2.1 REINFORCED EARTH:

The reinforced earth consists of a combination of earth and reinforcing elements. The reinforcement is often a linear element of a layer placed between the soil layers to enable them to withstand higher stresses and to improve the basic properties of the foundation material. The soil exhibit low tensile strength tending to a negligible value in the case of granular soils. In the earth, the internal stresses developed due to load application generates the frictional forces between the soil and the reinforcing material and transfers the stresses to reinforcing elements due to friction between the two materials. Thus the reinforcing material resists lateral deformation and increases the load carrying capacity of the foundation material.

According to history of reinforced earth \cite{70}, since the beginning of civilization, man has attempted to use soil with other materials to enable it for being used for his necessities. Typical uses include use of branches of trees etc. to support tracks over marshy area as to build hutments, large structures etc. Reinforced soil was used by Babylonians more than 3000 years ago to build ziggurats with woven mats of reeds. These have also been used in parts of the Great Wall of China made about 2000 years ago. The Dutch and Romans used willow to reinforce dives and animal hides.

The relatively recent discovery of methods of preparing high-modulus polymer materials by tensile drawing, in a sense “cold working” has raised the possibility that such material can be used in the reinforcement of a number of construction materials, including soil. Today the major function of such geogrids is in the area of the reinforcement. The key features of the geogrids is that the opening between longitudinal and transverse ribs, called the “apertures”, are large enough to allow the soil strike through from one side of the geogrid to the other. The ribs of the geogrids are quite stiff compared to the fibers of the geotextiles. Also not only rib strength is important but junction strength is also
important. The reason for this is that the soil strike-through within the apertures bears against the transverse ribs, which transmit their loads to the longitudinal via the junctions. The junction is the location where the longitudinal and transverse ribs are connected. The original Geogrids were first made in the United Kingdom by Netlon, Ltd. and were brought in 1982 to the U.S. by the way of Canada by the Tensar Corp. A similar product by Tenax Corporation is also available.

Textile material was perhaps first used in road construction in South Carolina in the early 1930’s. The first use of a woven synthetic fabric for erosion control was in 1950’s in Florida by Barett. In 1960’s geotextile were extensively used for erosion control both in Europe as well as U.S.A. later in 1969, Giroud used nonwoven fabrics as a filter in the upstream face of an earthen dam. In 1971 Wager initiated use of woven fabrics as reinforcement for embankments constructed on very soft foundations.

The term “Reinforced Earth” was used after a French Engineer Henry Vidal, as he was the founder of this technique. Once while walking across a dry sandy beach, he noticed that mounds of dry sand could be made to stand at a steeper angle after the addition of horizontal layers of pine needles. In modern days, the success of the geotextile depends on synthetic fibers, which are resistant to degradation by the micro-organism present in the soil. Although even today some fabrics made from natural fibers such as jutes are also being used.

2.2 TYPES REINFORCING MATERIALS:

A wide range of alternatives exists in making a choice of reinforcing materials. However for the selection of reinforcement the load on the structure and the function of the structure should be considered. Moreover the cost aspect also should be kept in mind while selecting the type of reinforcement. Various types of reinforcing materials are listed below [105].

1. Bamboo Reinforcement: Amongst the various types of reinforcement used in reinforced earth construction, bamboo members have been in
use for long time. They are used both as strips and mats, but bamboo deteriorates quickly in wet conditions and is also prone to fungus and insect attacks. The bamboo reinforcements need elaborate preservative treatment before use. Bamboo, having poor mechanical & physical properties in comparison to geotextile or metals, can only be used in small/temporary works.

2. **Metal Reinforcement:** The most commonly and extensively used reinforcement in earth reinforced structures is mild steel or high tensile bars and mats. The steel reinforcement has excellent physical and mechanical properties. However, steel reinforcement is subjected to corrosion by chemical or electrochemical reaction depending upon the physical properties of the solid, thus necessitating corrosion protection measures like galvanization, which often renders it costlier.

3. **Fiber Glass:** Fibre glass reinforcement has high strength and is also corrosion resistant, but it costs more and hence is suitable only for special and small structures.

4. **Jute fibers:** The inclusion of jute fibers constitutes an effective means of imparting cohesion to premoulded and compacted soil. Due to the inclusion of fiber, impact resistance can be improved. The inclusion of jute fibers can be with randomly oriented. Jute fibers within 2-3 years duration disintegrate with the influence of water, heat and sunlight. Hence it is recommended for temporary structures.

5. **Coir:** Coir fibers are the most essential distinctive such as soil stabilization, erosion control, and landscaping slope protection and reinforcement. Coir fibers rot due to the ecological natural cycle. Apart from this, coir fibers are highly water absorbent. Coir has the greatest tearing strength and retains this property in wet conditions, which is cost effective. The coir netting is easy to handle and install. It is a simple process and does not require skilled labour.


6. **Geosynthetics**: Geosynthetic fibers are made of polypropylene, polyethylene, polyamide, and polyester. They have become increasingly popular for use as reinforcement in earth structures in recent years. They are known to be durable and have a long life. They have sufficient strength and the mechanical properties to make them suitable for reinforcement structures.

