CHAPTER 2
LITERATURE REVIEW

2.1 General
A variety of reinforcing materials are used for reinforced earth applications. They include metallic strips, geosynthetics and natural materials. Out of these, geosynthetics are being extensively used in the recent years for a variety of civil engineering applications. Unlike the metallic reinforcements, geosynthetics can serve several other functions in addition to the function as reinforcement. Different types of geosynthetic products are being manufactured and the industry is growing rapidly with findings of new engineering applications day by day. The subsequent section presents the reported studies on the use of synthetic materials as a soil reinforcing element.

2.2 Previous studies on geosynthetic reinforced soil
Over the last two decades, the beneficial effects of using geosynthetic in the form of planar reinforcements to increase the bearing capacity of soil have been clearly demonstrated by several investigators. The initial studies on the effect of soil reinforcement for the improvement of bearing capacity of footings was carried out by Binquet and Lee [1975(a), (b)] and subsequently pursued by many others. Binquet and Lee [1975(a), (b)] conducted a series of model tests on strip footings on reinforced sand with aluminium strips. It was found that placing the reinforcement at a certain depth from the footing base appreciably increases the bearing capacity of foundation soil. Considerable work has been published regarding the behavior of footings on a reinforced soil layer (Akinmusru and Akinbolade, 1981; Frageszy and Lawton, 1984; Guido et al., 1985; Khing et al., 1993; Yetimuglu et al., 1994).
Akinmusru and Akinbolade (1981) have conducted tests on square footings (width=100mm) with woven strips as reinforcing elements. They have reported that for the ratio of depth of first layer (u) to the width of footing (B) between 0.5 and 1.0, the increase in bearing capacity ratio (BCR) was considerable and optimum number of layers was found to be 3. Guido et al. (1985) have used square footing of width 31 cm and geotextile for their tests. They have found that the optimum value of N was also 3 and the optimum value for the width of reinforcement was equal to 2.5B.

Khing et al. (1993) have performed experimental tests on closely spaced strip footings reinforced with geogrid and concluded that the effective depth and further width of reinforcement from the edge of footings are equal to 2.5B and 2B respectively.

Yetimoglu et al. (1994) have investigated the bearing capacity of rectangular footings on geogrid reinforced sand by performing laboratory model tests and finite element analysis. The effect of the depth to the first layer of reinforcement, vertical spacing of reinforcement layers, number of reinforcement layers, and the size of reinforcement sheet on the bearing capacity were investigated and found to be 0.25 B, 0.2B, 4.5B respectively. Both experimental and analytical studies indicated that there was an optimum reinforcement embedment depth at which the bearing capacity was the highest where single layer reinforcement was used. Also there appeared to be optimum reinforcement spacing for multi-layer reinforcement sand. The bearing capacity of reinforced sand was also found to increase with reinforcement layer number and reinforcement size when the reinforcement was placed within a certain effective zone. In addition, the analysis indicated that increasing reinforcement
settlement beyond a certain value would not bring about further increase in the bearing capacity.

Boushehrian and Hataf (2003) have investigated the bearing capacity of circular and ring footings on reinforced sand by conducting laboratory model tests along with numerical analysis. The effects of the depth of the first layer of reinforcement, vertical spacing and number of reinforcement layers on bearing capacity of the footings were investigated. Both experimental and numerical studies indicated that, when a single layer of reinforcement is used, there is an optimum reinforcement embedment depth for which the bearing capacity is greatest. There also appeared to be an optimum vertical spacing of reinforcing layers for multi-layer reinforced sand. The bearing capacity was also found to increase with increasing number of layers.

Dash et al. (2004) have presented the results of laboratory model test carried out to study the relative performance of different forms of reinforcement (i.e., geocell, planar and randomly distributed mesh elements) in sand beds under strip loading. It is reported that geocell reinforcement is the most advantageous soil reinforcement, and failure was not observed even at a settlement equal to about 45% of the footing width, and a load as high as eight times the ultimate capacity of the unreinforced soil, whereas, with planar reinforcement, failure took place at a settlement of about 15% of the footing width and a load of about four times the ultimate capacity of the unreinforced soil. For the case with randomly distributed reinforcement, mesh failure was recorded at a load about 1.8 times the ultimate capacity of the unreinforced soil and at a settlement of about 10% of the footing width.
Patra et al. (2005) have reported laboratory model test results for the ultimate bearing capacity of a strip foundation supported by multi-layered geogrid-reinforced sand. It was concluded that, the ultimate bearing capacity increases with the increase in embedment ratio.

