EFFECT OF GEOTEXTILE ON BEARING CAPACITY OF SHALLOW FOOTING

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Submitted by:
PRIYA VAID
(ROLL NO. 801523009)

UNDER THE SUPERVISION OF

RAJESH PATHAK
Associate Professor
Deptt. of Civil Engineering
Thapar University, Patiala

DEPARTMENT OF CIVIL ENGINEERING
THAPAR UNIVERSITY,
PATIALA-147004
JULY 2017

DECLARATION

I, Priya Vaid, hereby declare that this thesis entitled **"Effect of geotextile on bearing capacity of shallow footing"** is an authentic record of my study carried out as requirements for the award of degree of **Master of Engineering** in **Infrastructure Engineering** in the Civil Engineering Department, Thapar University, Patiala under the supervision of **Mr. Rajesh Pathak, Associate Professor,** Department of Civil Engineering, Thapar University, Patiala during July 2015 to July 2017. This matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

Date: 15/07/2017

(Priya Vaid)

Roll No. :801523009

CERTIFICATE

This is to certify that above statement made by the student concerned is correct and true to the best of my knowledge and belief.

Mr. Rajesh Pathak

Associate Professor

Department of Civil Engineering

Thapar University, Patiala

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Priya Vaid
(801523009)

ABSTRACT

The study was done to investigate the performance of reinforced soil foundation. The construction of reinforced soil foundation has a cost effective alternative to conventional methods. Performance characteristics were improved by using one or more layers of non-woven geotextile placed beneath the footing to create a composite material. The reinforcement in the soil interacts with the soil and is resisted by friction, adhesion or passive / bearing capacity. Experimental investigation has been carried out to study the behaviour of non-woven geotextile embedded in sand. In order to achieve this aim, many calibration tests and conventional tests such as specific gravity, grain size distribution, direct shear test, rain-fall method for deposition of sand, plate load test have been performed. The sand was deposited at a relative density of 62% and the plate load test have been conducted on the footings of different sizes and shapes (square, rectangle and strip) for $u/B=0.5$, $h_1/B=0.5$ and $h_2/B=0.5$, where B is the width of the footing, u is the first depth of geotextile from the base of the footing, h_1 is the second depth of geotextile from base of the first layer of geotextile, h_2 is the third depth of geotextile from base of the second layer of geotextile. Load carrying capacity and pressure-settlement characteristics of sand with and without geotextile have been studied in each test. From the overall study, it can be concluded that the BCR value for smaller size footings were found greater than the larger size footings. The ultimate bearing capacity values of nonwoven geotextile-reinforced sand are more than the unreinforced ones in all the cases.

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CHAPTER-1

INTRODUCTION

1.1 REINFORCED SOIL

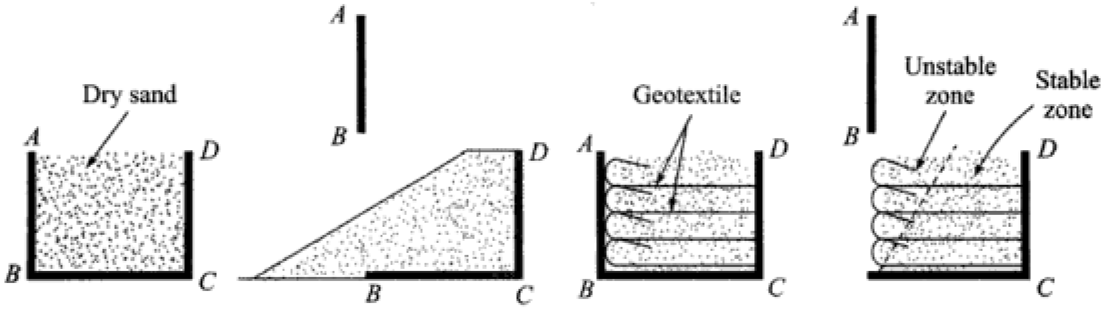
When innovative engineers developed reinforced concrete, the utility of concrete was significantly enhanced. The material properties of the concrete make it resistant to compressive stress and cannot withstand tensile stresses and are reinforced with reinforcing bars to remove the defect. The material characteristics of soil can also use reinforcement. The term "reinforced soil" refers to a soil that is reinforced by placing reinforcing material in the soil in the form of a strip, bars, sheets or grids (meshes). When load is applied to the soil, these materials resist the tensile stresses generated in the soil in a manner similar to that in concrete reinforcement. However, there are some differences between soil reinforcement and concrete reinforcement, namely:

i. The reinforcement in the soil interacts with the soil and is resisted by friction, adhesion or passive / bearing capacity, while the reinforcement in the concrete interacts with the concrete through cement bonding,
ii. The reinforcement in the soil may be a metal (e.g., a steel strip) or a non-metallic (e.g., geotextile), and the reinforcement in the concrete is usually a metal (steel bar).
iii. Reinforcement in the soil is not to withstand compressive stress, but reinforcement in concrete can always be done.

The reinforcing elements may be installed in the soil in two ways, one by placing them in the horizontal layer during the filling operation at a preset pitch, and the other means for inserting the reinforcing elements into the existing pattern according to a predetermined pattern soil.

To understand the mechanism of reinforcement to improve soil performance, we look at two laboratory-scale experiments. In the first case, the tank ABCD as shown in Fig. 1.1 (a) is filled with dry sand. When we remove the side AB of the container, the vertical surface of the sand cannot remain stable, and the soil is rearranged as an inclined surface as shown in Figure 1.1 (b). We now repeat the above experiment by using geotextile material as a reinforcement in the soil. Geotextile is a soft material, similar to a strong or thick cloth. When the sand is filled in the tank, the material is placed in the horizontal layer and folded at the end as shown in Fig. 1.1 (c). After the tank is loaded into the top, when we remove the AB side, the vertical surface of the sand does not collapse. We may observe some uplift, but the face remains vertical and stable. This is because the geotextile reinforcement prevents movement when the soil particles in the destruction zone begin to move. The reason for this happens when the length of each layer of the geotextile reinforcement layer is found to be buried in a non-moving soil. Figure 1.1 (d). When the soil quality of the unstable (failure) area begins to move, it is attempted to reinforce the geotextile.

However, the movement of the geotextile can be prevented by stabilizing the area of the soil, thereby firmly grasping the reinforcement and not allowing it to be pulled out. This ensures that soil pain in the faulty area cannot move because they cannot slip through the reinforcement. As a result, the reinforcement of the entire soil remains stable. The effect of reinforcement is to keep the soil quality together, as if some "obvious confining pressure" acts on the periphery of the soil, or seems to develop some "obvious cohesion" or "apparent tensile strength" in the soil.



(a) (b) (c) (d)

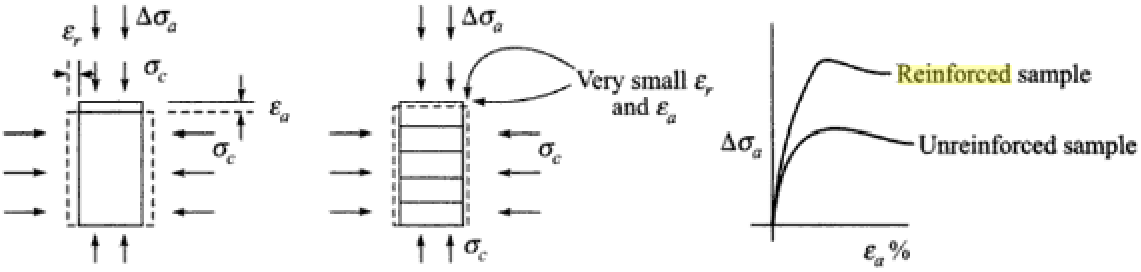
Tank filled with sand Side AB removed Tank filled with Side AB removed

Sand and reinforcement

Figure 1.1: Influence of reinforcement on vertical face of sands (Manoj Datta, Shashi K Gulhati).

We are now conducting another experiment in which we will examine when we take two medium-density sand samples, one reinforced sample, and the other is not reinforced and is carried out in a three-axis apparatus under consolidated drainage conditions test. The bars were introduced into a soil sample in the form of four sheets of thin aluminum foil placed horizontally in the sample. These tests can make two important observations:

i. During the shear phase, the enhanced sample exhibits lower radial and axial strain compared to the unreinforced sample before failure, compared to the corresponding deviator stress as shown in figure 1.2 (a) and (b), and
ii. At failure, the deviator stress of the enhanced sample is significantly larger than that of the unreinforced specimen, indicating that the shear strength of the former is higher, as shown in figure 1.2 (c).



(a) Unreinforced sample

(b) Reinforced sample

(c) Axial stress v/s Axial strain

Figure 1.2: Triaxial tests on samples of reinforced sand and not reinforced sand (Manoj Datta, Shashi K Gulhati).

The above two observations again emphasize that the stiffening element opposes the lateral expansion of the sample and also counteracts the soil damage caused by the development of its internal tensile stresses and the frictional resistance against soil particle motion. Failure occurs only when the bar is broken or when the soil slides on the bar.

1.2 GEOSYNTHETICS

When a geotechnical engineer encounters an unsatisfactory soil condition at the scene, he / she can choose to increase the soil density, mix the soil with the additive, enhance the soil or replace the soil. Some of these processes use materials belonging to a group of materials called geosynthetics. Geosynthetics are man-made products. They are flexible and planar (sheet-like) and are made of synthetic polymeric material, sometimes made of natural material. They are man-made fabrics that are integrated with the soil to stabilize the terrain.

1.3 CATEGORIES OF GEOSYNTHETICS:

1. Geotextiles (Nonwoven, Woven)
2. Geogrid (Bonded, Extruded, Knitted, Woven)
3. Geomembrane (Bituminous, Elastomeric, Plastomeric)
4. Geonets
5. Geocomposites
6. Geosynthesis clay liners
7. Geofoams

Geotextile:

Geotextiles are permeable textile material provided for erosion control, increasing soil stability or auxiliary drainage. The application of geotextiles were basically to mix natural fibers or vegetation directly with soil. Modern geotextiles are usually made of synthetic polymers such as polypropylene, polyester, polyethylene and polyamide. Woven, knitted or nonwoven are the general types of geotextiles.

Non-woven geotextile:

The nonwoven fabric geotextile is made of 100% staple fiber polyester and polypropylene acupuncture filter fabric. They have excellent water flow rates and drainage to filter soil fines. Nonwoven geotextiles have a variety of uses, some of which include grooved drains and wrapped perforated tubes to prevent erosion and combine with geomembranes to provide protective cushioning.

Other uses include road reinforcement, filtration, and separation of roads, roofs, tunnels, ponds, ditches, landfills, coastline and membrane liners, grading stability, erosion control, and many other civil engineering and building applications. The product is resistant to tearing, puncturing, soil chemicals, UV, mildew and freeze-thaw. Figure 1.3 shows the pictorial representation of non-woven geotextile.

Figure 1.3: Pictorial representation of non-woven geotextile.

Woven geotextile:

The woven geotextiles are made by simply brazing a pre-stressed, non-biodegradable cracked polypropylene tape into a simple weave pattern, primarily for sub-gradient stability requiring considerable strength. This weaving geotextile product is economical and provides the required high strength at a very low cost. Manufactured woven geotextiles have high resistance to gravity, UV resistance, soil chemicals, mildew and insects. The slit braided geotextile is an excellent partition that helps to speed up the installation of road construction projects and embankment construction as it increases the life of paved and unpaved areas. Woven geotextiles are mainly used for separation, enhancement and filtration. Figure 1.4 shows the pictorial representation of woven geotextile.

Figure 1.4: Pictorial representation of woven geotextile (www.tradeindia.com).

Geogrids:

Geogrid is used to reinforce soil and similar materials of geosynthetics. Geogrids are usually used to reinforce the retaining wall, as well as the base or subsoil beneath the road or structure. The soil is separated in a tense situation. Compared with the soil, geogrid tension. This fact allows them to transfer power to a larger soil area than otherwise. Geogrids are usually made of polymeric material, such as polyester, polyvinyl alcohol, polyethylene or polypropylene. They may be knitted or knitted by yarn, heat welded by the strip of material, or by the holes of the regular pattern in the sheet of stamping material, and then stretched into a grid. Figure 1.5 shows the pictorial representation of geogrid.

Figure 1.5: Pictorial representation of geogrid (www.tensarcorp.com).

Geomembrane:

The geomembrane is a very low-permeability synthetic membrane liner or obstruction that is used with any geotechnical-related material to control fluid (or gas) migration in an artificial project, structure, or system. The geomembrane is made of relatively thin continuous polymer sheet, but it can also be impregnated with asphalt, elastomer or polymer spray, or as a multi-layer asphalt composite. Continuous polymer sheet geomembrane is by far the most common. Figure 1.6 shows the pictorial representation of geomembrane.

Figure 1.6: Pictorial representation of geomembrane (www.geoworld.ir).

Geonets:

Geonets and some related geospacers form another area of expertise in the geotextile field. They are formed at an acute angle by successively extruding the parallel polymer ribs. When the ribs are opened, the relatively large pores form a mesh structure. The two most common are biaxial or trihedral or different types of drain cores can be used. They generally consists of rough, irregular or sheets of polymer, three-dimensional rigid polymer fibers of different structures, and small drains or geotextiles with spacers. They are designed to function completely in the drainage area for the transport of various types of liquids or gases. Figure 1.7 shows the pictorial representation of geonet.