2.2.1 **Types of Geo-synthetics**

In the words of professor Robert M. Koerner (1986)\(^{70}\) it is defined as “An exciting new concept in engineered materials has emerged for the civil engineering community and the rapidity at which the related products are being developed and used is nothing short of amazing. The geo synthetics have arisen from a relatively minor and specialist products status to a world wide billion dollar industry in a ten years period.” The reasons for this are numerous, the primary ones being that.

- They are sometimes, the only means of construction.
- They can be rapidly installed.
- They are being aggressively marketed.
- They can revitalize the textile industries
- They generally replace scarce raw material resources like steel and cement.
- They are good alternatives to conventional designs.
- They are indeed needed
- Their timing is very appropriate.

The principle types of Geo synthetics are

1. Geo textiles
2. Geo grids
3. Geo nets
1. Geo textiles: They form the largest group of geo-synthetics. They are textiles in the traditional sense, but consist of synthetic fibers rather than natural ones such as cotton, wool or silk. Geo textiles are mainly of two types, woven made up of monofilament, multifilament or tapes or non-woven which are mechanically bonded, heat bonded or resin bonded made of staple fibers or continuous filaments. Geo-textiles are porous to water flow across their manufactured plane and also within their plane, but to a widely varying degree, Geo-textile fabric always perform at least one of five discrete functions.
   1. Separation
   2. Reinforcement
   3. Filtration
   4. Drainage
   5. Moisture barrier.

Non-woven textiles have been extensively used for filtration, separation and drainage functions and also serve as moisture barrier. Woven geotextiles are applied as soil reinforcement for embankments or gravity structures, round seepage barriers and membrane reinforcement as well as cover or support for membrane.

2. Geogrids: This is a small but rapidly growing segment of Geosynthetics area. They are manufactured from selected polymers by extension or by aligning molecular chains of polymers. A geogrid
is a synthetic planar structure formed by a regular network of tensile elements with aperture of sufficient size to allow interlocking with surrounding soil, rock, earth or any other geotechnical material, and is characterized by high dimensional stability and high tensile modulus of elongation. The main functions of geogrids are separation and reinforcement.

3. Geonets: They are usually formed by a continuous extrusion of polymeric ribs at acute angles to one another. When the ribs are opened, relatively large apertures are formed in a netlike configuration. Their design function is completely within the drainage area where they have been used to convey fluids of all types.

4. Geomembranes: Geomembranes represent the second largest group of geo synthetics. The materials are “impervious” thin sheets of rubber or plastic material used primarily for linings and covers of liquid or solid storage facilities. Thus the primary function is always as a liquid or vapour barrier.

5. Geocomposites: A geocomposite consists of a combination of geotextile and geogrid, or geogrid and geomembrane or geotextile, geogrid and geomembrane or any one of these three materials with another material (like deformed plastic sheets, steel cables or steel anchors). The major function encompasses the entire range of functions listed for geo synthetics like separation, reinforcement, filtration, drainage and moisture barrier. The application areas are many and growing steadily.

6. Geostrips: Geo strips are used as soil reinforcement in the form of cut fabric or long strips. They are generally produced from polypropylene and high-density polyethylene. They can be connected with the anchors at the ends. The anchors may be in the
form of loops, rings, or spirals, which may help in confining, soil elements.

7. **Geocells:** Cells made from prefabricated polymeric system are called as Geocells. These systems are made from thick HDPE strips, stitched or welded together at regular intervals. The hexagonal or rhomboidal cells can be made of Geosynthetics honeycomb design. They can be transported to the job site in folded configuration and are unfolded and placed directly on the soil and then filled with soil or concrete materials. The material is compacted inside the cells, when filled with soil, they can be sprayed with emulsified asphalt, when filled with concrete, and they do not need any other treatment except compaction. These Geocells are used for footing foundation roads and canal lining.

8. **Geo-others:** The general area of geo synthetics has exhibited such innovation that many systems define categorization. For want of a better phrase, geo-others describes items such as threaded soil masses, polymeric anchors, and encapsulated soil cells. As with Geocomposites their primary function is product dependent and can be any of the five major functions of Geosynthetics.

### 2.3 RING FOUNDATION:

Foundations of vertical cantilever structures like chimneys, silos, transmission towers etc. and those of heavy tower like structure as water tanks, t. v. antennas are normally circular in plan, even if they are hexagonal or octagonal in plan they are generally analyzed as circular Ring for the purpose of preliminary design. Due to symmetry of loading torsion at the centre between two consecutive supports and at the centre will be zero. Annular plate combined with ring beam is generally used to support number of equally spaced columns or wall. Column give vertical reaction and soil pressure acts as a uniformly distributed load. Ring foundation is a
unique example of annular plate with ring beam. I.S. code [59] deals with the analysis and design of ring foundation. A.K. Singh et. al. (2002) [126] have analyzed the annular plate with ring beam resting on elastic foundation by using finite difference method and put forward a more precise central difference expression for third derivatives based on Taylor’s series. Computer programs have been developed and results have been verified with those obtain by the I.S. code. Analysis of ring foundation by Finite element method was done by A. Varadarajan and R. Ahuja [144].