The ultimate bearing capacity of strip footings resting on subsoil consisting of a strong sand layer overlying a low bearing sand deposit was investigated by Kumar et al. (2007). The principal problems analysed were (i) the effect of stratified subsoil on the foundation bearing capacity; (ii) the effect of reinforcing the top layer with horizontal layers of geogrid reinforcement; and (iii) the effect of reinforcing stratified subsoil on the settlement of foundation. It is reported that, there is up to 3 to 4 times increase in ultimate bearing capacity of strip footing resting on sand after replacing the top thick (thickness=width of footing) layer of existing weak soil with well graded sand layer and reinforcing it with 2-4 layers of geogrid reinforcement.

Chung and Cascante (2007) have presented results of laboratory testing and numerical simulation on the effect of reinforcement (fibre glass and fibre mesh) on the low-strain stiffness and bearing capacity of shallow foundations on dry sand. The effect of the location and the number of reinforcement layers was studied in the laboratory, whereas numerical simulation was used to study the reinforcement interaction. Laboratory tests showed an increase of 100, 200, and 275% increase in bearing capacity of a square foundation when one, two, and three layers of reinforcement were used. Numerical simulation demonstrated that if reinforcement is placed up to a depth of one footing width (B) below the foundation, better redistribution of the load to deeper layer is achieved thus reducing the stresses and
strains underneath the foundation. Further, numerical simulation and experimental results clearly identified a critical zone between 0.3B and 0.5B.

Construction represents a major contribution to climate change, resource depletion and pollution at a global level. A strategy for more sustainable construction is a significant step towards a more successful, socially and environmental friendly atmosphere making a strong contribution to the better quality of life. Construction is the second largest market for plastics after packaging, accounting for 20% (4.89 million tonnes) of total plastics consumption in 1995 (Mwasha, 2009). High consumption of plastics in construction industry has critical environmental effects since out of the 47 chemicals ranked highest in carcinogenic emissions by the Environment Protection Agency (EPA), 35 are involved in plastic production. Plastics such as poly vinyl chloride (PVC), used for indoor and outdoor construction works are potential sources of high CFCs and hydrochlorofluorocarbons (HCFCs) both of which are ozone-destroying chemicals. There are many disadvantages associated with the use of polymeric materials in construction industry such as: polymeric materials are manufactured using petroleum products which are expensive especially for the developing countries, they are non-renewable resources, can create environmental pollution.

As a result of increasing environmental awareness worldwide, there is need to consider the potential for the use of biodegradable materials rather than synthetically manufactured materials, particularly in situations requiring short-term soil reinforcement. There are numerous ground engineering situations where the critical period for stability is immediately, or very shortly, after construction. In such situations, it is common practice to incorporate reinforcement to provide an additional
stabilizing force. If the foundation soil is slow draining then loading of the ground will create excess pore pressure within the foundation soil. Subsequently, with time, excess pore water in the foundation will dissipate from beneath the loaded area and the shear strength of the foundation will increase. Hence the stability of the system will improve with time and the stabilizing force, which needs to be provided by the reinforcement will diminish. After a certain time (typically between a few months and a few years) the whole system will be stable with little or no assistance from the reinforcement and in many cases, the reinforcement becomes totally redundant. In such situations, the use of a reinforcing material, other than synthetic which has a limited, but predictable working life, is sound engineering practice and this is the concept of limited life geotextiles.