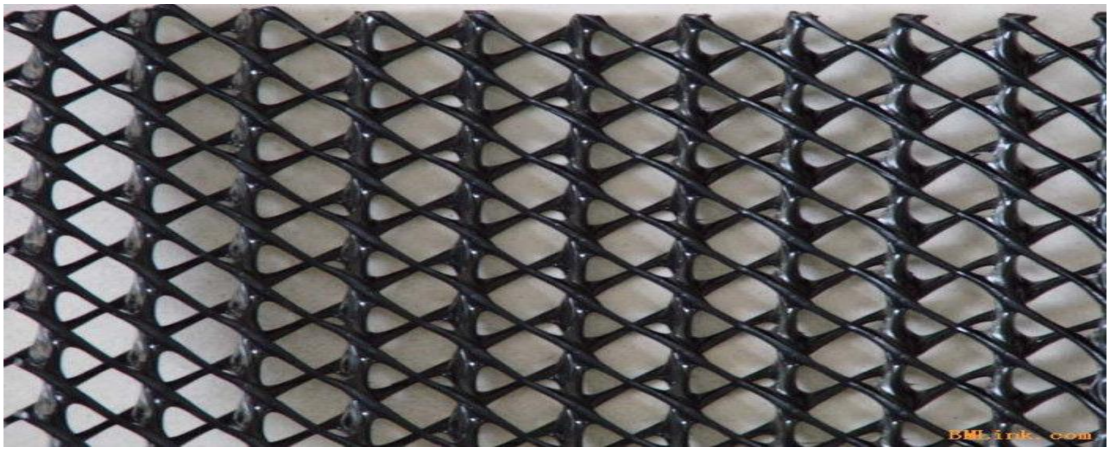


Figure 1.7: Pictorial representation of geonet (www.geotextile-fabric.com).

Geocomposites:

Geological composites consist of geotextiles, geogrids, geologic and / or geomembranes composed of factory-made units. In addition, these materials may be combined with another synthetic material (e.g., a deformed plastic sheet or cable) or even with soil. As an example, geologists or geographers who have geotextiles on both surfaces and GCL composed of geotextiles / bentonite / geotextile sandwiches are geocomposites. The main functions include the full functionality of the previously discussed geosynthetics: separation, enhancement, filtration, drainage and containment. Figure 1.8 shows the pictorial representation of geocomposite.

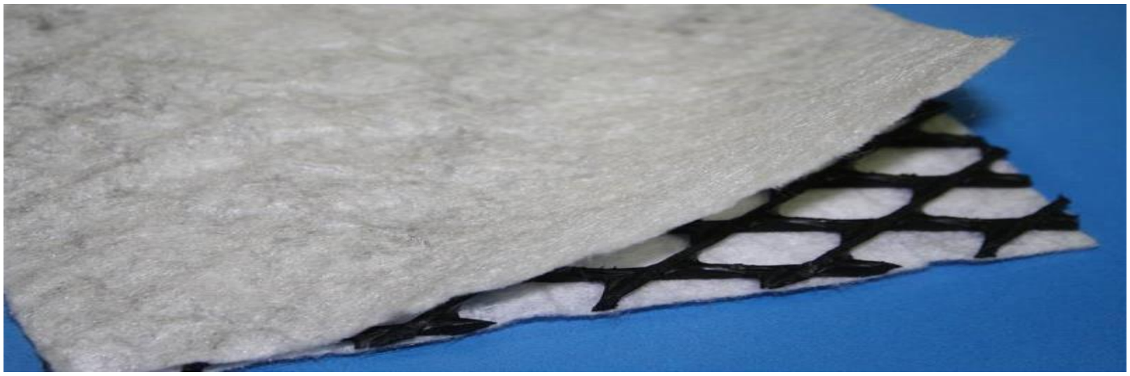


Figure 1.8: Pictorial representation of geocomposite (en.aratfil.com).

Geosynthesis clay liners:

Geosynthetic clay liners or GCLs are made up of polymeric materials and natural soils. The thin layers of bentonite clay are sandwiched between two geotextiles or bonded to a geomembrane. By acupuncture, bonding, or stitching the structural integrity of the subsequent composite material can be obtained. For transportation, geological, geotechnical, hydraulic, containment and many private development applications, GCL is used as a composite component under the geomembrane. Figure 1.9 shows the pictorial representation of geosynthetic clay liner.

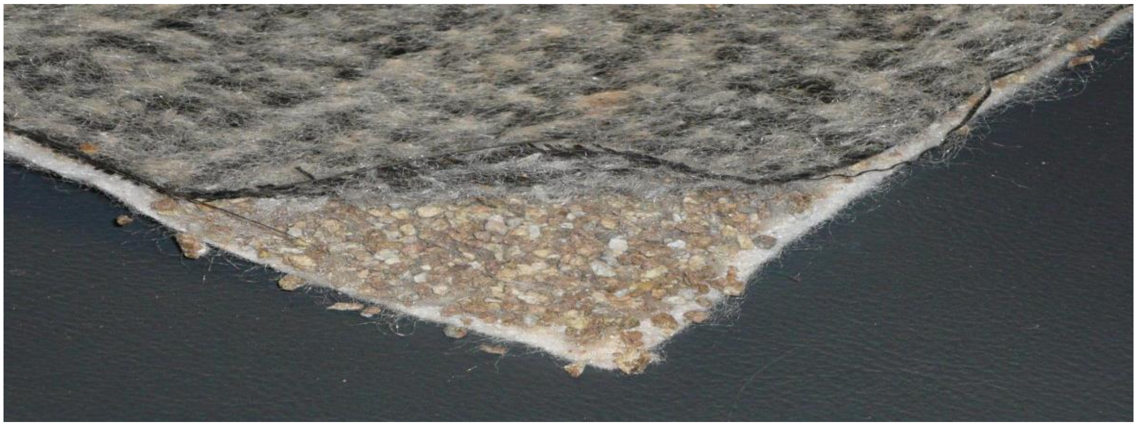


Figure 1.9: Pictorial representation of geosynthetic clay liner (www.claysandmineral.com).

Geofoams:

It is a product produced by the polymer expansion of polystyrene, producing a "foam" consisting of closed but gas-filled cells. The product is usually very light but large, and side-by-side stack provides lightweight filling in many applications. Typical applications of geofoams include: when the soil embankments built over the soft, weak soils; under roads, airfield pavements and railway track systems subject to excessive freeze-thaw conditions. Figure 1.10 shows the pictorial representation of geofoam.

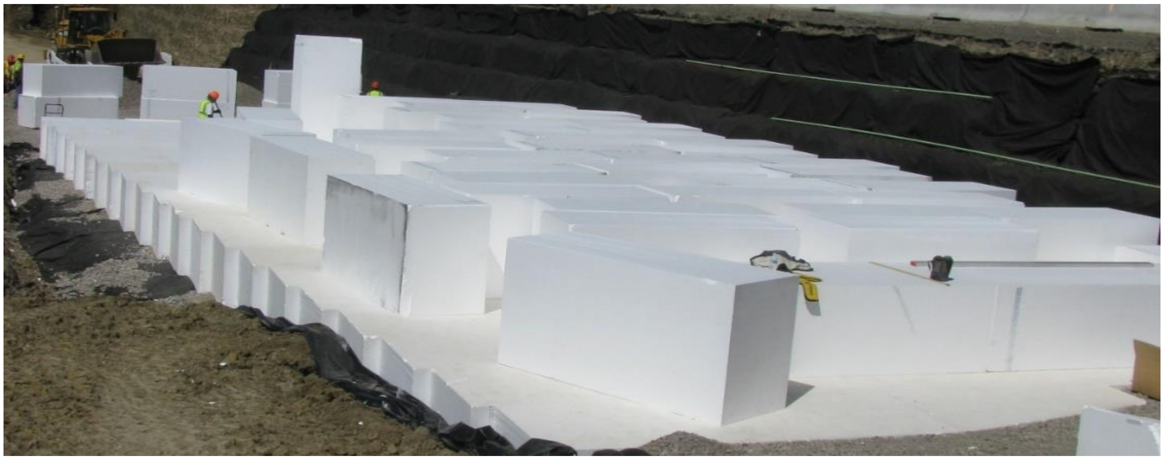


Figure 1.10: Pictorial representation of geofoam (www.constructionspecifier.com).

1.4 FUNCTIONS OF GEOTEXTILE

1. Separation

The geotextile will prevent two different sizes of soil layers from mixing with each other, as shown in the figure 1.3.

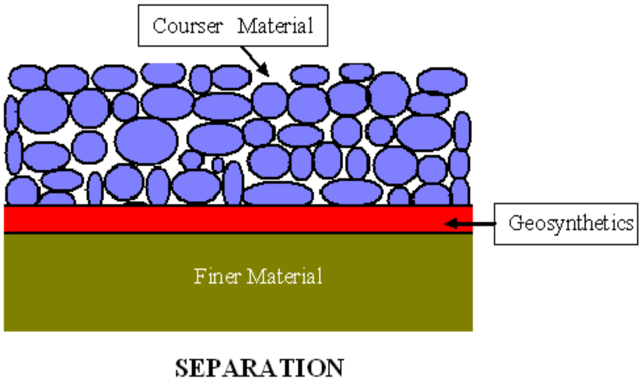


Figure 1.11: Mechanism of Separation of geosynthetics in Soil-aggregate layer (www.tikp.co.uk).

2. Drainage:

The geotextile will collect excess water from the soil, such as rain or excess water, and discharge it.

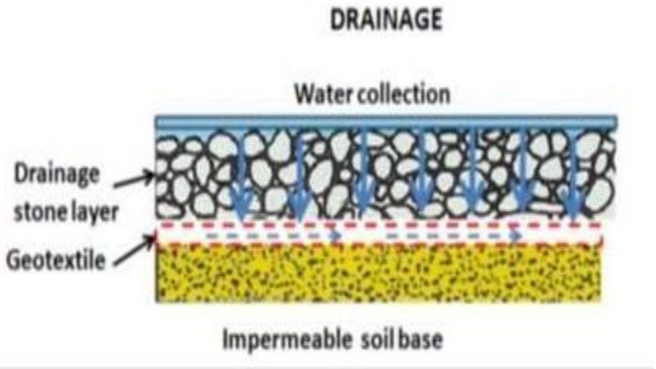


Figure 1.12: Mechanism of Drainage of geosynthetics in Soil-aggregate layer (www.tikp.co.uk).

3. Filtration

Geotextiles are ideal for reverse filtration in soils adjacent to geotextiles. In all the soil, the water allows the particles to be moved. A portion of these particles will stop at the filter interface; some will stop within the filter itself and the remainder will enter the drain. Geotextile Complex acupuncture structure can keep fine particles without reducing the permeability of the drain.

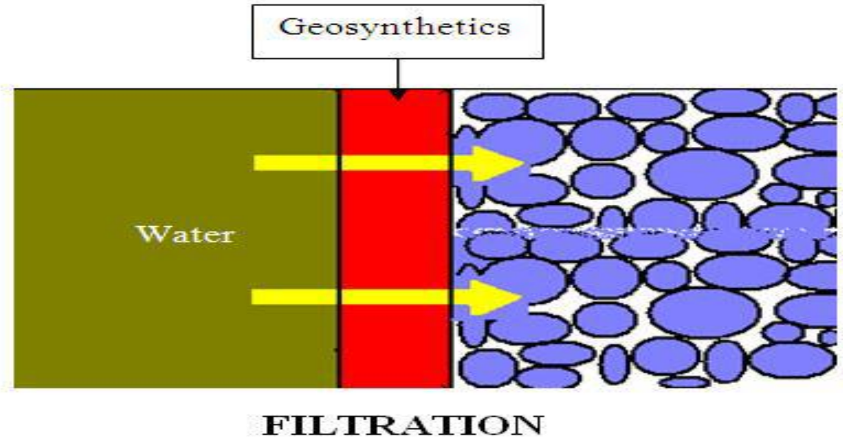


Figure 1.13: Mechanism of Filtration of geosynthetics in Soil-aggregate layer (www.tikp.co.uk).

4. Protection:

Geotextiles are ideal for the prevention of embankment erosion by wave action, current or repeated descent. You can place a layer of geotextile to prevent the leaching of fine materials. They can be used for rocky beaches or mattress structures. They can even be easily placed underwater.

5. Reinforcement:

Heavy geotextiles can be used to enhance the ground structure by filling materials. Due to their high soil fabric friction coefficient and high tensile strength, they are ideal for enhanced solution.

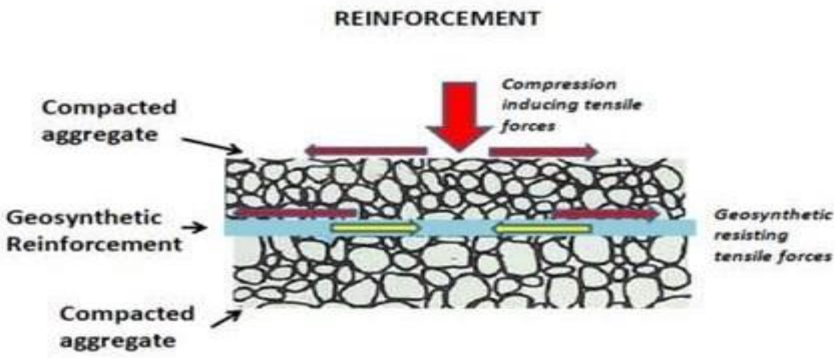


Figure 1.14: Mechanism of Reinforcement of geosynthetics in Soil-aggregate layer (www.tikp.co.uk).

