the jute material in pavement sub layers.
2. Further studies shall be carried out to understand the optimal benefits from critical jute-geocell geometry while aggregate infill is used.
3. Model tests may be extended for aggregate infill overlying clay beds.
4. Studies can be carried out on various natural reinforcing materials.

More studies can be done for various opening sizes of geocell for pavement subgrades.

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