Natural fibres are ideal “raw materials” for the manufacture of limited life geotextiles. Such materials certainly degrade with time, but there is a huge range of natural fibres available and these exhibit very different strength and durability characteristics such as: some fibres have very high initial tensile strength and some fibres exhibit very slow, progressive loss of tensile strength with time. The use of natural materials such as jute, cotton, sisal and coir as reinforcing materials in soil started in the early 1990’s (Ayyar et al., 2002). The main advantage of these materials are that they are locally available and are biodegradable and hence do not create environmental problems. The ability of the natural fibres to absorb water and degrade with time are the principal properties that give them an edge over synthetic materials. The subsequent sections present the general features and reported literature on the geotechnical applications of the most durable natural fibre, namely coir.
2.3 Coir

2.3.1 General

Kerala, a narrow strip of land wedged between the Western Ghats on the East and Arabian Sea on the West is the home of coir. The State of Kerala accounts for nearly 50% of the indigenous production of coir. Abundance of skilled labour and logistics of the region offering backwater areas and lagoons within easy reach and the source of availability of raw materials have contributed to the development of coir industries in Kerala. Coir industry provides employment to people belonging to weaker sections in rural areas mainly for women. Coir is a versatile natural fibre extracted from mesocarp tissue, or husk of the coconut fruit. After thrashing the husk, the long fibre is removed and used for manufacturing a variety of products of multifarious use including home decor, furnishing of luxury apartments and industrial purpose.

The unique colour of this fibre has earned for it the favourite name 'the golden fibre' although it is known in other countries as coir or cocos fibre. Products made from coir acquired worldwide reputation and naturally coir industry could attract large markets. This wide acceptance of coir was largely because of its golden sheen, tensile strength and resistance to dampness. These qualities made coir useful in various applications.

Coir fibres are extracted from the fibrous outer shell of a coconut. The individual fibre cells are narrow and hollow, with thick walls made of cellulose. They are pale when immature but later become hardened and yellowed as a layer of lignin is deposited on their walls. There are two varieties of coir: brown and white. Brown coir is harvested from fully ripened coconuts. It is thick, strong and has high abrasion
resistance. It is typically used in mats, brushes and sacking. Mature brown coir fibres contain more lignin content and less cellulose than fibres such as flax and cotton, and the fibres are resilient, strong and highly durable but less flexible than flax and cotton (Bismarck et al., 2001).

Coir is reputed to be the among the strongest and most durable of natural fibres (Girish and Ramanatha Ayyar, 2001; Ayyar et al., 2002). It is a biodegradable organic fibre material containing about 46% lignin and 54% cellulose. Because of the high lignin content, coir is much more advantageous in different applications such as erosion control, or improving the performance of embankments. Various successful field trials and case studies have shown that these materials have a lot of potential in the field (e.g., Rao and Balan, 2000).

2.3.2 Previous Studies on coir fibre reinforced soil

Rao and Balan (1997) have carried out durability studies of two varieties of coir yarn viz., white and brown in different soil environments. The rate of degradation of coir in sand and water at different pH environments were also studied. The rate of degradation was predominant in the early periods ranging from 4 to 8 months and later it was slower. In sand the coir retained its initial strength for upto one month and in clay for three months. Coir is found to degrade at a faster rate in water than in soil environments of the same pH value.

Rao and Balan (2000) have conducted triaxial shear tests with coir fibres (25mm long and 50mm long) using different fibre contents. The results showed that, behavior is similar to that observed with synthetic fibres and meshes.
Ramanatha Ayyar et al. (2001) conducted a series of triaxial compression tests on silty sand reinforced with sand fibre cores of 25 mm diameter using coir fibres of varying diameter and length under confining stresses of 104kPa, 155kPa and 206kPa. Tests were also done using PVA coated coir fibres. It was concluded that with the introduction of coir fibres in sand core, failure strain and deviator stress increased. The introduction of fibres in sand core increased the strength for the same core density. Higher diameter of fibres were seen to increase the strength of soil inspite of lower numbers and longer fibres did not necessarily increased the strength. PVA coated coir fibres offered greater rigidity and hence more effective for soil stabilization.

A study on bearing capacity improvement using coir geotextiles has been reported by Girish (2002). Different types of coir geotextiles like plain needled felt, knotted coir net, felt with mesh backing were used. Strength study was done by conducting plate bearing test and penetration test. Sand at a lower density was used to represent weak sand deposit. The frictional properties of geotextiles were studied by conducting modified shear test and fabric pull out test. In order to study the effect of cement coating, all the above mentioned tests were done on PVA–cement coated fabrics. From the study, it was conclude that coir geotextiles can be effectively used as reinforcement to improve the bearing capacity of weak soils and it has the potential to replace the synthetic geotextiles.