Ring foundations have not much attracted the attention of research investigators. In the past, attempts to develop analytical solutions for estimating settlements, tilts under reactive pressures using elastic theory was given by Egorov (1965) [38], Brodocheva (1968) [20] and also finite element technique have been made by Milovic (1973) [82], Bowles (1975) [21]. Experimental studies under both axial and eccentric vertical loads have been reported by Haroon & Shah (1983) [55]. Haroon and Misra (1980) [54] have made an effort to obtain an empirical relationship for ultimate bearing capacity of annular footing on sand based on non-dimensional technique. Haroon and Shah [55] have reported a study based on non-dimensional technique and small scale experiments on clay to evaluate ultimate bearing capacity and shape factor of annular footings resting on the surface of clayey soil. The behaviour of ring foundation on very dense cemented sands was examined by plate loading tests at a flat site located in Kiefan, Kuwait by Nabib F. Ismael (1996) [89]. Computer aided analytical solution using finite difference method for a beam resting on elastic foundation was suggested by Singh (2002) [126]. An analysis has been developed for ring footing subjected to eccentric inclined load and resting on sand to predict the pressure ratio $Pr (q/q_o)$ by Swami saran et al. (2003) [137], where $q_o$ is the pressure on the ring footing resting on unreinforced sand bed at a given settlement $S$, and $q$ is the pressure on the same ring footing resting on reinforced sand bed at the same settlement $S$. They have proposed an analytical procedure to predict the pressure-vertical settlement and
pressure-tilt characteristics of ring footings subjected to eccentric-inclined load resting on cohesion less soils, using the non-linear constitutive laws of such soils. Stress-strain characteristics of reinforced soil and their modeling using finite element analysis has been reported by Swamisaran (2004) [139]. Ring footing on clay was reported by Swamisaran and Al-Smadi (2001) [138]. A simple unified procedure has been suggested for studying the interaction behaviour of an axisymmetrically loaded annular slab on idealized soil models in homogeneous isotropic and multilayered isotropic half-space by K. Chandrashekhara and S. Joseph Antony (1997) [27]. Kishida et al. (1987) [69] have studied the effect of a geotextile spread over the open space of a ring foundation, which was fastened to its circular beam. They observed through the experimental study that the ultimate bearing capacity of the reinforced ring foundation was equal to that of the circular plate foundation but the settlement of the reinforced ring foundation was larger than that of the circular plate foundation.

2.4 GEOCELLS:

The geocell reinforcement is a recently developed technique in the field of soil reinforcement. This is a three dimensional, polymeric, honeycomb like structure of cells interconnected at joints. The reinforcement mechanism in the geocells is by all-round confinement of soil within its pockets. Unlike planar reinforcements, the geocell confinement reduces lateral spreading of the in-fill and thereby increases the overall rigidity of the reinforced foundation bed. The geocell layer intercepts the potential failure planes and its rigidity forces them deeper into the foundation soil leading to higher bearing capacity. Raft foundations are widely used in supporting structures for many reasons such as weak soil conditions or heavy column loads. In many cases, some problems arise such as the construction is adjacent to an old building and/or the foundation depth is so great that the excavation needs to be braced during foundation construction. One of the available solutions is to use piles to support the excavation sides during construction. Due to
the difficulty of removing these piles, they become part of the permanent structure and two problems arise. The first problem deals with the structural analysis of the raft if the piles are used as end supports for the raft. The second problem is the effect of these piles on the lateral movement of the soil underneath the raft and the effect of this confinement of the soil underneath the raft and on the bearing capacity of the soil. While there are several solutions for the first problem, such as isolating the raft from the piles, the confining effect of these piles on the raft behaviour is not clearly understood. Looking to the problem in a smaller scale, it can be modeled as a circular footing supported on a soil which is surrounded by confining cylinder. Sujit Kumar Dash et. al (2001) [31] presented the results of laboratory – model tests on a strip footing supported by a sand bed reinforced with a geocell mattress. According their study with the provision of geocell reinforcement, failure was not observed even at a settlement equal to 50% of the footing width and a load as high as 8 times the ultimate bearing capacity of the unreinforced sand. The strength of confined sand was studied by Rajgopal et al. (1999) [103]. They have carried out a large number of triaxial compression tests to study the influence of geocell confinement on the strength and stiffness behaviour of granular soils. Several investigators have reported significant effects of soil confinement by using horizontal soil reinforcement to increase the bearing capacity of supporting soils. This was achieved by placing layers of geogrid at different depths and widths under the footing. The use of vertical reinforcement along with horizontal reinforcement was investigated as well by Dash et al. in 2001 [33]. They performed an experimental study on the bearing capacity of a strip footing supported by a sand bed reinforced with a geocell mattress. Critical dimensions of reinforcement and depth of placement for mobilizing maximum bearing capacity improvement were presented. Finite element analysis of strip footing supported on geocell reinforced sand beds has been reported by Madhavi Latha (2001) [72]. M. El Sawwaf and A. Nazer in 2005 [76] reported the results of laboratory model tests on the influence of soil confinement on the behaviour of a
model footing resting on granular soil. Confining cylinders with different heights and diameters were used to confine the sand. They concluded that