1.5 OUTLINE OF THESIS

The thesis has been divided into five chapters:

- 1st chapter is about the general introduction of Geosynthetics and their classification.
- 2nd chapter is the literature review of the research work conducted with the use of geotextiles for improving the bearing capacity of soil.
- 3rd chapter deals with the experimental programme wherein all test procedures are explained in detail.
- 4th chapter deals with the results and discussions where findings of experimental programme are discussed.
- 5th chapter consists of conclusion of the dissertation.

CHAPTER-2

LITERATURE REVIEW

2.1 LITERATURE REVIEW

To increase the load bearing capacity, numerical and experimental studies have developed cost-effective and convenient methods for using geosynthetic reinforcement. The horizontal layer of this geosynthetic reinforcement has been used beneath the soil mass.

Over some decades, to increase the load bearing capacity of sand reinforcing materials such as metal strips and geosynthetics have been clearly identified. To improve the load bearing capacity of soil some studies have been conducted by the researches to understand the reinforcing material roles. Numerical and laboratory model tests were discussed with and without geosynthetics.

Ranadive M. S., Jadhav N. N. (1999) discussed about the reinforced foundation which supports the shallow spread footing has considerable potential as a cost effective alternative to conventional method of foundation support. To create a composite material with improved performance characteristics, the technique of one or more layers of geosynthetic reinforcement has been used beneath the footing. The ability of geotextile to reinforce this system is through friction which is derived from the soil-geotextile interface. Using sand as the fill material tests were conducted. To present the performance of reinforced soil other than sand an attempt has been made and to fulfill this load tests were conducted on soil using model strip footing with, without, single and multiple layers of geotextiles at various depths below the footing. Load settlement characteristics have been observed for each soil-geotextile reinforcement. For all positions of reinforcing layers in all tests improvement have been observed in bearing capacity of reinforced soil over that of unreinforced soil. At the settlement of 45mm, the load settlement curves for reinforced soil in all tests continues to rise beyond the failure point of unreinforced soil at settlement of 45mm. Hence, the bearing pressure is resisted through the contribution of reinforcement.

Latha G. Madhavi, Somwansh Amit (2009) presented the results of the laboratory model test and the numerical simulation of the square feet resting on the sand. To study the basis of improvement of the bearing capacity and various reinforcement parameters like type, quantity, tensile strength, layout and configuration of the geosynthetic layer carrying capacity through the system of model research is carried out. A steel tank 900mm x 900mm x 600 mm is used for model testing. Four kinds of geogrid, that is, strong and weak biaxial, uniaxial geogrid and a geology with various tensile strength have been used for testing. The tests results were observed by varying the reinforcement depth, no. of geosynthetics layers within the reinforcement zone, provided in planar and also by varying the width of geosynthetic layers in various tests. All the parameters of bearing capacity improvement and the settlement of the square footing were compared with unreinforced sand. Hence, shows that the effective reinforcement depth is two times the width of the foundation. The geosynthetic layer spacing is half the width of the base. Hence it is concluded that the configuration and layout of the reinforcement plays a very important role in improvement of bearing capacity rather than tensile Strength of geosynthetics. Variation of bearing pressure with footing settlement for different types of geosynthetics is shown in Fig 2.1.

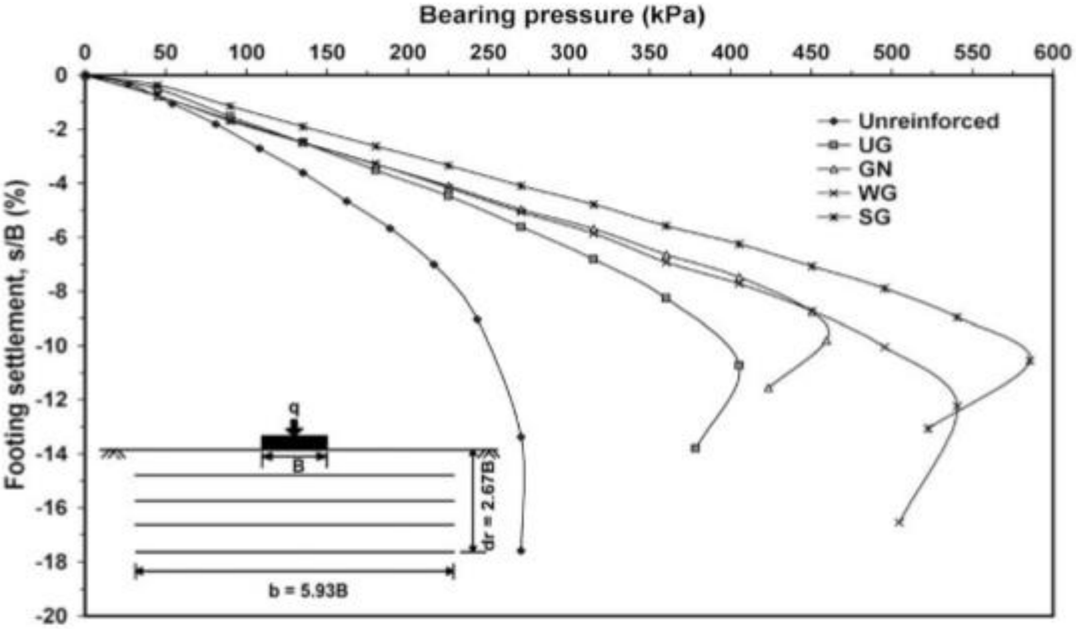


Figure 2.1: Pressure versus Settlement curves

Latha G. Madhavi, Somwanshi Amit (2009) discussed about the results on square footing using geotextile reinforcement with sand by performing numerical studies and laboratory model loading tests. In each test, relative performance were compared using different Geosynthetics like geogrids, randomly distributed grid element with the base bed; using the same amount of reinforcement. To strengthen the sand bed geology biaxial geogrid and geonet are used. Geonet is used in two forms, those are plane layer and geogrid, and biaxial geogrid for three forms of reinforcement, namely the plane layer, randomly distributed grid elements and geocell. To understand the distribution and displacement of stress below the footing unreinforced and reinforced lab load test identify the basis in the numerical model and analyze the results. For soil strengthening technology investigation, these studies have proved that the geocell is one of the most favorable form as long as the material in the loading process will not break. Geogrids are used in the form of randomly distributed grid elements are not as good as the other two forms.

Ghahramani A. et.al (2010) discussed about the storage and filling of embankments under repeated traffic loads is based on an example of the basis for cyclic loading, which is much lower than its permissible carrying capacity. Attention to the uniformity and uneven settlement of this structure. The soil under this foundation can be reinforced with geosynthetics to improve its engineering performance. This paper describes the use of a new generation of steel bars, grid anchors, at the limit load ratio, to reduce the permanent settlement of these bases. Perform an unloading-heavy field test to study the square footage behavior of the sand reinforced with the system under such loads. The influence of the basic size and the strengthening type on the cyclic behavior of the strengthened sand was studied by computer code, experiment and numerical study. The large results show that the permanent settlement is reduced to 30% compared to the unstiffened condition by using mesh anchoring. In addition, the number of loading cycles to a constant dimensionless settlement is reduced to 31% compared to the unstiffened condition. Another objective of this paper is to propose equations for reinforced soils under cyclic loading to prevent complex calculations involved in deformation analysis. According to these equations, large-scale tests are not required, and on geologic and grid-anchored reinforced sand, the number of permanent settling calculations and the number of load cycles for each foundation of a given size reaches this number and should be easily performed. Pressure versus settlement curves for the footing is shown in Fig 2.2.

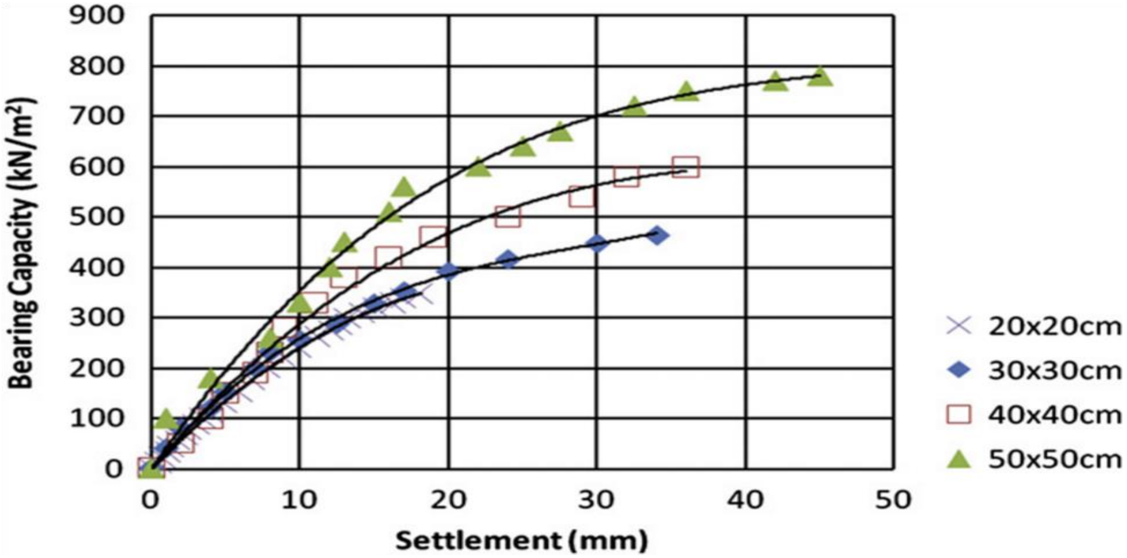


Figure 2.2: Pressure versus settlement curves

Sivakugan Nagaratnam et.al (2010) studied the beneficial effects of geotechnical foundation prestressed geosynthesis in mathematics. It’s time to study the improvement degree for the embedding depth of the reinforced layer on the base of the sand bed by pretreatment. To study the behavior of prestressed geotextile reinforced sand bed support to load circular foundation, the laboratory physical model test and finite element analysis were carried out. Increasing prestressing in geotextile reinforcement can significantly improve the foundation's sedimentation response and carrying capacity. For the surface basis, the prestressing capacity of the prestressed tiles (prestress equal to 2% of the allowable tensile strength of the geotextile) is about twice the load capacity of the geometrically reinforced sand without prestressing. For a larger base depth the beneficial effect of the prestressed geotextile configuration is apparent as compared to the non-reinforced and reinforced (non-stressed) counterparts. To address soil-structure interaction problems numerical and experiments results are also used to validate some empirical relationships that are commonly used. The results were well consistent obtained by using the finite element analysis of the program with the experimental results. Pressure versus settlement curves for the footing is shown in Fig 2.3.

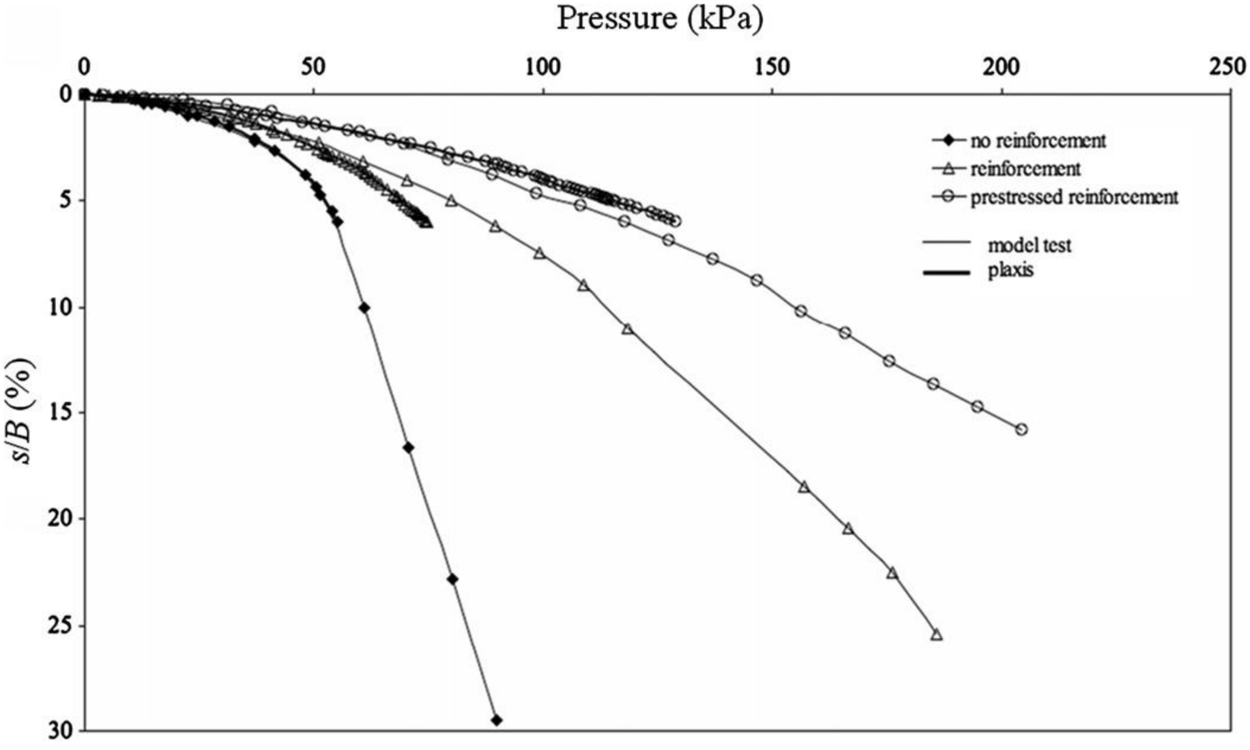


Figure 2.3: Pressure versus settlement curves.

