CHAPTER 1

INTRODUCTION

1.1 GENERAL BACKGROUND OF THE PROBLEM

The soil for a civil engineer is the weathered material at the earth's crust. The discrete particles that make up the soil are not strongly bonded together, they are free to move relative to each other, which is responsible for their low mechanical properties. These low mechanical properties pose serious problems for civil engineers to design and construct structure on and with soil. Besides this the increasing tempo of construction activity the world over is creating heavy pressure on existing land space. The quest for new and competent site often points to the need for improving existing sites which are otherwise deemed unsuitable for adopting conventional shallow foundations. Bypassing the weak surface soil and adopting deep foundations is a possible solution, but this is a costly venture which one can ill afford particularly in case of smaller structures. Under these circumstances the most feasible alternative is to look for measures which can modify the surface soil and improve its engineering properties. In this context since long time, engineers are attempting to improve mechanical properties of soil by various techniques such as lime stabilization, stone column and mechanical stabilization. Inclusion of stronger material into the soil is one of the age old art in this direction. Ropes, fibers and bamboo strips are used to strengthen the rural road bases and soil below low-cost and low-rise buildings. Such composite structures have higher strengths and or more resistant to cracks and crack propagations than plane unreinforced mud structures. The main advantage of these constructions is low cost. But, yet no mechanistic explanation was available till 1968, until a French engineer Henry Vidal proposed this technique and called it as 'Reinforced earth'. Since then reinforced earth technique is one of the latest and fast growing techniques in the field of civil engineering. Much of the work reported so far in the literature relates to earth retaining structures (Munster, 1930; Vidal, 1968 and Schlosser and Elias, 1978).

One of the areas where reinforced earth technique could be very effectively used is in the improvement of bearing capacity (Vidal, 1969). Reinforced soil bed is a soil
foundation containing horizontally embedded thin flat metal strips, ties or grids called as reinforcements. Model studies of footings on reinforced soil beds by several researchers (Binquet and Lee, 1975 a and b; Basset and Last, 1978; Akinmusuru and Akinbolade, 1981; Patel, 1982; Ramaswamy and Young, 1983; Fragaszy and Lawton, 1984; Singh, 1988; Bindumadhava, 1990; Beena, 1993; Yetimoglu et al., 1994; Raghavendra, 1996; Waugh and Chandrasekharan, 1996, 1998 and 2004; Nainan et al., 1997; Sridharan et al., 1998; Raghuveer Rao et al., 2000; Shin et al., 2001; Toyoaki Nogami and Tan Yee Young, 2003 and Sirharam et al., 2004) have clearly indicated the advantages and possibilities of improvement in bearing capacity and stiffness of the load-displacement behaviour by reinforcing foundation soil. This technique of reinforcing soil bed is yet to be fully exploited. Compared to the number of reinforced earth retaining structures constructed world over, the number of foundations constructed are very few. One of the reasons being the lack of reliable methods of design and analysis. Several researchers have proposed both empirical and analytical methods of analyses and design of reinforced soil beds (Binquet and Lee, 1975b; Huang and Tatsuoka, 1988; Sridharan et al., 1988 and Balakrishna, 1992). Since a number of simplifying assumptions have been made in these analyses, their predictions deviate from experimental behaviour considerably. Various experimental investigations and the discussions on the available literature point to the fact that the important parameters which affect the behaviour of reinforced soil bed are: properties and behaviour of soil material and properties of reinforcement. It is almost impossible to conduct the experimental studies to understand each of these parameters either independently or jointly as it is quite time consuming and expensive. To completely understand the behaviour of reinforced soil beds numerical techniques are advantageous and one requires a model which take into account properties of soil, reinforcement and soil-reinforcement interface behaviour.