- The soil confinement has a significant effect on improving the behaviour of circular footing supported on granular soil. The ultimate capacity was found to increase by a factor of 17 as compared to the unreinforced case.
- Based on the experimental results, soil confinement could be considered as a method to improve the bearing capacity of isolated footings bearing on medium to dense sand.
- In case where structures are very sensitive to settlement, soil confinement can be used to obtain the same allowable bearing capacity at a much lower settlement.
- For large diameter confining cells relative to footing size, the cell-sand-footing system behaves as a one unit but as the failure approaches, the footing only settles while the cell seems to be unaffected.
- For small diameters of confining cells relative to footing size the cell-sand-footing system behaves as a deep foundation and the failure occurs as a shear failure in the soil surrounding the cell.
- Increasing the height of the confining cell, resulted increase in the surface area of the cell-model footing which transferred footing loads to deeper depths and lead to improve the bearing capacity ratio.

2.5 SHALLOW FOUNDATIONS:

Footings are a common type of foundation for engineered structures. Bearing capacity, settlement and base contact pressure is required for the complete analysis and design of foundations subjected to central vertical load. Foundations laid at depths smaller than their width are classified as shallow. They can be square, rectangular, circular, trapezoidal or another shape. They are also referred to as strip foundations or isolated footings. The design and
construction of a foundation requires sound knowledge of the principle of structural and soil mechanics. Structural considerations require that the foundation should be safe against the shear forces and moments induced by the loads on the structure. All possible load combinations should be considered: dead load, live loads, winds, earthquakes or any other. Shear forces and moments at the most critical sections must also be evaluated. The structural design of footings is available in most textbooks on R.C.C. construction. The soil mechanics concerns general requirement of stability and depth, to make the foundation safe against bearing – capacity failure, and to keep settlement within permissible limits.

2.5.1 BEARING CAPACITY:

The ultimate bearing capacity \( q_u \) of a soil is the intensity of loading on the foundation which would cause shear failure of the soil.

The safe bearing capacity \( q_s \) is obtained by dividing the ultimate bearing capacity by a suitable factor of safety. This factor varies from 2 to 3, the higher values being used for more important structures.

The allowable bearing pressure \( q_a \) is the intensity of loading at which footing settlement does not exceed permissible limits.

The term net or effective bearing capacity \( q_{net} \) takes into account the weight of the soil removed before placing the foundation.

Thus \( q_{net} = q_u - \gamma D_f \)

Where, \( D_f \) is the depth of foundation below existing ground level. Terzaghi studied the case of a long, continuous strip footing resting on a homogeneous soil having shear-strength parameters \( c \) and \( \phi \) as given by the Mohr-Coulomb criteria. Then after other theories were also developed by Skempton, Vesic, Meyerhof and others [67], [99]. In classical bearing capacity theories, the bearing capacity of footings on the surface of dry sand deposits is expressed as
\[ q_u = 0.5 \gamma B N_y S_y, \]

Where, \( \gamma \) is the unit weight of soil; \( B \) represents the width of a rectangular footing, or diameter of a circular footing; \( N_y \) is a bearing capacity factor; and \( S_y \) is shape factor. Well-known formulas for \( N_y \) proposed by Terzaghi (1943), Mayerhof (1963), and Hansen (1970) are all functions of soil friction angle. Both \( N_y \) and \( S_y \) depend on footing size. Experimental data collected by De Beer (1965) have shown that the bearing capacity factor \( N_y \) decreases with foundation size. Recent results of tests reported by Fanyu Zhu et.al. (2001) in a large centrifuge indicated that the bearing capacity increases exponentially with foundation size. In order to determine the values of the shape factors to be introduced in the formula of ultimate bearing capacity of shallow foundations, an extensive series of tests on small footings on fine sand was performed by E.E. de Beer [13]. They reported that the shape factor \( S_y \) in the weight term is independent of the angle of friction, while \( S_q \) and \( S_c \) are not. A new concept for the calculation of the bearing capacity of shallow foundations was presented by Eugen W. Perau in 1997 [40]. In their study, The Terzaghi-Buisman equation was transformed and extended to include all possible load cases. The shape ratio was rigorously defined. Torsional moment factors considering eccentric horizontal loads were proposed and defined for the first time in order that complete 6-dimensional interaction diagrams could be derived. An equation has been formulated based on the classical Terzaghi-Buisman equation taking all possible load combinations into account. They have reported a complete calculation scheme for all possible load combinations. The classical solution to the bearing capacity problem predicts the limit load on symmetrically loaded shallow strip footings. A useful hypothesis was suggested by Mayerhof to account for eccentricity of loading, in which the footing width was reduced by twice-the-eccentricity to its 'effective' size. This hypothesis sometimes has been criticized as being overly conservative. Radoslaw L. Michalowski and Liangzhi [101] have examined Mayerhof's suggestion and presented the bearing
capacity of eccentrically loaded footings calculated using the kinematics approach of limit analysis. It was found that the effective width rule yields a bearing capacity equivalent to that calculated based on the assumption that the footing is smooth. A novel analysis was proposed by Shamsher Prakash et al. (1984) \[120\], to predict the pressure settlement characteristics of footings, using the hyperbolic stress-strain curves of soils as the constitutive law. A method for predicting the settlement of foundations on sand operating under typical working loads has been reported by Barry Lehane and Martin Fahey (2002) \[12\]. The method account for the well known effects on soil stiffness of strain, stress level, and density dependence, but adopts the simplifying assumption that the stress distribution beneath a loaded foundation can be obtained from Boussinesq’s equations for an elastic half space. J.G. Sieffert and Ch. Bay-Gress (2000) \[124\] have compared the methods used by the European countries to evaluate the bearing capacity of shallow foundations. Comparisons of several formulations of bearing capacity factors, depth and shape factors, load inclination and eccentricity factors, as well as values of those factors were presented. The important conclusion was that the calculated bearing capacity depends highly on the country. Therefore, the bearing capacity needs to be better understood using parametric and numerical analysis.