Noorzad Reza & Manavirad Ebrahim (2012) presented the benefits of using steel bars to improve soil properties have been proven. Over the last thirty years, the use of geotextile and other polymer reinforcing materials has increased. To improve the bearing capacity and settling characteristics some possible applications like earth reinforcement techniques have become useful and economical techniques for solving many problems in geotechnical engineering practice. Study presents the effect of geotextile inclusions on the bearing capacity of two adjacent strip-like bases on the surface of soft clay. Using the computer code Plaxis (ver 8), a two-dimensional plane strain model was used to perform extensive finite element analysis of two feet with widths of 1 and 2 m. Using a soft clay for analysis, the soil is represented by the hardened soil model and the Mohr-Coulomb model two yield criteria, reinforced by the elastic element, and at the interface between the reinforcement and the soft clay, the interface element has been used. The various boundary conditions are analyzed by parameters such as the number of geotextile layers, the vertical spacing of the layers, the depth of the uppermost layer of the geotextile, the tensile stiffness of the geotextile layer, and the distance between the two foundations, including unreinforced and reinforced. From the numerical results, the underlying carrying capacity ratio and the interference factor already exist estimate. On the basis of the present study, it can be concluded that there is an optimal distance between the distance between the top and the optimum depth to achieve the maximum bearing capacity of the closely spaced bar base. If the reinforcement is placed within the effective depth, the bearing capacity increases as the number of layers increases.

Chen Qiming et.al (2013) studied the behavior of geosynthetics to enhance the sand foundation and also the effect of different parameters on its performance by laboratory model test. The parameters studied in this study include top-of-the-range spacing, stiffened layers, interlayer vertical spacing, tensile modulus and geotechnical reinforcement type, embedding depth and foundation shape. The influence of geosynthetics on the vertical stress distribution and the strain distribution along the steel bar are also studied. The test results demonstrate the potential for the use of geosynthetics to enhance sand. The test results also show that the reinforcement configuration / layout has a significant effect on the strengthening of the sand foundation. There are two or more layers of reinforcement, and settlement at all base pressure levels can be reduced by 20%. The sand reinforced by the composite of the geogrid and the geotextile is better than the use of geogrid or geotextile reinforced sand alone. The reinforced inclusion can reassign the applied base load to a more uniform pattern, thereby reducing the stress concentration, which will lead to subsidence settlement. Finally, the results of the model test are compared with those analyzed by the authors in the previous study. The analytical solution is well predicted for the experimental results of the geosynthetic reinforced sand foundation. Pressure–settlement curves for model footing tests (B/L: 1.0) are shown in Fig 2.4.

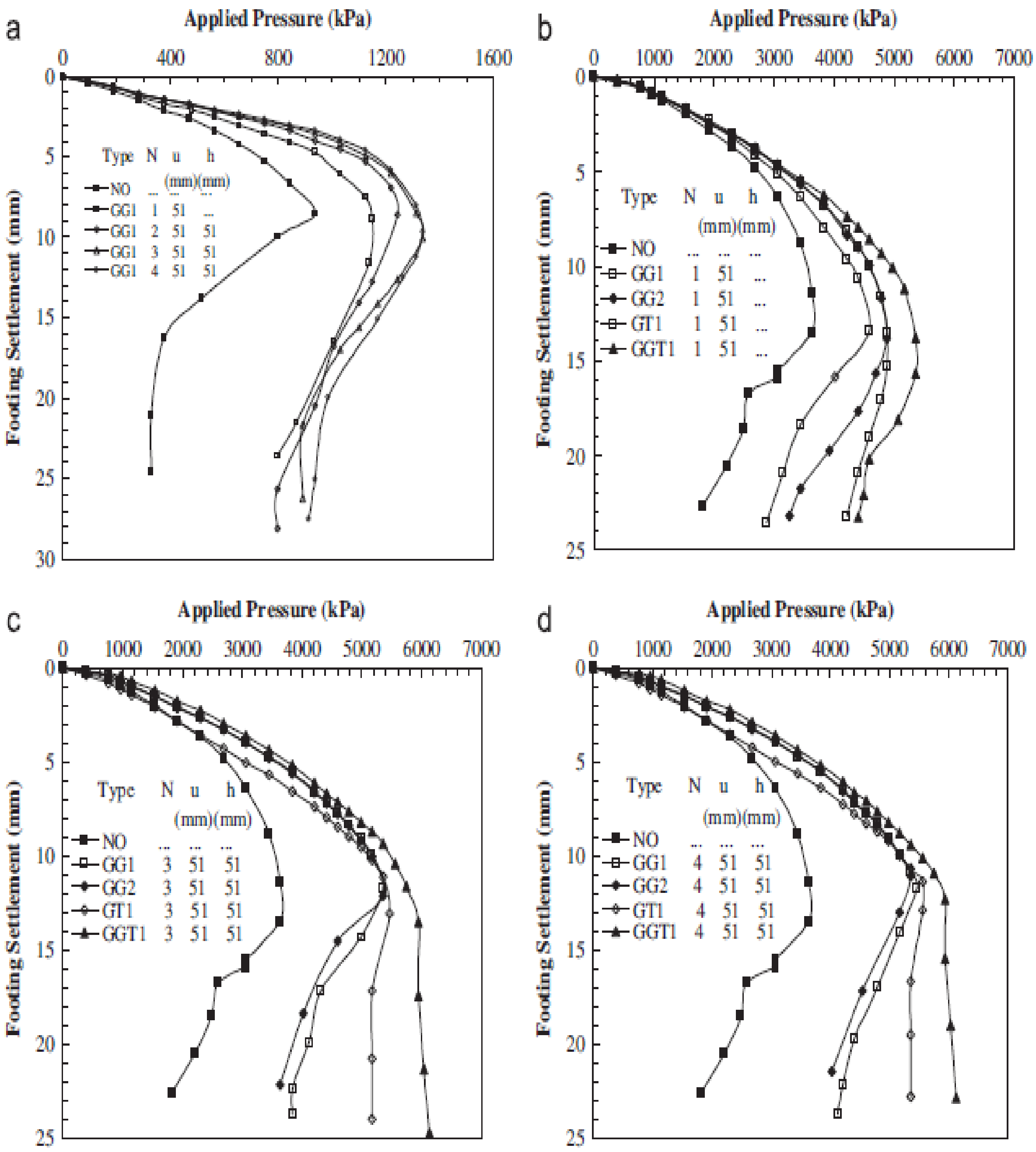


Figure 2.4: Pressure versus settlement curves (B/L: 1.0). (a) $D_f/B=0.0$, (b) $D_f/B=1.0$, (c) $D_f/B=1.0$ and (d) $D_f/B=1.0$.

Bazne Mohammed O. A. et.al (2014) studied for drainage purposes that whether geonets can also contribute to the bearing capacity of clay. To study the effect of Geonet on the bearing capacity of low pressure soft clay a wide range of numerical and laboratory tests were carried out. A model with basic shapes (squares, two circles, and rectangles) and a variety of constructions (i.e., the depth, number, length, and spacing of the reinforcement layer) were tested in the laboratory. In addition, finite element modeling results were compared with the laboratory tests results. Results showed that the load carrying capacity of low pressure clay with reinforcement is six times the natural conditions and also the optimal reinforcement length of the monolayer model is 3B (where B = base width), and the length is not improved. However, the optimum strength for two layers and three-layer models, is 2B. To seek the advantages of reinforcement, the layers should be placed at the depths of B / 3, B / 2 and B for the first, second and third layers of reinforcement respectively. The square footing shows the highest load capacity improvement as compared to different shapes of footing, with a load bearing capacity ratio of 7.6. Numerical and experimental results were compared and showed very good results. Fig. 2.5 represents bearing pressure versus settlement for footings in unreinforced model and Fig. 2.6 represent bearing pressure versus settlement for footings with three layers reinforced model.

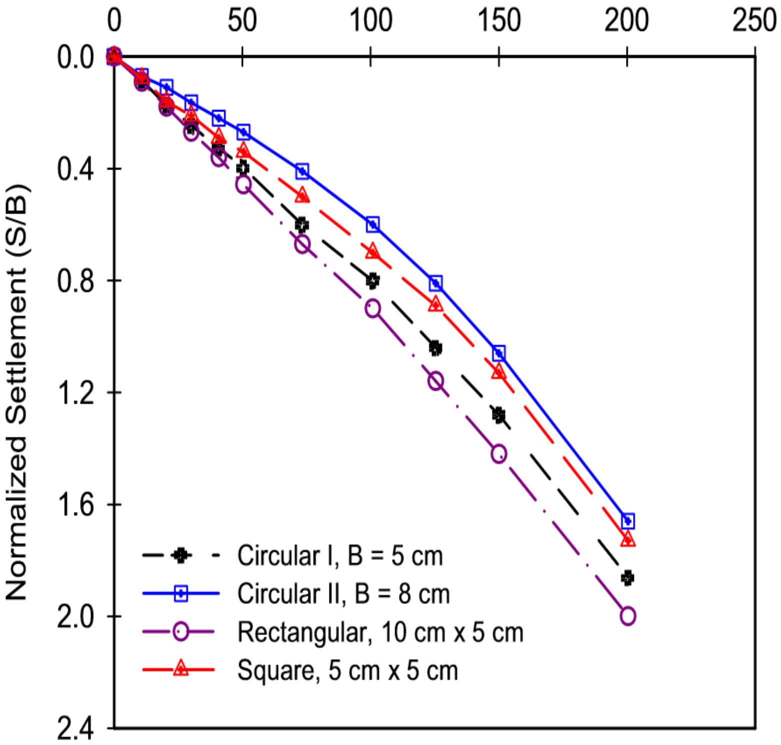


Figure 2.5: Bearing pressure versus settlement for footings in unreinforced model.

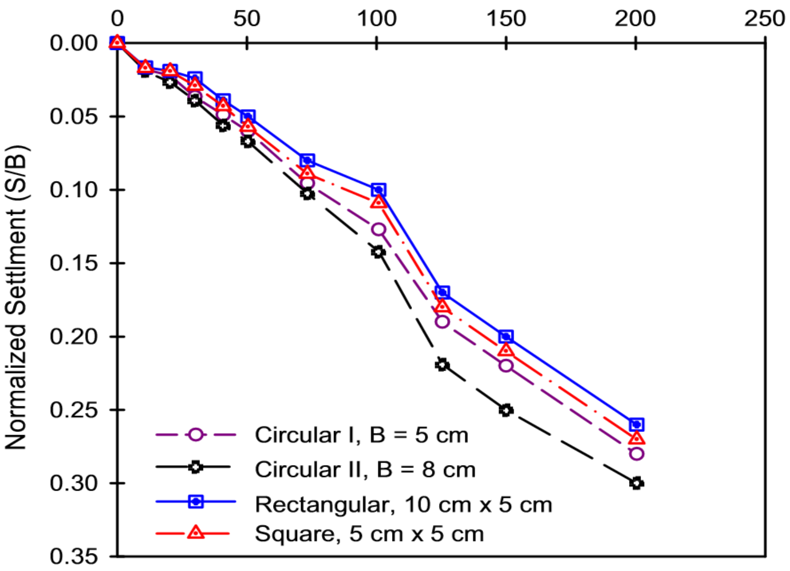


Figure 2.6: Bearing pressure versus settlement for footings with three layers reinforced model.

Habibi Daryoush et. al (2014) presented the details of the foundation load test of laboratory model test bed with single layer braided geotextile reinforcement and wraparound ends reinforcement is mainly studied with different relative density of sand bed. The experimental results of this study were compared with the finite element analysis using software PLAXIS 2D (version 9.0). To increase shallow foundation carrying capacity, numerical and experiments studies have continued to develop cost-effective and convenient methods for using geosynthetics. In the previous studies, horizontal layer of geosynthetic reinforcement has been used beneath the soil. The method of wrapping around the ends of the geosynthetics has additional advantages:

The ultimate load capacity is improved, and the stiffness of the sand bed based on the road bed modulus is significantly increased and the land space is saved to construct a reinforced sand system. This study clearly shows that by using geosynthetic reinforcement and the new practice of wrapping around the ends of the geosynthetics in the foundation, it is possible to support heavier structures without allowing large settling. Pressure versus settlement curves are shown in Fig. 2.7.