Babu and Vasudevan (2005) have carried out triaxial shear tests on coir fibre reinforced soil specimen. The tests were done at different fibre contents. It was observed that both strength and stiffness of soil increased considerably due to the inclusion of coir fibres. Major principal stress at failure was observed to increase up to three times. It was also reported that deviator stress for coir fibre reinforced soil
increases as the diameter of fibre increases. The same trend was observed with increasing fibre content and confining stress.

Cyrus and Jose (2005) attempted to study the compressibility behavior of Cochin marine clay improved with coir fibre. Oedometer tests on specimens reinforced with randomly distributed coir fibres were conducted. Their study revealed that compression index values decrease with increase in fibre content up to 0.8% and then a reverse trend was seen at higher percentages. This was explained by the fact that the volume occupied by coir fibre is more leading to more fibre to fire interaction and thus compression of coir fibre is dominant.

Rao et al. (2005) conducted triaxial compression test to determine the strength characteristics of sand reinforced with coir fibre. The result of their tests indicated that the inclusion of coir fibres improved the performance of sand specimens. From their study, it was understood that the inclusion of coir fibres increased the deviator stress developed at any strain level, which confirms the ability of coir fibres to strengthen the sand. For sand reinforced with coir fibres, the initial tangent modulus and secant modulus increased with increase in confining stress.

Babu and Vasudevan (2007) reported different methods for evaluating the strength of fibre reinforced soil, and the application of these methods to predict the strength response of coir-fibre-reinforced soil and also suggested a simple analytical approach to predict the stiffness modulus of fibre reinforced soil. They also proposed regression equations for the major principal stress, shear strength parameters and compression index of black cotton soil at any fibre content.

Vinod et al. (2007) have carried a study into the undrained response of clay specimens reinforced with sand-coir fibre cores in triaxial test. A thin PVC pipe kept
centrally inside a split mould was used to form the core in the triaxial tests. The clay was placed inside the mould around the PVC pipe at maximum dry unit weight-optimum moisture content condition while the sand-coir mixture was placed inside the pipe at the same bulk unit weight as that of clay. The influences of variables such as replacement area ratio (ratio of cross-sectional area of sand-coir fibre core to that of the triaxial test specimen), confining pressure, fibre content, and fibre aspect ratio on the behavior of the composite soil specimen were critically examined in this study. It was found that stress-strain strength properties of clay specimens reinforced with sand-coir fibre core is appreciably better not only when compared with untreated clay specimens but with sand core reinforced clay specimens as well. Such an improvement was of importance to allow reduced requirement of sand and increased use of natural fibre. An optimum fibre content of 1% (by weight) was identified for strengthening of the sand core. The reinforcement effect was found to increase appreciably with increase in replacement area ratio and to a smaller extent with increase in fibre aspect ratio.

Coir fibre can be converted to fabric by both woven and non woven process. The raw material, i.e., the husk of coconut needs to be processed in order to obtain geotextiles. The different steps involved are: retting of coir husk; extraction of fibre; spinning of yarn or needle punching; and weaving to obtain desired geotextile. Woven coir geotextiles are produced by interlacing at right angles with two more sets of threads. One set of threads known as the warp run along the length of the coir geotextile with the other known as weft running perpendicular to the warp. The plain geotextile gives maximum interlacement between warp and weft threads thereby imparting maximum dimensional stability, rigidity and strength to geotextile. There is
also another variety of coir product, namely hand knotted coir netting consisting of openings of regular size produced by integrally connecting two threads with knots. Subsequent section presents the salient features of reported studies on coir geotextiles.