2.5.2 SHALLOW FOUNDATIONS ON REINFORCED EARTH:

Reinforced soil bed is a soil foundation containing horizontally embedded reinforcements. The reinforcements restrain the lateral deformation of the soil through friction by increasing lateral confinement. The improvement in the bearing capacity and settlement of isolated footings on sand bed after being reinforced with different materials has been the subject of a number of investigators. Reinforced Earth is a composite construction material in which the strength of engineering fill is enhanced by the addition of strong inextensible tensile reinforcement. The basic mechanism of Reinforced Earth involves the
generation of frictional forces between the soil and the reinforcement. These forces are manifested in the soil in a form analogous to an increased confining pressure which enhances the strength of the composite. Additionally the reinforcement has the ability to unify a mass of soil that would otherwise part along a failure surface. Reinforced Earth is potentially a very versatile material. Foundations have been arbitrarily differentiated from slabs by the fact that they are intended to support loaded areas that are small in comparison to the reinforced plan area. In comparison to reinforced walls very little research, and even less construction, has been carried out. The reinforced earth is one such technique which has drawn the attention of many researchers and field engineers, because of its overall economy and ease of construction, coupled with simplicity, technique over the past two decades. Subsequently several researchers have reported the beneficial effects of soil reinforcement on the performance improvement of shallow foundations. It is the pioneering work of Binquet and Lee (1975) that marked the beginning of systematic study in the field of reinforced earth beds. Subsequently several researchers have reported the beneficial effects of soil reinforcement on the performance improvement of shallow foundations (Akinmusuru and Akinbolade, 1981; Fragaszy and Lawton, 1984; Guido et al., 1986; Huang and Tatsuoka, 1990; Khing et al., 1992). In most of these studies, geotextiles, metals, or fibres were used as reinforcement. Guido et al. (1986) conducted laboratory model studies on both geotextile and geogrid soil foundations, and showed clearly that the geogrid reinforcement was more effective than the geotextile from the standpoint of improving the bearing capacity of footings on reinforced sand. Reinforcement placed within the tensile arc of the strain field causes realignment of the strain field which improves performance in both stiffness and load carrying capacity. Reinforcement when introduced into soil and aligned with the tensile strain arc disturbs the uniform pattern of strain that would develop if the reinforcement did no exist. The reinforcement also inhibits the formation of continuous rupture surface through the soil, with the result that
the soil exhibits an improved stiffness and strength. Fig. 2.1 shows the failure pattern of reinforced soil below the foundation.

![Diagram of reinforced soil bed]  