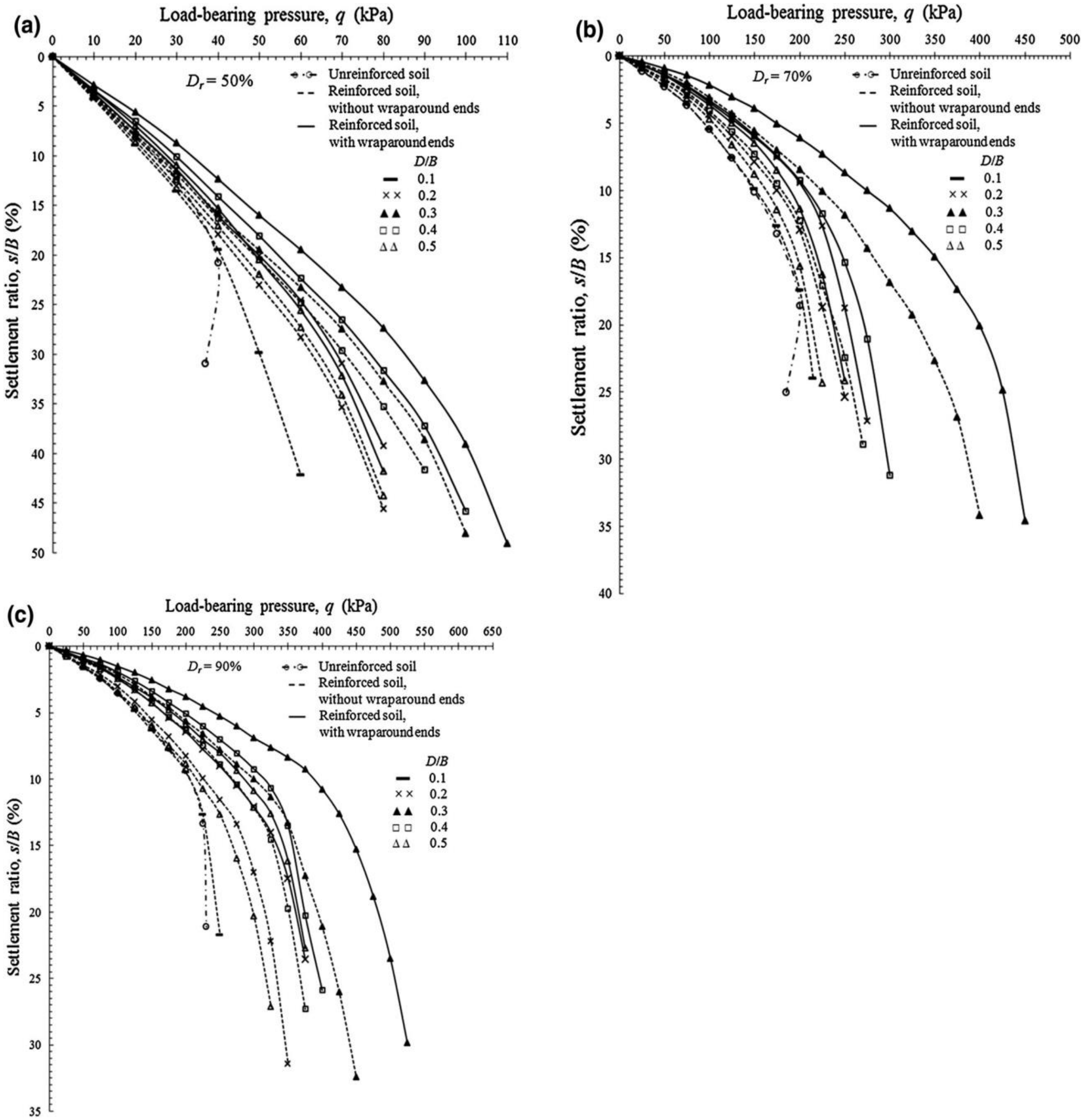


Figure 2.7: Pressure versus settlement curves.

(a) Pressure versus settlement ratio (D_r = 50 %). (b) Pressure versus settlement ratio (D_r = 70 %). (c) Pressure versus settlement ratio (D_r = 90 %)

Balan Antony et.al (2015) presented here is a study to improve the load carrying capacity of coastal sand using the high density polyethylene (HDPE) / woven fabric as a reinforcement for the discrete layer of the Indian Kerala delta. The load carrying capacity was evaluated using a plate load test. The effects of reinforced structures (reinforced with adhesives, individual adhesives and individual sanders) and reinforcing bars (single and grid patterns) were studied. The test parameters selected in this study are: the depth of the uppermost layer, the compaction density and the number of reinforced layers. It was found that the synthetic adhesive had no adhesion at the interface between the reinforcement and the soil. It is to be noted, however, that a sheet having a binder-dried sheet has a significant effect on the bearing capacity, particularly at a lower density. The single-mode reinforcement is considered a favorable choice for the smallest reinforcement. Reinforcement in a single or grid pattern has sufficient strength to improve.

Jun Park Jeong et.al (2016) emphasized to establish the technical standard for geogrid reinforcement, the purpose of this paper is to analyze the reinforcement efficiency and behavior as geogrid dimensions and filling materials. The results show that the influence of the load on the bearing capacity and stress distribution of the subgrade soil is analyzed according to the height, width, shape and the type of the filling material. Based on the large model test, the bearing capacity evaluation shows that the maximum carrying capacity is 4 to 8 times higher than the maximum bearing capacity compared with the non-reinforced ground, and the maximum carrying capacity is 1: Granite soil, 1.2 (width: height) when the cell shape is filled with gravel and at 1: 0.8 (width: height)). In addition, in the reinforced ground, the maximum earth pressure is reduced by 50% to 60% due to the lower stress distribution due to the shallow foundation of the geological reinforcement layer as compared to the unstiffened ground.

Hussein M.G., Meguid M.A. (2016) discussed the interaction between soil and geogrid is critical to the analysis and design of soil structures for geogrid reinforcement. The first step in the precise modeling of this interaction is to select the appropriate material model for the geogrids that can simulate the tensile test results. Considering its precise geometry, the 3D response of the geogrid must be able to capture by the model. Modeling the geogrid inclusions into continuous sheets has been shown for a reasonable simulation of the general reaction of the soil-geogrid system; however, he was not able to explain the various sources of interaction between geogrid and surrounding soil. This study developed a two-phase numerical study to understand the three aspects of this complex interaction problem. With one or more geogrid layers installed under the footing, the model was able to capture the 3D response of the soil-geogrid system. Hence, resulted in an increase in the ultimate bearing capacity by increasing the number of geogrid layers. For the case of N = 1 geogrid deformations and tensile stresses were found to be generally larger than those calculated for N = 2.

The first stage focuses on the three-dimensional modeling of unconfined biaxial geogrids subjected to tensile loads. The applicability in solving the soil-structure interaction problem of the geogrid model is studied in the stage second by studying the response of the reinforced foundation subjected to the load on surface of square shape. The conclusion is that modeling the three-dimensional geogrid geometry is very important for accurately capturing the geogrids real response under deterministic and uncertain conditions. The modeling method can be applied to other reinforced soil applications for the analysis of undetermined and soiled geogrids.

Shooshpasha Issa et.al (2016) describes the use of nonwoven geotextiles to improve the ultimate bearing capacity of shelves on sand with moderate density. Reinforced soil is a composite material in which the element with high tensile strength is used to increase the corrosion resistance. Geosynthetics are mainly used for soil strengthening. The plate load test of 27cm × 27cm, 35cm × 35cm square plate was studied. The influence of geotextile first layer, vertical spacing and geotextile layer on ultimate bearing capacity was studied. In addition, the effect of numerical testing on plate size was examined by performing 3-D finite element analysis of square plates with different sizes. The experimental results show that for systems with four geotextiles, the maximum load capacity is achieved with a vertical spacing of 0.3 B between the outer layer and the geotextile, where B is the width of the plate. The numerical analysis shows that the bearing capacity (BCR) value decreases with the increase of the plate size to 65cm, but the increase of the plate size has a certain influence on the BCR value.

CHAPTER-3

EXPERIMENTAL PROGRAMME

Model tests were carried out by using the model tests facility developed at the geotechnical laboratory at Thapar University, Patiala. The experimental programme and the test results of various footings on the reinforced sand bed are presented.

3.1 MATERIALS USED

The sand was collected from Patiala, Punjab and was consisted of gravels, which were removed before the tests. The properties of oven dried sand are given in Table 3.2. Figure 3.1 shows the particle-size distribution curve of the sand. Angle of internal friction as listed in Table 3.2 was determined by direct shear test. The properties of reinforcement used in the test is listed in Table 3.1.

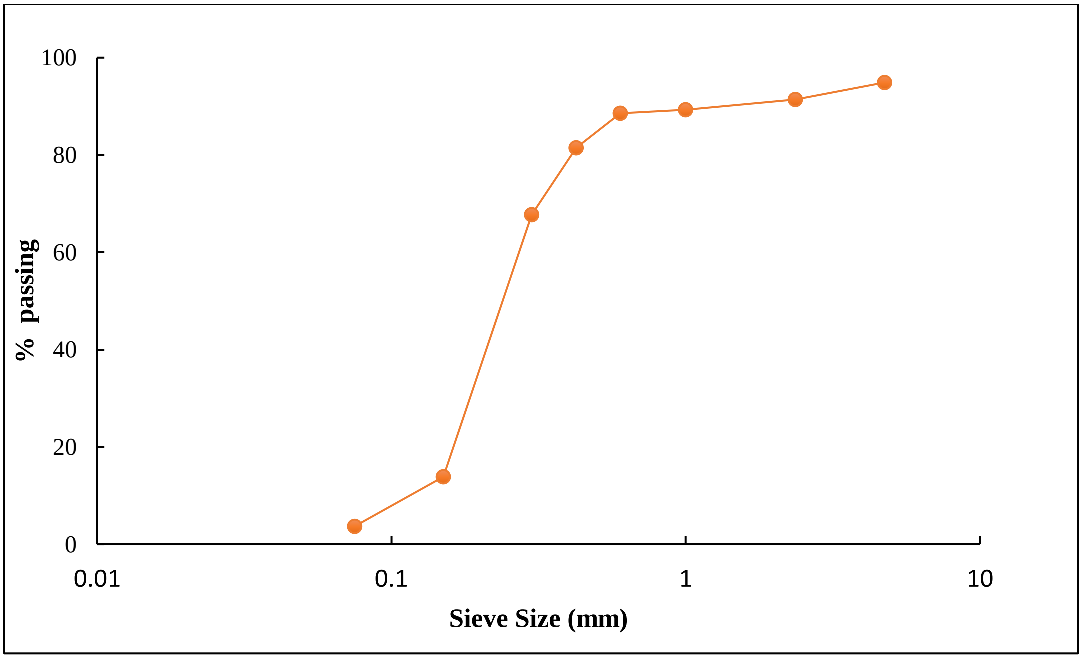


Figure 3.1: Grain Size Distribution of Sample.

Table 3.1: Properties of geotextile (Maccaferri India)

Description	**Properties**
Type of Geotextiles	Non -Woven
Type of fiber	Polypropylene
Pore size	less than 75 microns
Grab Tensile strength	570 N
Puncturing strength	180 N
Grab Elongation	50%
Permittivity	1 $\sec^{-1}$
Water Permeability	20.4 lit/ m^2/ sec

3.2 EXPERIMENTAL SETUP

3.2.1 Specific Gravity

As per IS 2720 (Part III) pycnometer analysis was done for specific gravity determination for sand. The value for specific gravity for the material was found to be 2.66.

3.2.2 Grain Size Analysis

Various size of sieves (4.75mm, 2.36mm,1mm, 600 micron, 425 micron, 300 micron, 150 micron, 75 micron) were used to determine the particle size, coefficient of curvature (C_c), uniformity coefficient (C_u) listed in Table 3.2 and the sand was found to be fine sand as per IS: 2720 (Part IV). Figure 3.2 shows the particle-size distribution curve of the sand.

3.2.3 Direct Shear Test

The angle of internal (shearing) friction was determined by direct shear test as per IS: 2720 (Part XIII) listed in Table 3.2.

3.2.4 Relative Density Test

Maximum and minimum dry unit of sand was determined by relative density test as per IS: 2720 (Part XV) listed in Table 3.2.

Table 3.2: Properties of sand

Property	**Value**
Specific Gravity	2.66
Minimum Dry unit weight (kN/m^3)	13.53
Maximum Dry unit weight (kN/m^3)	16.87
D_{60}	0.28
D_{30}	0.19
D_{10}	0.12
Coefficient of uniformity, C_u	2.33
Coefficient of curvature, C_c	1.07
Angle of internal friction, ϕ (°)	30

3.2.5 Test Tank

The tank used for depositing the sand was made up of cast iron. The size of the tank was 0.60 m x 0.60 m x 0.60 m as shown in the Figure 3.2.

Figure 3.2: Test tank used in the experiment.

3.2.6 Geometry of the model

Figure 3.3 shows the geometry of the model with the first depth (u) of geotextile from the base of the footing (u/B = 0.5), the second depth (h_1) of geotextile from the base of first layer of geotextile (h_1/B = 0.5) and the third depth (h_2) of geotextile from the base of second layer of geotextile (h_2/B = 0.5). B is the width of the footing. W is the width of geotextile.

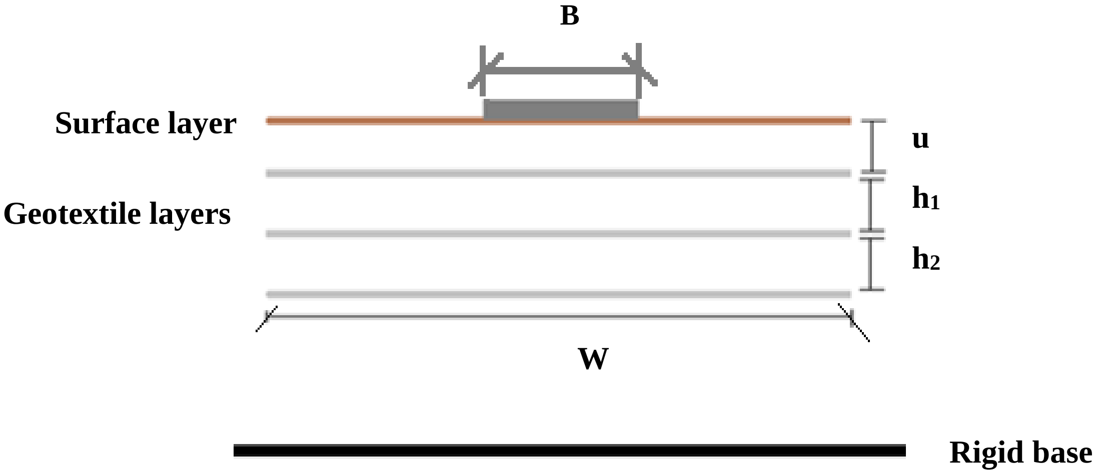


Figure 3.3: Geometry of the model.