2.3.3 Previous studies on coir geotextile as reinforcement

Rajagopal and Ramakrishna (1997) have reported a study on the degradation behavior of coir geotextiles with clayey soils. Wide-width tensile tests were conducted on samples immersed in tap water for varying periods of time. Some of the samples were dried and then tested in dry condition. In general, it was concluded that the strength of coir geotextiles in wet conditions is very less. The strength in the wet conditions decreased by more than 70%, whereas samples dried after wetting had almost the same strength as virgin samples. Studies were also performed on coir fibres by exposing them to bacterial strains obtained from different sources. The loss of weight of samples indicated the effect of these organisms on coir. The bacteria did not survive in the coir medium for more than 7 days during which time the coir samples lost only 1% to 2% weight indicating that the coir is not susceptible to decay by these organisms.

The performance of a coir fabric reinforced model retaining wall was investigated by Ayyar and Girish (1999). A comparative study of natural geotextile reinforced and synthetic geotextiles reinforced wall was also made. Three model retaining walls were constructed up to a height of 1 m using three different reinforcing materials and their behavior was studied under the application of various surcharge loads. The material used as reinforcement were coir needled felt reinforced with nylon net stitching, coir needled felt reinforced with coir grid stitching and geosynthetics
product net guard The deformation of walls with natural geotextiles was found to be very low and comparable to that of wall reinforced with synthetic fabric.

Girish (2002) has reported the results of plate bearing test and modified shear test on geotextiles coated with polyvinyl alcohol-cement mixtures. From the study, it was concluded that durability of coir geotextiles can be improved by the poly vinyl alcohol–cement coating.

Rao and Dutta (2002) have conducted some preliminary studies on the application coir based geotextiles for rural roads. Static as well as cyclic plate load tests were done. Kaolinite clay was used to represent the soft subgrade material and a layer of sand was used at the top to present the granular course. It was found that with decrease in aperture size of the geotextile, the bearing capacity of reinforced samples improved significantly. Based on test results, it was concluded that use of coir geotextiles is of great potential in rural roads, particularly on soft clays.

Babu et al. (2008) have performed laboratory California Bearing Ratio tests to investigate the beneficial use of two types of woven coir geotextiles in two types of soils. It was concluded that by using coir geotextiles, the aggregate thickness can be considerably reduced and the percentage reduction depends on the quality of geotextiles, property of soil and the placement depth of the reinforcement. The maximum improvement ratio obtained from the tests was about 1.5 for red soil and about 3.5 for clayey silty when the reinforcement was placed at a depth of H/4 from the top (H- Height of specimen in the mould). Also, a regression model was developed to estimate the modified CBR of the reinforced subgrade soil.

Tensile and pullout behavior of woven coir geotextiles was investigated by Subaida et al. (2008). Tension tests were conducted on coir fibres, yarns and woven
coir geotextiles at different gauge lengths and strain rates and expressed the tensile strength as a function of fibre strength, yarn properties and weaving pattern. Pullout test and modified direct shear tests were conducted on geotextiles in granular soils of different grain sizes. At normal stress ranges, bond resistance of coir geotextiles-sand interface obtained was more than the shear strength of soil. But consistent values of bond resistance were not obtained at higher normal stresses in their study. The opening size of mesh relative to the soil grain size was found to influence the pull out interaction between the soil and geotextile. For closely woven geotextile, pullout resistance did not vary, much in soils of different grain size, where as for geotextiles with open meshes, pullout resistance was found to be more in fine sand compared to coarse sand.

Rao et al. (2009) have conducted studies on the characterization of natural geotextiles along with their physical & mechanical properties and influence of deformation rate. The results of their study revealed that the thickness of natural geotextiles can be taken as that corresponding to normal pressure 2 kPa after 1 minute of application of pressure. Compressibility of non-woven geotextiles is significantly higher than that of woven geotextiles. Further, it was also observed that for a change in deformation rate from 10 to 300 mm/min, there is no change in strength, for natural geotextiles, except for the non-woven. The tensile strength of natural geotextiles can be taken as that corresponding to 200 mm wide x 100 mm length specimen at a deformation rate of 10 mm/min, for all practical purposes. The woven coir geotextiles have more tensile strength in the machine direction than in the cross-machine direction. Their tensile strength is influenced by number of yarns. The non-woven coir
geotextiles have more tensile strength and tensile elongation in the machine direction than in the cross-machine direction. The behaviour of the non-woven coir geotextiles is influenced by the presence of the type of stitching, yarn used, coir/jute netting and the coir web weight. The variance in tensile strength and tensile elongation of the non-woven coir geotextiles is generally more in comparison to woven coir geotextiles.