**Fig. 2.1 Modes of failure of reinforced soil bed below foundation.**  
*(Binquet and Lee, 1975)*

Binquet and Lee (1975) \(^{17,18}\) concluded laboratory tests on strip footing resting on sand bed reinforced by strips of aluminum foil. They reported that the optimum number of reinforcing layers (N) varies between 6 and 8. They have proposed a method of analysis for the two-dimensional plane-strain case of reinforced soil bed below strip footings. This elastic analysis, with several simplifying assumptions, was based on superposition of components of load carried by soil and reinforcements. Similar conclusion was reported by Sreekantiah (1990)\(^{130}\) who stated that the bearing capacity ratio BCR = Bearing capacity of reinforced soil / Bearing capacity of non-reinforced soil, increases with increasing the number of reinforcing layers up to N=7. On the other hand, Akimusuru et. al. (1981)\(^{3}\) tested square footing placed on homogeneous sand bed reinforced with flat strips of rope.
fiber. Their result showed a sharp increase in the bearing capacity when the reinforcing layers increased from 2 to 3. Guido et al. (1986) [52] carried out experimental work on square footing using geogrids and geotextiles as reinforcement for sand bed. They reported that the bearing capacity ratio (BCR) increased with the increase in the number of reinforcing layers up to and optimum number of (N=3) after which not much benefit was observed. Al-Ashou et al. (1994) [6] have studied the effect of number of reinforcing layers on the interference between footings on reinforced sand bed and concluded that the bearing capacity of isolated and adjacent footings increased with increase in the layers of the reinforcement for strips and square footings. The punching shear failure of reinforced sand bed under strip footing caused sharp bent in the reinforcing strips especially under the center of the footing. Sridharan B.R. et al (1988) [132] reported the shape and size effects of the foundations on the bearing capacity of unreinforced as well as reinforced soil beds. Some important conclusions they have made based on the experimental investigation that the shape of the footing does not affect the behaviour of reinforced sand bed unlike in the case of unreinforced condition. H.B. Raghvendra (2004) [102] reported the effect of properties and length of reinforcement on load-carrying capacity of reinforced soil beds. Sitaram T.G. and Sirish (2004) [128] described laboratory model tests to determine the bearing capacity of multiple layers of geogrid reinforced sand beds. According to their study with provision of geogrid layers in a sand bed as reinforcement, high-performance improvement is achieved in terms of increase in bearing capacity and reduction in surface heaving. As the embedment depth increases, the load-carrying capacity of the foundation increases both with and without reinforcement. With the provision of geogrid reinforcement, the pressure transmitted to the subgrade soil reduced enormously. The footing pressure was redistributed over a wider area at the corresponding embedment depth of the footing along with the provision of geogrid reinforcement & with the increase in the depth of embedment. For any embedment depth of the circular footing, the
critical depth of reinforcement for deriving maximum benefit in terms of increase in bearing capacity from geogrid reinforcement was about 2.0 which correspond to a maximum of five geogrid layers with spacing of 0.4d. Srinivasa Murthy et.al. (1993) have suggested improved method of analysis of reinforced soil. They have modified the assumptions for the analysis of reinforced soil beds over those of Binquet and Lee as follows:

1. The total load carried by the footing on a reinforced soil bed will have components in the form:
   - Load transferred through the soil directly, $P_s$ and
   - Load transferred through reinforcements, $P_r$
   - i.e. $P = P_s + P_r$ where $P$ is the total load.

2. The component of load directly transferred through the soil $P_s$ alone causes settlement of the footing.

3. The boundary between the downward and outward moving zones is the vertical plane passing through the edge of the footing.

4. With the application of the load, right angle kinks are formed in the reinforcement along the potential slip plane, which transmit the tension in the reinforcement as vertical force to resist the applied load.

5. Elastic theory is applied to estimate the stress distribution inside the soil mass.

6. Failure can occur in either of the modes of friction or tie, however it is assumed that the friction failure is critical for the evaluation of the mobilized tension in the reinforcement.

B. Day in 2002 has suggested modifications in design curves for bearing capacity of reinforced foundation bed given by Binquet and Lee. Schlosser et.al. (1983) first suggested a failure mechanism, in horizontally reinforced ground loaded by a footing, based on the concept of ‘deep footing’ and ‘wide-slab’, as schematically shown in Fig. 2.2.
The ultimate bearing capacity of a reinforced sandy ground, \( q_u(\text{reinforced}) \), is expressed as follows:

\[
q_u(\text{reinforced}) = n \cdot (B + \Delta B) \cdot \gamma \cdot N_y + \gamma \cdot D_R \cdot N_q
\]

\[
= q_u(\text{DR}>0) + q_u(\text{slab})
\]

in which,

\[
q_u(\text{DR}>0) = q_u(\text{DR}=0) + \gamma \cdot D_R \cdot N_q
\]

\[
q_u(\text{DR}=0) = n \cdot B \cdot \gamma \cdot N_y
\]

\[
q_u(\text{slab}) = n \cdot \Delta B \cdot \gamma \cdot N_y
\]

- \( q_u(\text{DR}>0), q_u(\text{slab}) \): the bearing capacity components generated by deep footing and wide slab mechanisms, respectively.
- \( q_u(\text{DR}=0) \): ultimate bearing capacity of surface footing on unreinforced ground
- \( N_y, N_q \): the bearing capacity factors for the self weight and the overburden stress at the level of footing base, respectively.
- \( D_R, B, \Delta B \): the depth of reinforcement, the width of footing, and the increase of the width of footing due to the wide-slab effect, respectively (Fig. 2.2).
- \( n \): shape factor.
- \( \gamma \): unit weight of soil.

The bearing capacity ratio for reinforced ground, \( BCR_R \), is:

\[
BCR_R = \frac{q_u(\text{reinforced})}{q_u(D_R=0)}
\]

\[
= \frac{q_u(\text{DR}>0)}{q_u(D_R=0)} + \frac{q_u(\text{slab})}{q_u(D_R=0)}
\]

\[
= BCR_D + BCR_S
\]
in which,

$\text{BCR}_D$: a component of bearing capacity ratio generated by the deep-footing effect

$\text{BCR}_S$: a component of bearing capacity ratio generated by the wide-slab effect.