3.2.7 Footings

In the experiment various footing were used for the test. Two Square footings of size 20 cm x 20 cm and 30 cm x 30 cm, rectangular footings of size 15 cm x 40 cm and 20 cm x 50 cm and strip footing of size 7.5 cm x 60 cm and 15 cm x 60 cm were used for the testing as shown in Figure 3.3.

Figure 3.4: Footings used in the experiment.

3.2.8 Strain Measurement and Loading

For noting down the settlement caused by series of loads, four strain gauges with the least count 0.01 mm were placed on the four corners on the footing plate for measuring the settlement of footing as near to perfection as possible. The loading was done with the help of a hydraulic jack placed on the footing. The whole set up is shown in Figure 3.4.

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Figure 3.5: Loading and Strain measurement used in the test.

3.2.9 Testing Procedure

The following testing procedure were adopted for the stress-settlement studies of footings resting on surface of sand with relative density 62%. All the tests were performed on the surface.

1. Initially the sand was placed inside the tank up to a level of 20 cm height with four equal layer. Sand was dropped from the required height to achieve the required density by rain-fall method by means of a sieve. Medium packing (relative density 62%) was achieved by. dropping the sand from a height of 25 cm for every 5 cm layer and the same procedure was

followed up to a height of 60 cm in three layers of 20 cm. The curve plotted are shown in figure 3.5.

2. The loading was done through hydraulic jack on all the types of footings as mentioned in section 3.2.6. At time interval of about 30 min, when the settlement on all the four gauges becomes constant then the settlement was noted on all four gauges which were placed on the corners of the footing.
3. After this the procedure was repeated with non-woven geotextile (45 cm x 60 cm) with three layer system. Firstly the test was conducted with square footings of size 20 cm x 20 cm and 30 cm x 30 cm with one layer of geotextile having u/B=0.5, where u= the first depth of geotextile from the base of the footing. And the loading was done in the same manner as mentioned in above points. The stress-settlement graphs were plotted for both the footings with u/B=0.5.
4. Then the procedure was conducted for the second and third layer having h_1/B=0.5 and h_2/B= 0.5 respectively, where h_1 = the second depth of geotextile from the base of first layer of geotextile and h_2 = the third depth of geotextile from the base of second layer of geotextile. Loading was done through the hydraulic jack and the curves were plotted for stress-settlement with and without geotextiles.
5. All this above procedure with three layer system of geotextile was adopted for rectangular footings of size 15 cm x 40 cm and 20 cm x 50 cm and for strip footings of size 7.5 cm x 60 cm and 15 cm x 60 cm with u/B= 0.5, h_1/B=0.5 and h_2/B=0.5. Loading was done through the hydraulic jack and the curves were plotted for stress-settlement with and without geotextiles. Table 3.3 shows the parameters and their values used in the test.

Table 3.3 Parameters and their values used in the test.

Parameter	**Values**
Relative density	62%
Size of footing	
Square	20 cm x 20 cm and 30 cm x 30cm
Rectangular	15 cm x 40 cm and 20 cm x 50 cm
Strip	7.5 cm x 60 cm and 15 cm x 60 cm
Geotextile layer	
Single layer	u/B=0.5
Two layer	h_1/B=0.5
Three layer	h_2/B=0.5

Where, u= the first depth of geotextile from the base of the footing.

h_1 = the second depth of geotextile from the base of first layer of geotextile.

h_2 = the third depth of geotextile from the base of second layer of geotextile.

B= width of the footing.

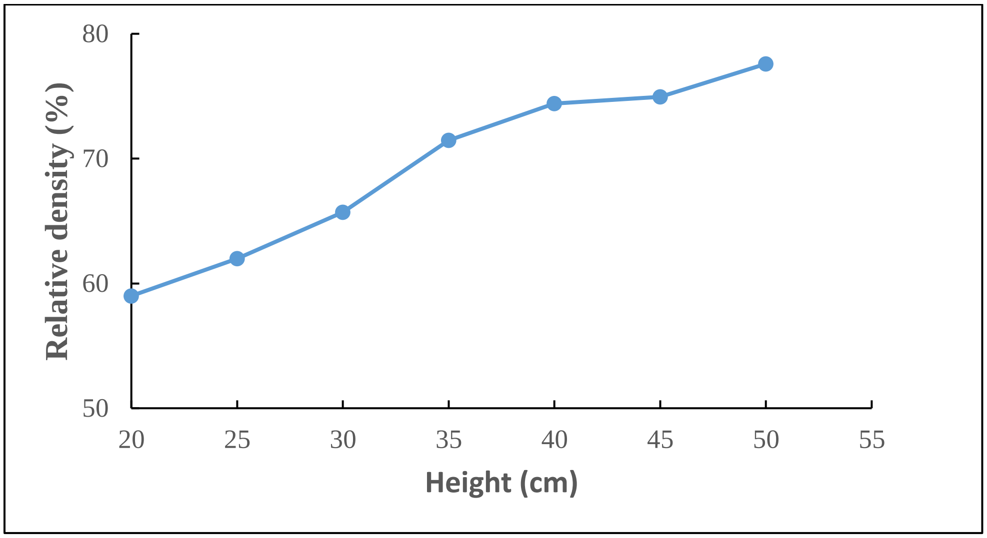

Figure 3.6: Relative Density and Height of fall plot for sand (By rain fall method).

CHAPTER-4

RESULTS AND DISCUSSION

The results obtained from various experimental tests conducted in laboratory are summarized in this chapter. The behaviour of footings resting on sand with and without geotextiles with respect to pressure-settlement aspect is discussed here-

1) Figure 3.5 shows the plot between height of fall of sand and relative density, obtained by rain-fall method to deposit the sand. It can been seen that the relative density of sand increases gradually with the increase of height of fall of sand through the sieve opening.
2) Figure 4.1 shows the comparison between pressure and settlement characteristics of square footing of size 20 cm x 20 cm with and without geotextile. It has been seen that the increase in ultimate bearing capacity with one, two and three layer of geotextile is about 81.52 %, 125.98% and 192.69% respectively when compared to unreinforced system.
3) Figure 4.2 shows the comparison between pressure and settlement characteristics of square footing of size 30 cm x 30 cm with and without geotextile. It has been seen that the increase in ultimate bearing capacity with one, two and three layer of geotextile is about 31.67%, 68.63 % and 116.14% respectively when compared to unreinforced system.
4) Figure 4.3 shows the comparison of ultimate bearing capacity for square footings with one layer of geotextile (u/B=0.5). It has been seen that for square footing of size 30 cm x 30 cm, percentage of ultimate bearing capacity increases by 103.68% when compared to 20 cm x 20 cm.
5) Figure 4.4 shows the comparison of ultimate bearing capacity for square footings with two layers of geotextile (h_1/B=0.5). It has been seen that for square footing of size 30 cm x 30 cm, percentage of ultimate bearing capacity increases by 109.53% when compared to 20 cm x 20 cm.
6) Figure 4.5 shows the comparison of ultimate bearing capacity for square footings with three layers of geotextile (h_2/B=0.5). It has been seen that for square footing of size 30 cm x 30 cm, percentage of ultimate bearing increases by 107.36% when compared to 20 cm x 20 cm.
7) Figure 4.6 shows the comparison between pressure and settlement characteristics of rectangular footing of size 15 cm x 40 cm with and without geotextile. It has been seen that

the increase in ultimate bearing capacity with one, two and three layer of geotextile is about 77.59%, 135.76% and 187.47% respectively when compared to unreinforced system.

8) Figure 4.7 shows the comparison between pressure and settlement characteristics of rectangular footing of size 20 cm x 50 cm with and without geotextile. It has been seen that the increase in ultimate bearing capacity with one, two and three layer of geotextile is about 30.09%, 75.20% and 120.33% respectively when compared to unreinforced system.
9) Figure 4.8 shows the comparison of ultimate bearing capacity for rectangular footings with one layer of geotextile (u/B=0.5). It has been seen that for rectangular footing of size 20 cm x 50 cm, percentage of ultimate bearing capacity increases by 13.34% when compared to 15 cm x 40 cm.
10) Figure 4.9 shows the comparison of ultimate bearing capacity for rectangular footings with two layers of geotextile (h_1/B=0.5). It has been seen that for rectangular footing of size 20 cm x 50 cm, percentage of ultimate bearing capacity increases by 14.97% when compared to 15 cm x 40 cm.
11) Figure 4.10 shows the comparison of ultimate bearing capacity for rectangular footings with three layers of geotextile (h_2/B=0.5). It has been seen that for rectangular footing of size 20 cm x 50 cm, percentage of ultimate bearing capacity increases by 18.58% when compared to 15 cm x 40 cm.
12) Figure 4.11 shows the comparison between pressure and settlement characteristics of strip footing of size 7.5 cm x 60 cm with and without geotextile. It has been seen that the increase in ultimate bearing capacity with one, two and three layer of geotextile is about 157.19%, 353.65% and 471.57% respectively when compared to unreinforced system.
13) Figure 4.12 shows the comparison between pressure and settlement characteristics of strip footing of size 15 cm x 60 cm with and without geotextile. It has been seen that the increase in ultimate bearing capacity with one, two and three layer of geotextile is about 44.85%, 95.29% and 134.54% respectively when compared to unreinforced system.
14) Figure 4.13 shows the comparison of ultimate bearing capacity for strip footings with one layer of geotextile (u/B=0.5). It has been seen that for strip footing of size 15 cm x 60 cm, percentage of ultimate bearing capacity increases by 31.58% when compared to 7.5 cm x 60 cm.

15) Table 4.1 shows the summary of the model test.

16) Figure 4.16 shows the comparison of BCR for square footing. It has been seen that with one, two and three layer of geotextile, the BCR for square footing of size 20 cm x 20 cm came to be 1.82, 2.26 and 2.93 respectively and for 30 cmx 30 cm, the BCR came to be 1.32, 1.69 and 2.16 respectively. BCR (ratio of reinforced to unreinforced bearing capacity) goes on increasing as we increase the number of geotextile layers. Hence from above it can been seen that the BCR value for the smaller footing is greater than the larger footing.

17) Figure 4.17 shows the comparison of BCR for rectangular footing. It has been seen that with one, two and three layer of geotextile, the BCR for rectangular footing of size 15 cm x 40 cm came to be 1.78, 2.36 and 2.87 respectively and for 20 cm x 50 cm, the BCR came to be 1.3, 1.75 and 2.20 respectively. BCR goes on increasing as we increase the number of geotextile layers. Hence from above it can been seen that the BCR value for the smaller footing is greater than the larger footing.

18) Figure 4.18 shows the comparison of BCR for strip footing. It has been seen that with one, two and three layer of geotextile, the BCR for strip footing of size 7.5 cm x 60 cm came to be 2.6, 4.54 and 5.81 respectively and for 15 cmx 60 cm, the BCR came to be 1.45, 1.95 and 2.35 respectively. BCR goes on increasing as we increase the number of geotextile layers. Hence from above it can been seen that the BCR value for the smaller footing is greater than the larger footing.

Table 4.1 Summary of the Test

Footing	**Reinforcement configuration**	**u (cm)**	**h_1 (cm)**	**h_2 (cm)**	**Ultimate Bearing Capacity (q_u=kN/m^2)**	**BCR**
Square 20 cm x 20 cm	Unreinforced	…	…	…	37.06	...
	N=1, u/B=0.5	10	…	…	67.27	1.82
	N=2, h_1/B=0.5	10	10	…	83.75	2.26
	N=3, h_2/B=0.5	10	10	10	108.47	2.93
Square 30 cm x 30 cm	Unreinforced	…	…	…	104.06	...
	N=1, u/B=0.5	15	…	…	137.02	1.32
	N=2, h_1/B=0.5	15	15	…	175.48	1.69
	N=3, h_2/B=0.5	15	15	15	224.92	2.16
Rectangular 15 cm x 40 cm	Unreinforced	…	…	…	28.33	...
	N=1, u/B=0.5	7.5	…	…	50.31	1.78
	N=2, h_1/B=0.5	7.5	7.5	…	66.79	2.36
	N=3, h_2/B=0.5	7.5	7.5	7.5	81.44	2.87
Rectangular 20 cm x 50 cm	Unreinforced	…	…	…	43.83	...
	N=1, u/B=0.5	10	…	…	57.02	1.3
	N=2, h_1/B=0.5	10	10	…	76.79	1.75
	N=3, h_2/B=0.5	10	10	10	96.57	2.20
Strip 7.5 cm x 60 cm	Unreinforced	…	…	…	18.64	...
	N=1, u/B=0.5	3.75	…	…	47.94	2.6
	N=2, h_1/B=0.5	3.75	3.75	…	84.56	4.54
	N=3, h_2/B=0.5	3.75	3.75	3.75	106.54	5.81
Strip 15 cm x 60 cm	Unreinforced	…	…	…	43.55	...
	N=1, u/B=0.5	7.5	…	…	63.08	1.45
	N=2, h_1/B=0.5	7.5	7.5	…	85.05	1.95
	N=3, h_2/B=0.5	7.5	7.5	7.5	102.14	2.35