Subaida et al. (2009) conducted an experimental study to investigate the beneficial use of woven coir geotextile as reinforcing material in a two-layer pavement section. Monotonic and repeated loads were applied on reinforced and unreinforced laboratory pavement sections through a rigid circular plate. The effects of placement position and stiffness of geotextile on the performance of reinforced sections were investigated using two base course thickness and two types of woven coir geotextiles. The test results indicated that the placement of geotextile at the interface of the subgrade and base course increased the load carrying capacity significantly at large deformations. Considerable improvement in bearing capacity was observed when coir geotextile was placed within the base course at all levels of deformations. The plastic surface deformation under repeated loading was greatly reduced by the inclusion of coir geotextiles within the base course irrespective of base course thickness. The optimum placement position of coir geotextiles was found to be within the base course at a depth of one-third of the plate diameter below the surface.

The effectiveness of horizontally placed braided coir rope reinforcement on the strength improvement and settlement reduction of loose sand was investigated by Vinod et al. (2009) for modeling footings using plate load tests in the laboratory. The influence of parameters such as depth of reinforcement embedment, length, number of
layers and number of plies of braided coir rope was examined. The model test results indicated that up to about a six-fold improvement in strength and about ninety percent reduction in settlement (vertical displacement) can be achieved through the use of the proposed reinforcing method. The optimum value of embedment depth of a single layer of braided coir rope reinforcement was identified as 0.4 times the footing width. It was also found that optimal benefit was realized for a length ratio equal to about 3 and by reinforcing the zone of soil directly beneath the model footing upto a depth equal to about 0.6 times the width of footing. Increase in the number of layers within the significant depth leads to a proportionate increase in strength improvement ratio, while the optimal settlement reduction is realized with three layers of braided coir rope reinforcement.

Vinod and Minu (2010) have reported the beneficial effect of five varieties of coir product inclusion (three types of woven coir geotextile and two types of hand knotted coir netting) on the California bearing ratio behavior of four soils: a natural silty clay; a commercially available soft clay; lateritic soil; and sand over soft clay subgrade. The study indicated that CBR improvement sufficient enough to eliminate the need for a strong base course in unpaved roads is achievable through the use of these coir products. The general strength mobilization theory applicable to geosynthetic reinforcements, according to which the lower the CBR value of the subgrade is, the higher is the degree of improvement due to reinforcement inclusion, was not observed to be valid for coir geotextiles and nettings.

2.4 Objectives of the present study

Review of literature presented in the previous section, in general, point towards the fact that coir reinforcement can be used effectively in improving engineering
behavior of soft/loose soils and it has great potential to replace synthetic geotextiles. However no significant study has been reported on the use of woven coir geotextiles and hand knotted coir nettings as reinforcement in soft/loose soil. Hence a detailed experimental study has been conducted to obtain an in-depth understanding on the reinforcing benefits of one type of woven coir geotextile and two types of hand knotted coir nettings. The durability of the above varieties of coir is also planned to be studied. An affirmative result, if obtained, would lead to the development of a cost-effective, environmentally friendly solution to one of the major challenges (construction on weak/loose soils) faced by the Society.

The present study aims

- to examine whether woven coir geotextile and hand knotted coir netting can significantly improve the bearing capacity of loose sand deposits.
- to quantify the effect of the following parameters on bearing capacity improvement of loose sand:
  - Depth of placement of geotextile/netting;
  - Length of geotextile/netting;
  - Number of layers of geotextile/netting;
  - Spacing between multiple of layers of coir geotextile/netting;
- to obtain an empirical equation for strength improvement as a result of coir geotextile and netting inclusion;
- to examine the effectiveness of sand-coir fibre composite columns in stabilization of soft clay beds;
• to examine the durability of coir geotextiles and nettings under different environmental conditions (continuous submergence as well as alternate wetting and drying).