**Fig. 2.2 Schematic view of failure mechanism of reinforced sandy ground**

Huang and Hong [56] in 2000 have also used the deep footing and wide slab mechanism for predicting bearing capacity increase in reinforced sandy ground which was examined using tests performed under various test conditions. Mahmoud and Abdrabbo (1989) [78] have given a technical note based on an experimental study concerning a method of improving the bearing capacity of strip footing resting on sand subgrades utilizing vertical non-extensible reinforcement. The test results indicated that the reinforcement increases the bearing capacity of subgrades and modifies the load-displacement behaviour of the footing. B.M. Das et. al. (1998) [29] have reported laboratory model test results for the settlement of a square surface foundation supported by geogrid-reinforced sand bed and subjected
to transient load. They have concluded that geogrid reinforcement reduces the settlement due to transient loading. Omar et.al. (1993) [93] reported laboratory model test results for the ultimate bearing capacity of strip and square foundations supported by sand bed reinforced with geogrid layers. Using a simplified model, the load-settlement behaviour of a geosynthetic-reinforced soil was formulated by Toyoaki et. al.(2003) [141]. The model and foundations which they have suggested were flexible to accommodate non-homogeneity of the medium and multiple reinforcement layers with no or very less extra computational effort. Brown and Poulos (1981) [24] demonstrated how a finite element model of a reinforced earth can be used to investigate the increase in bearing capacity and stiffness of a foundation due to the placement of reinforcement in the soil. A variational method is applied to determine the bearing capacity of geosynthetic-reinforced soil by R.K. Dixit and J.N.Mandal (1993) [37]. In that method, the shape of the failure surface and the distribution of the normal stress over it were determined by the use of minimizing theorems of variational calculus. Results of the variational method were compared with the experimental results of other investigators. According to the analysis, the shape of the critical rupture surface was a log spiral. The shape of the critical rupture surface depends on both cohesion and angle of internal friction. The approach is valid only for shallow reinforcement. The bearing capacity increases significantly with the introduction of reinforcement. In finite element analysis, using discrete model of representation of reinforced soil system, the friction characteristics between the soil mass and a finite length of reinforcement can be modeled by introducing an interface element of zero thickness or thin layer elements of finite thickness. Several non-linear elastic models, such as bilinear model, K-G model, hyperbolic model, spline function model etc. are available. Swami saran et.al. (2004) [139] have suggested a suitable mathematical model for soil and reinforced soil bed as composite material in a polynomial form, which can be conveniently incorporated in the finite element algorithm. The soil-structure interface, developed under monotonic loading, was modeled based on physical
observations by Morched Zeghal and Tuncer B. Edil (2002) \cite{85}. The model incorporated the effect of grain crushing found to play a major role in the behaviour of the interface. Analysis of laboratory data revealed a close relationship between grain crushing and the work dissipated plastically during shear. Failure mechanisms of both unreinforced and reinforced foundations were shown by the results of the microscopic observation of model ground simulation by aluminum rods \cite{64}. Based on those failure mechanisms, a simplified upper-bound mechanism was proposed by Kentaro Yamamoto and Koji Kusuda (2001) \cite{65}. N.Kumar Pitchumani and M.R.Madhav (2000) \cite{88} have proposed a method to predict the reduction in surface settlements due to strip form of reinforcements placed beneath a rectangular loaded area. The elastic continuum approach was adopted to solve the problem and the shear interaction of reinforcing strips was considered. Since the outward lateral movement of the soil at the strip-soil interface was prevented by the mobilization of shear stresses at the interface, these stresses were directed inward, towards the centre of the strip. These stresses in turn introduce tension in the strip. The net result of these mobilized stresses was to push the soil on the surface upward near the centre of the loaded area. Consequently, there was a reduction in settlements of points along the surface. Thus the reinforcing strip helped in reducing foundation settlement. A rigid-plastic finite element analysis considering the effect of geometrical nonlinearity was been conducted by Kentaro Yamamoto and Jun Otani \cite{66} to quantitatively investigate both the increase of calculated bearing capacity and the progress in deformation localization corresponding to the settlement of a loading plate. Based on the comparative study between the test results and the numerical analysis, it was concluded that the proposed numerical method was capable of investigation quantity not only the bearing capacity but also the failure mechanism.
2.5.3 SHALLOW FOUNDATIONS UNDER CYCLIC/DYNAMIC LOADING:

Depending on the type of superstructure and the type of loading, a shallow foundation may be subjected to dynamic loading. The dynamic loading may be of various types, such as

- Monotonic loading with varying velocities;
- Earthquake loading;
- Cyclic loading; and
- Transient loading.