Several researches (Sridharan et al., 1998; Balakrishna, 1992 and Raghavendra, 1996)) in literature have conducted analysis on surface footing carrying the horizontal reinforcement in the soil system (Ideal reinforcement pattern). In practice it is very difficult, since foundation will always be below ground level and surface footing are seldom used. Raghuveer et al., (2000) have shown that reinforced soil system with horizontal layers of reinforcements beneath embedded footing carry more load than the
reinforced soil beneath surface footing at the same level of settlement. It also becomes impossible to strengthen the existing soil below laid footing, which have to carry additional load by keeping the reinforcement horizontal below the footings. Hence in practice the actual reinforcement pattern possible is to place the reinforcement other than horizontal manner. Studies on reinforced soil system strengthened by inclined or vertical pattern (practical pattern of reinforcement) is rarely available in literature.

In many practical situations soil systems are often non-homogenous and layered in nature, exhibiting varying strength characteristics. Reinforcements are often included in such layered soil systems if the ground conditions are of poor quality, with low or seasonally varying soil strengths to improve their performance. In case of reinforced soil bed even when soil system is a single soil layer system the inclusion of reinforcement into the soil imparts higher stiffness around the reinforcement making it non-homogeneous and layered system. Experimental investigations have shown that placing a finite layer of reinforced sand over the soft clay whose load carrying capacity has to be improved yields better results than including reinforcements inside soft clay itself (Bindumadhava, 1990). In this situation soil system becomes reinforced two-layer soil system. The above discussions will lead to the fact that the study of reinforced two-layer soil system is very much relevant and needs attention of researchers world over. In spite of this very limited studies have been reported on the reinforced two-layer soil systems (Giroud and Noiray, 1981; Bindumadhava, 1990; Huang and Tatsuoka, 1990; Brocklehurst, 1993 and Madhav and Ghosh, 1994). Most of these reported works are either on model studies or for the study of unpaved roads, where the emphasis is on repeated loading. These reported analyses seldom consider the situation of reinforced two-layer soil beds supporting footings, where the emphasis is on incremental loading. This aspect is very important as improvement in load carrying capacity of the reinforced soil bed increases with increase in imposed load on the footing. Therefore there exists a great need to do research in this area. Raghavendra et al., (1998) have shown that as the stiffness ratio and number of layers of reinforcement increases, load carrying capacity ratio increases for two layer soil system with horizontal layers of reinforcements.
In view of the above discussions an attempt is made to study the effect of introducing vertical/inclined pattern of reinforcement in to the soil below surface and embedded footing under static loading.

1.2 OBJECTIVES OF THE RESEARCH WORK

The main objectives of the present study are:

- To successfully model the behaviour of the surface and embedded footing upon reinforced soil system of both single layer and two-layer soil systems having vertical/inclined reinforcements.

- To analyze and understand soil-reinforcement interaction mechanism by which reinforced soil can bear higher loads than that of non-reinforced soil.

- To study the analysis of stress and progression of failure pattern of reinforced soil system under the footing by the inclusion of reinforcement.

1.3 ORGANISATION OF THE THESIS

This current study has been organised in the following order.

Chapter 1

This chapter covers the general background to the problem, the objective and scope of the present study. Chapter also presents an outline of the adopted approach.

Chapter 2

In this chapter relevant literature is reviewed. Several researches have proposed both empirical and analytical methods of analysis and design of reinforced soil beds/reinforced soil system (Binquet and Lee (1975 b); Huang and Tatsuoka (1988); Sridharan et al., (1988) and Balakrishana, (1992)). Since a number of simplifying assumptions have been made in these analysis, their predictions deviate from experimental behaviour considerably. Various experimental investigations and the discussions on the available literature point to the fact that the important parameters which effect the behaviour of soil material and properties of reinforcement. It is almost impossible to conduct the experimental studies to understand each of these parameters either independently or jointly as it is quite time consuming and expensive. So to
completely understand the behaviour of reinforced soil system numerical techniques are advantageous and one requires a model which takes into account properties of soil, reinforcement and soil-reinforcement interface behaviour. Some researchers (Raghavendra et al., (1995 and 1997); Najnan et al., (1997); Raghuveer Rao et al., (2000); Kentaro Yamamoto and Jun Otoni (2001); Shin et al., (2001)) in literature have conducted analysis on footing carrying the horizontal reinforcement in the soil system. It is equally important to analyse the soil-reinforcement interaction where reinforcements are placed in vertical/inclined manner. However, studies on reinforced soil system strengthened by inclined or vertical pattern (practical pattern of reinforcement) is rarely available in literature. Hence an attempt is made to study the effect of vertical / inclined reinforcement below the surface and embedded footing under static loading.