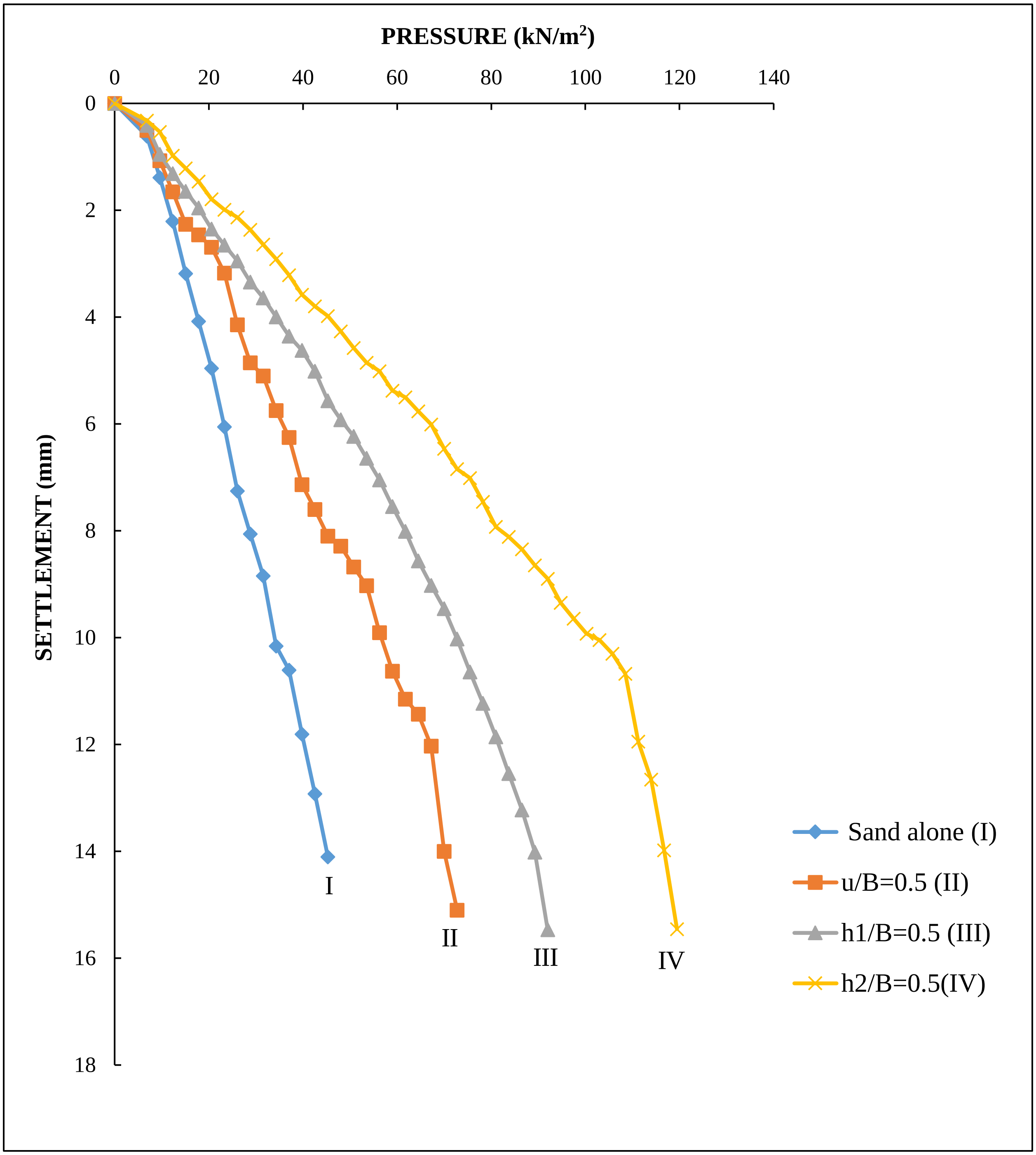

Figure 4.1: Pressure – settlement curve for Square footing of size 20 cm x 20 cm with and without geotextile.

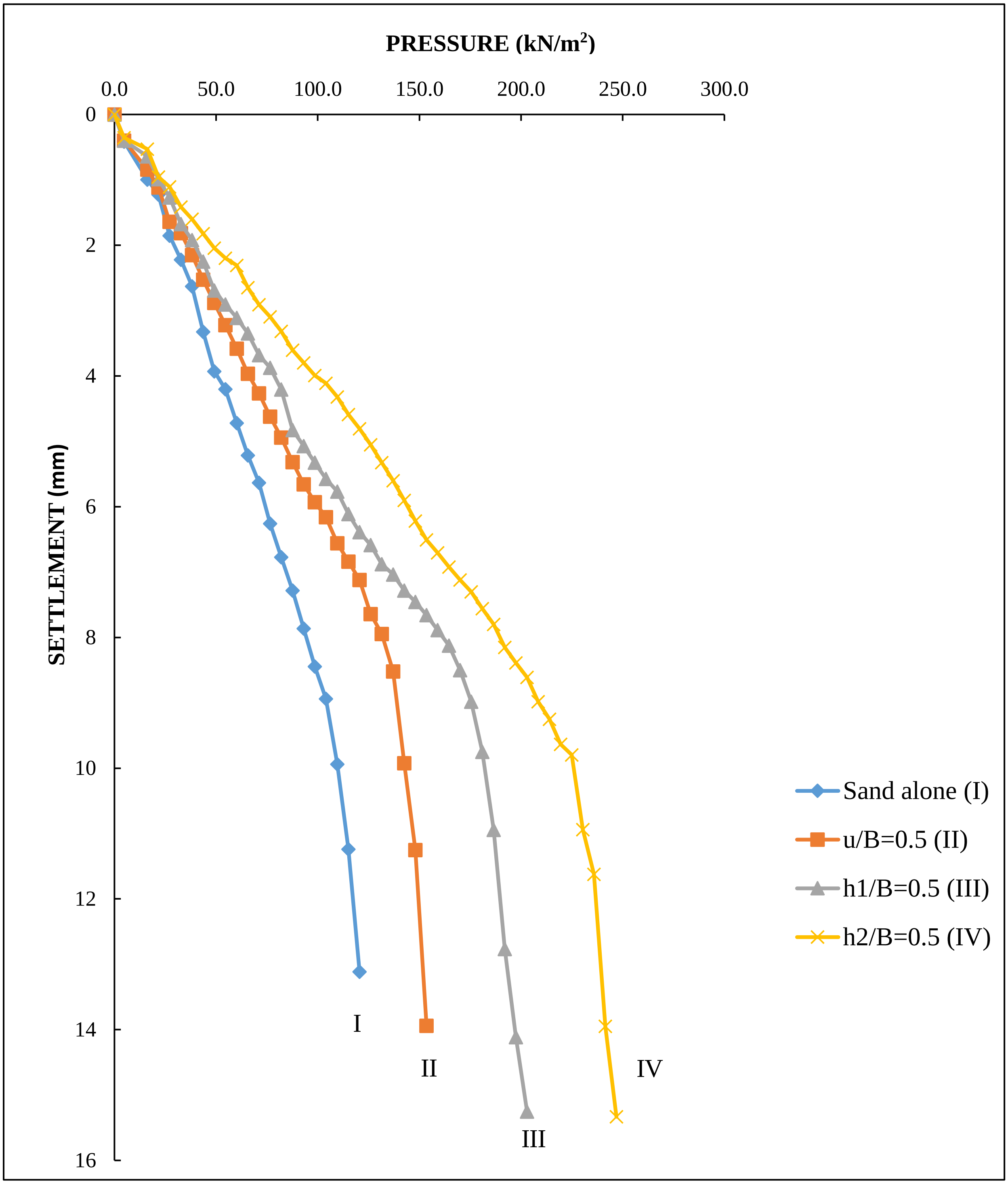

Figure 4.2: Pressure – settlement curve for Square footing of size 30 cm x 30 cm with and without geotextile.

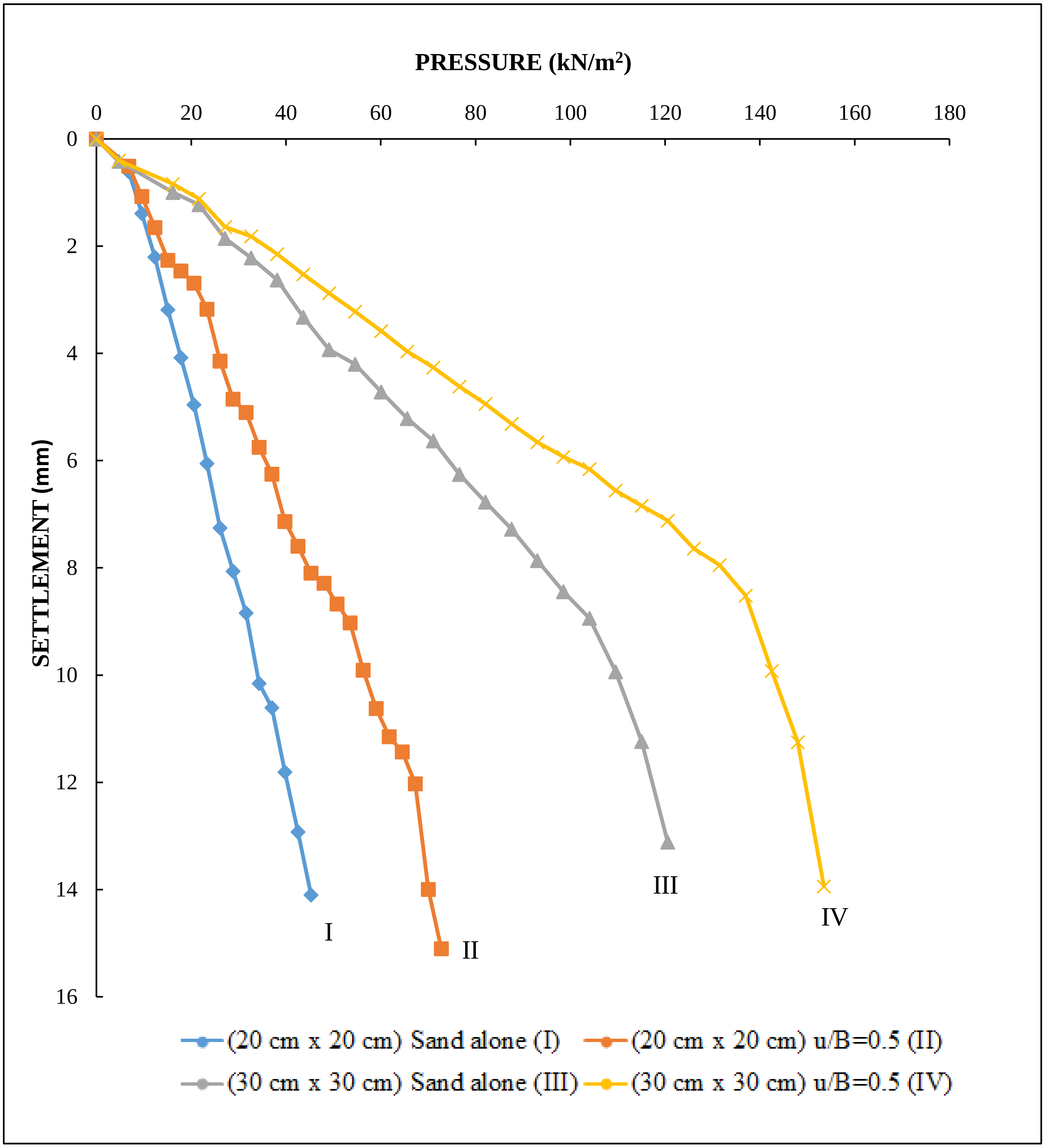

Figure 4.3: Comparison of Ultimate bearing capacity for Square footings with one layer of geotextile (u/B=0.5).

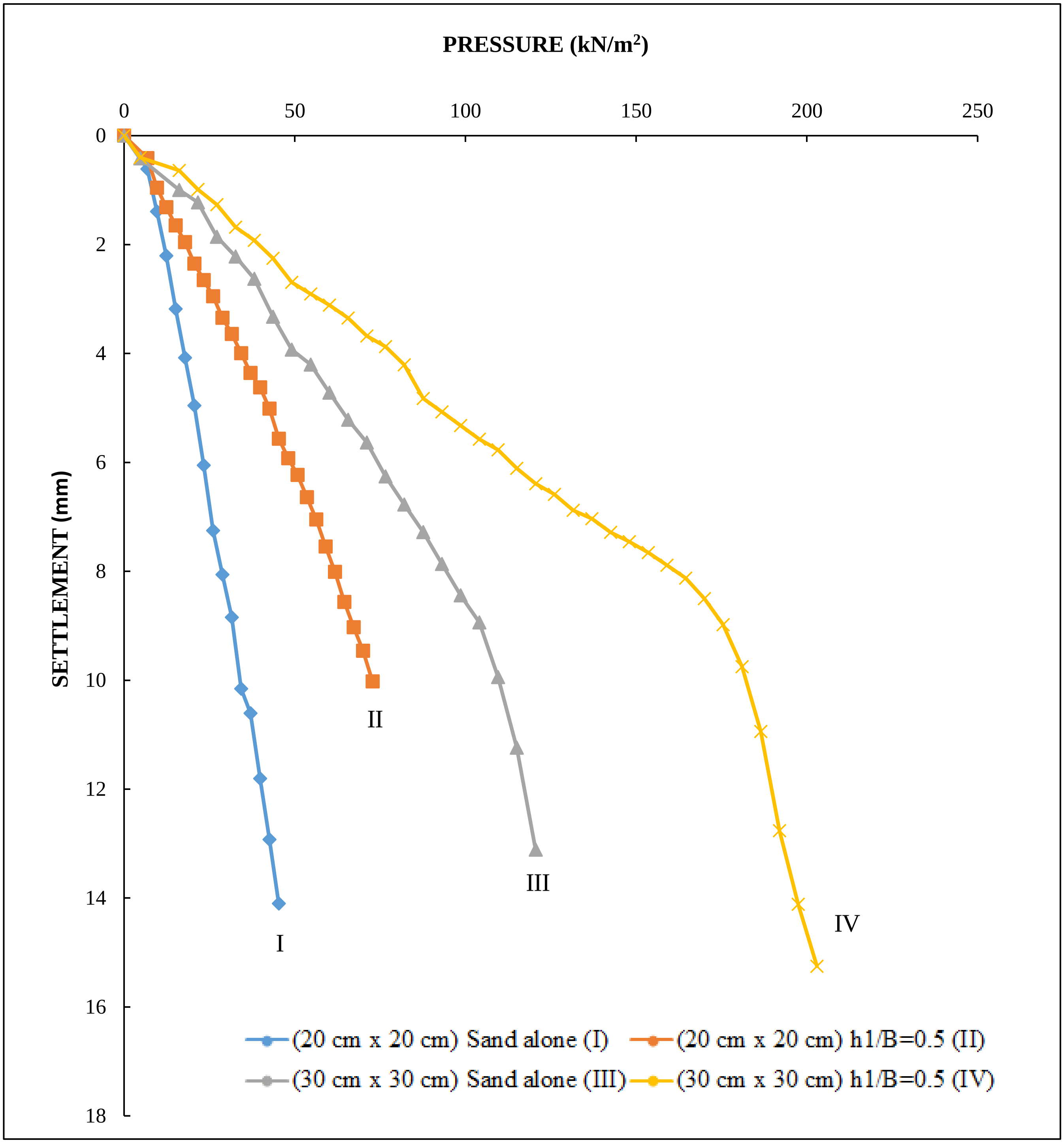

Figure 4.4: Comparison of Ultimate bearing capacity for Square footings with two layers of geotextile (h_1/B=0.5).