The ultimate bearing capacity and settlement of shallow foundations subjected to cyclic loading has been studied in the present work. Conventional considerations of the bearing capacity and the allowable settlement are not sufficient for the design of foundation subjected to dynamic loads. Resonance condition results in excessive displacement amplitude of the foundation, which is detrimental to the supporting structure. Hence, the determination of natural frequency is of prime importance to a designer when design is concerned with machine foundation. Baidya and Murali (2000) [11] reported the effect of stratum thickness on the dynamic response of foundation soil system based on the experimental study. Analysis of the soil-structure interaction is of major interest in geomechanics. It covers a wide range of problems such as those raised by the calculation of piles, shallow foundations, retaining walls, tunnels, embankments and reinforced earthworks. For structures submitted to repetitive loading like those resulting from earthquake, ocean waves, moving traffic and machine induced vibration, it is important to clearly describe the behaviour of the soil-structure interface under cyclic loading. Shahrour (1997) [117] reported a presentation of monotonic and cyclic tests performed with smooth and rough surfaces on loose and dense sands. These tests showed some important aspects of the behaviour of the interface that the cyclic shearing at constant normal stress induces softening (decrease of the resistance) in the case of dense sand and hardening in case of loose sand, the
interface exhibits a contracting behaviour after each stress-reversal followed by dilatancy. Cyclic shearing under a zero normal displacement induces an important decrease of the normal stress and consequently a drop of the mobilized shear stress. Then an elasto-plastic constitutive relation based on the concept of the bounding surface with only two families of surfaces has been developed. A rheological model was proposed by Mark Levinson et. al. (1975) [80], for soil-structure interaction under cyclic loading. Real modulus of elasticity of the soil usually increases with the depth of the soil due to the increase in overburden pressure. Therefore, incorporation of the effect of the soil non-homogeneity in the formulation to obtain the response of the machine foundations is an important step. Mehmet (1999) [81] developed equations that govern the dynamic behaviour of the machine foundations and considered the non-homogeneity of the elastic foundation, particularly for Gibson type soil were derived by using variational principles. Reinforced soil beds exhibit an improvement in strength and deformation characteristics under monotonic loading conditions, due to additional pseudo confinement caused by the lateral restraint and shear stress mobilization along the soil-inclusion interface. The influence of the lateral restraint on the cyclic behaviour of the soil was investigated by Alaa K. Ashnawy et. al. [4] (1999). They have studied the influence of loading level, geotextile type, reinforcement spacing and specimen diameter. Cyclic triaxial tests were performed on geotextile reinforced partially saturated clayey silt specimens to investigate the response of the material to repeated loading. The experimental results indicated that the inclusion of equally spaced geotextile layers within the triaxial specimens resulted in a significant reduction in cumulative permanent strain. The seismic bearing capacity factors of shallow strip footings were calculated by Soubra (1997) [129]. The approach used in his study was pseudo-static, where the seismic effects were considered by taking into account static inertia forces. An analysis of settlements of cyclically loaded shallow foundations on air dry, non-cohesive compacted subsoil was reported by Andrezej Sawidk et. al.(1998) [9]. The starting point of the
study was the results of experimental tests performed on a model foundation. It was assumed that the settlements were caused mainly by an oedometric compaction which takes place in a small zone beneath the foundation. The range of the compaction zone was estimated on the basis of some empirical observations. A paper has been published by N.M Patel and M. Paldas (1983) [96] on cyclic load tests on the reinforced foundation sand beds.

In order to develop an improved understanding of the behaviour of cohesionless soils under dynamic loading conditions, the dynamic stress-strain properties of sand represented by values of modulus and damping were investigated by Marshall L. Silver and H. Bolton (1971) [125]. The dynamic properties of medium quartz sand were determined by cyclic loading simple shear tests which provide a good representation of the shear conditions imposed on a soil element during many seismic events. The dynamic shear modulus was found to increase slightly with increase in numbers of cycles and with increasing relative density and to decrease significantly with increasing values of shear strain amplitude. The decrease in shear modulus with number of stress was greatest in the first 10 cycles after which changes in modulus were relatively small. They have determined values of hysteretic damping and it was found to increase with increasing shear strain amplitude & to decrease slightly with increasing numbers of cycles and increasing values of vertical stress. It was also found that the relationship between damping and shear strain was essentially independent of the relative density of the sand. A laboratory study was conducted to investigate the dynamic behaviour of Champlain Sea clay from two locations in the Ottawa River valley region by Y.L.Cao and K.T. Law (1992) [26]. An energy concept was introduced to interpret the test results. Mathematical relationships were established for describing the various aspects of dynamic behaviour. The study showed that the energy concept provides a promising way to analyze dynamic soil behaviour. A technical note presented by A. Sridharan and M.V. Nagendra (1981) [131] on the statistical analysis carried out on some of the available experimental results to
predict the resonant frequency and maximum displacement amplitude of a machine foundation-soil system under vertical vibration as a function of the size and weight of the foundation and of the excitation level. Upper bound solution for static and seismic bearing capacity problem of shallow strip footings was investigated by Abdul-Hamid Soubra (1999) [1].