Chapter 3

This chapter presents the method adopted to solve the problem. The method employs a general-purpose program. The program is referred to as Non Linear Soil Reinforcement Interaction program (NLSRIP, Raghavendra (1996)). The program is development of an existing Non Linear Soil-Structure Interaction Program (NLSSIP), coded by Duncan and Byrene (1980). Program uses non-linear confining stress dependent hyperbolic relationship for the soils. The soil matrix is represented by four nodded quadrilateral elements and reinforced by two dimensional beam/bar elements.

Chapter 4

This chapter presents the results of an extensive and systematic parametric study performed by varying length, number, position, which effect the behaviour of reinforced soil system. An attempt is made in this part of the investigation to understand the mechanism of vertical/inclined reinforcement inside the soil system under surface footing, in terms of altered stresses and displacements at each increment of imposed footing load. Attempts are made to explain higher load carrying capacity of the reinforced soil system. Changes in magnitudes of stresses and displacements with the inclusion of several reinforcing layers in various permutations and combinations have also been studied and presented in this chapter. The optimum configuration of the
reinforcement is three number of layers of reinforcement and length of reinforcement is three times the width of foundation when the embedment depth is minimum.

Chapter 5

This chapter presents analysis of reinforced soil system with vertical/inclined reinforcement under embedded footing. It is interesting to note that in literature most of the experimental and model studies have been reported for reinforced soil system beneath surface footings. However surface footings are rare and almost all footings are embedded. Raghuveer et al., (2000) have shown that reinforced soil system with horizontal layers of reinforcements beneath embedded footing carry more load than the reinforced soil beneath surface footing at the same level of settlement. An attempt is made to understand soil reinforcement interaction by studying the changes occurring due to inclusion of vertical/inclined layers of reinforcements inside the soil under embedded footing in terms of altered stresses and displacements developed in the reinforcement, at each increment of imposed footing load. The changes in magnitudes of stresses and displacements with the inclusion of several reinforcing layers under different embedment depths has also been studied.

Chapter 6

This chapter presents the analysis of reinforced soil system considering two-layer soil system with vertical/inclined layers of reinforcement.

In reality the soil systems are often non-homogeneous and layered in nature exhibiting varying strength characteristics. Common examples are the unpaved roads and footings on layered soil systems. Many a times when the ground condition is poor, as in the case of soft clays, reinforcing soil can be made more effective by introducing a reinforced sand bed of finite thickness beneath the footing. This may be termed as two-layer soil system. Researchers (Bindumadhava(1990); Burd,H.J. and Brocklehurst, C.J. (1990); Raghavendra (1996); Raghavendra et al., (1998)) have shown that as the stiffness ratio and number of layers of reinforcement increases, load carrying capacity ratio increases for two-layer soil system with horizontal layers of reinforcements. An attempt is made to study the displacements and stresses inside two-layer soil system at each increment of imposed footing load for both unreinforced and reinforced with
vertical/inclined layers of reinforcements into the soil system. The study provides a better understanding of the soil-reinforcement interaction in reinforced two-layer soil system.

Chapter 7

This chapter presents the important conclusions derived from the above research work and further scope for the work in this direction. It can be generally concluded from the present investigation that for both surface and embedded footing, introduction of vertical/inclined layers of reinforcement into the soil system increases the load carrying capacity and decreases the settlement of the footing for any given load. The optimum configuration of the reinforcement has been found for vertical/inclined layers of reinforcements. For a two-layer soil system, introduction of vertical/inclined layers of reinforcements, the improvement in load carrying capacity is due to the combined action of granular upper layer and reinforcement.

The detailed references pertaining to this study have been given at end of this chapter.