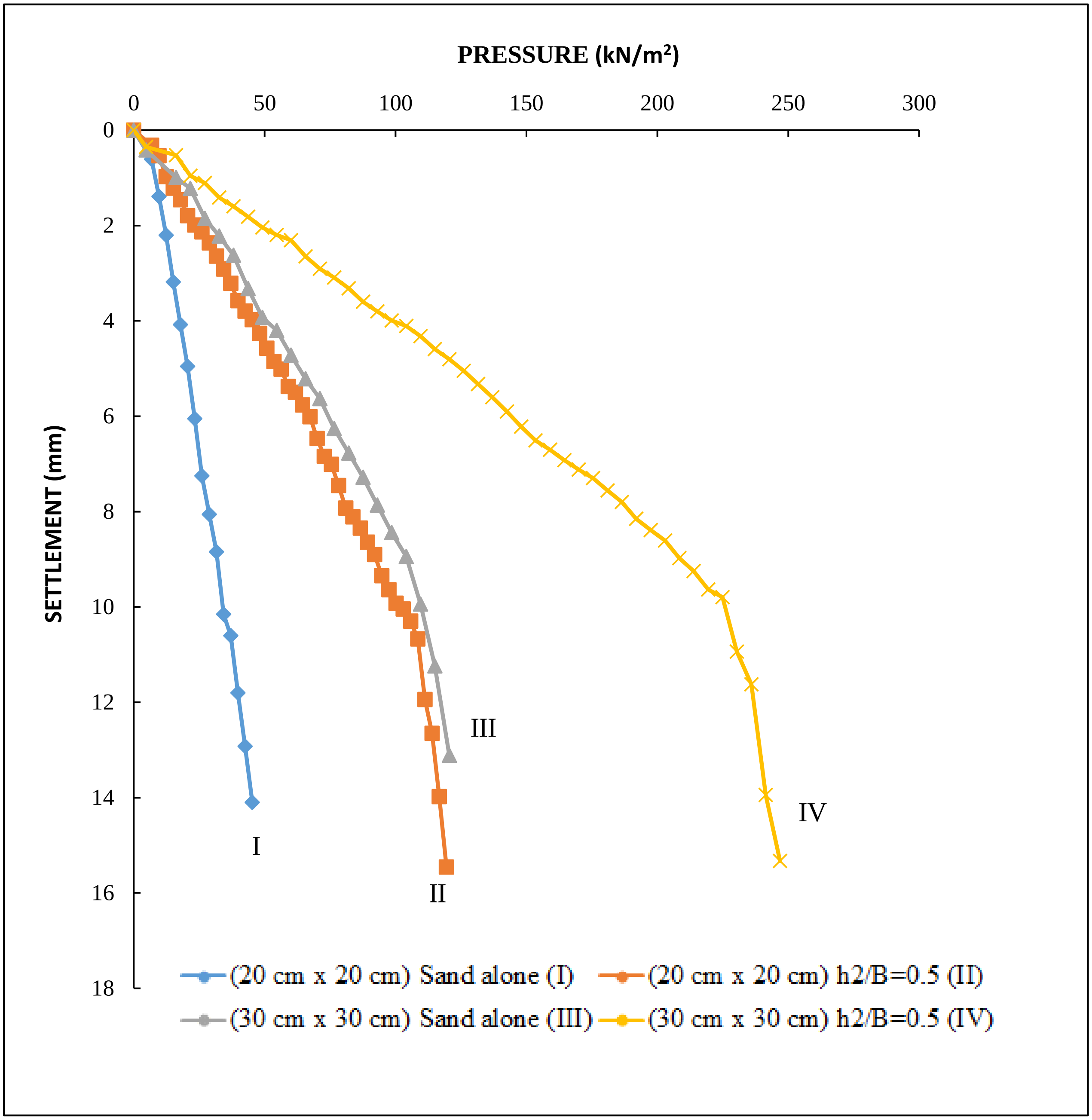

Figure 4.5: Comparison of Ultimate bearing capacity for Square footings with three layers of geotextile (h_2/B=0.5).

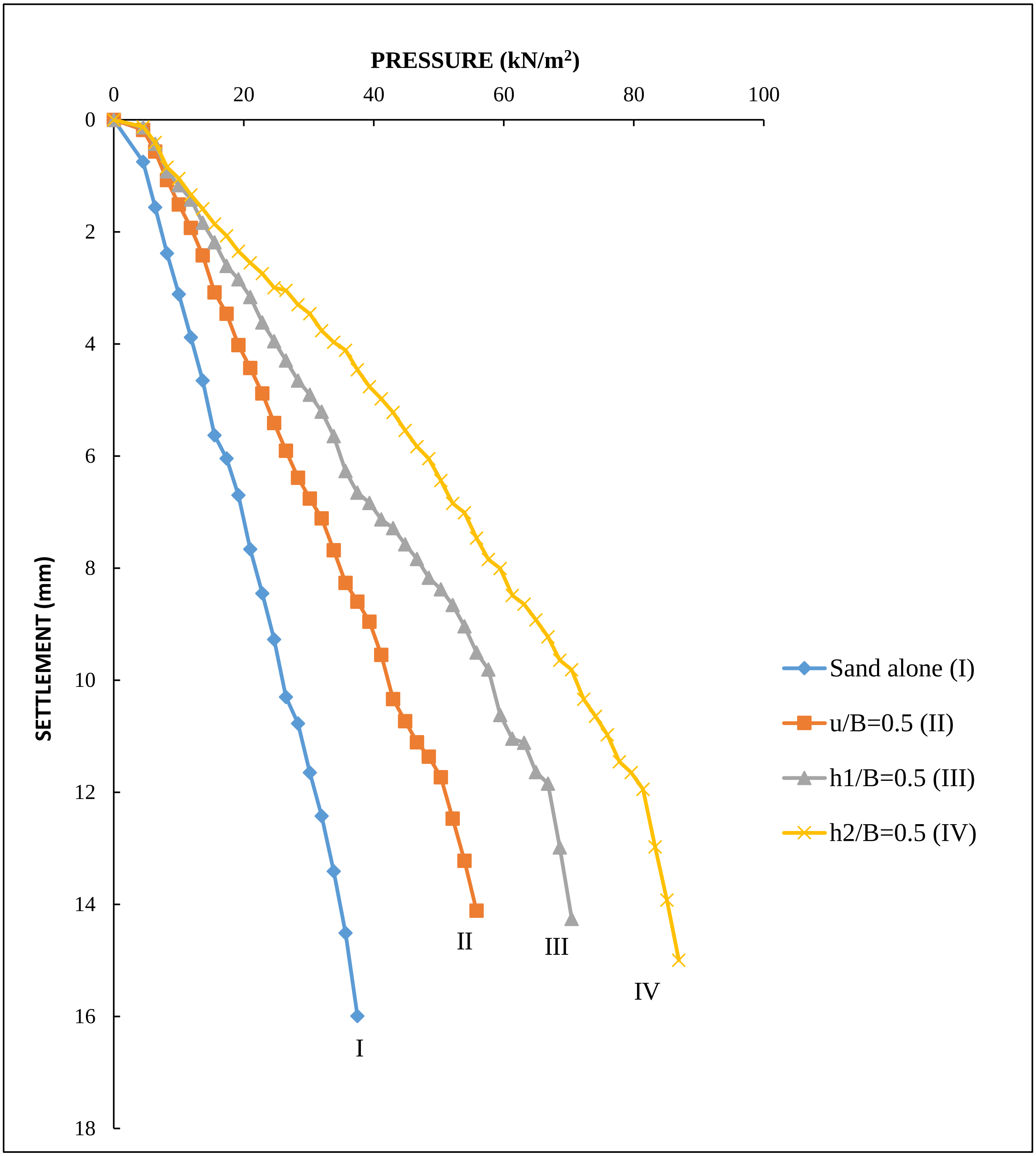

Figure 4.6: Pressure – settlement curve for Rectangular footing of size 15 cm x 40 cm with and without geotextile.

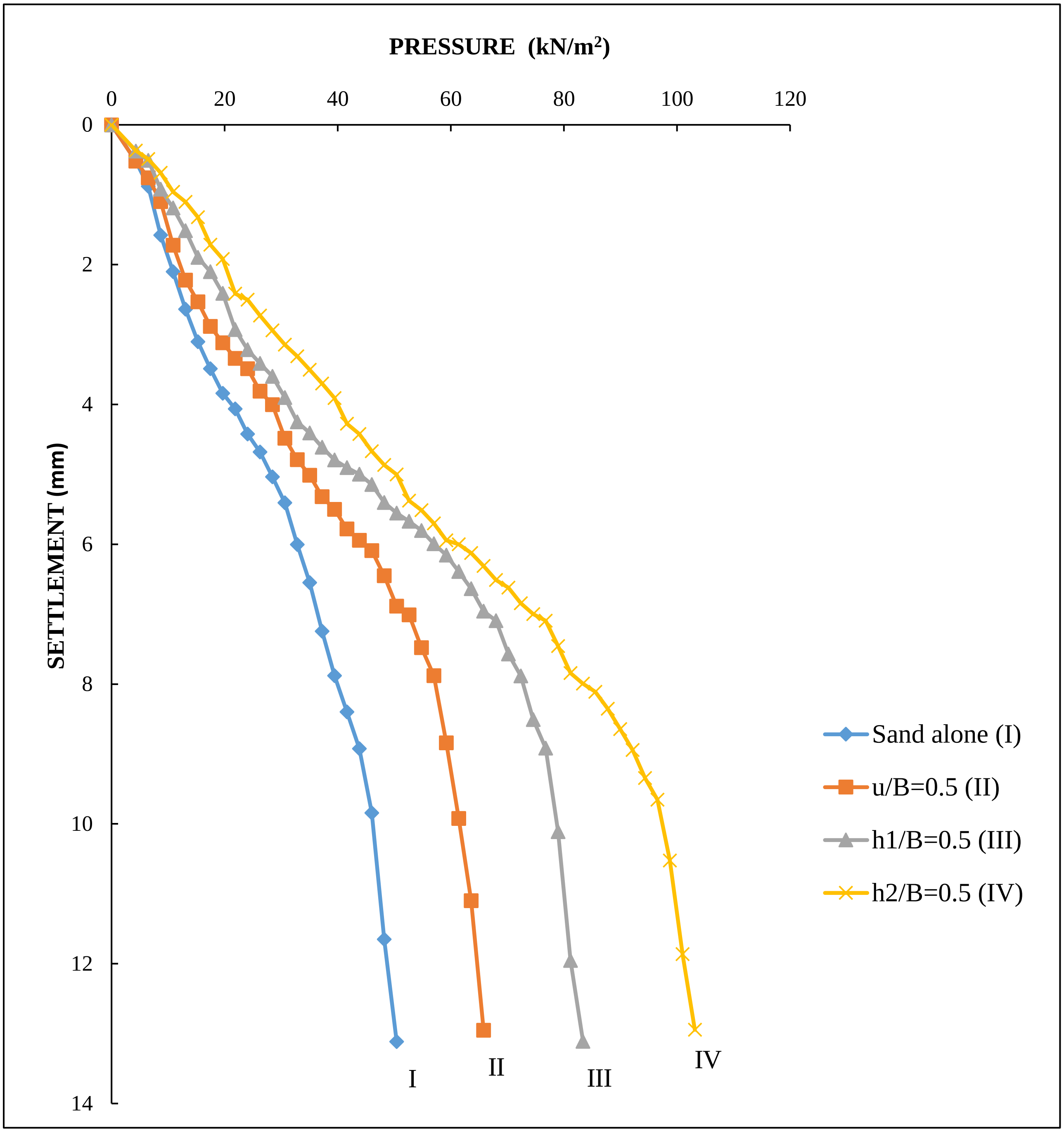

Figure 4.7: Pressure – settlement curve for Rectangular footing of size 20 cm x 50 cm with and without geotextile.

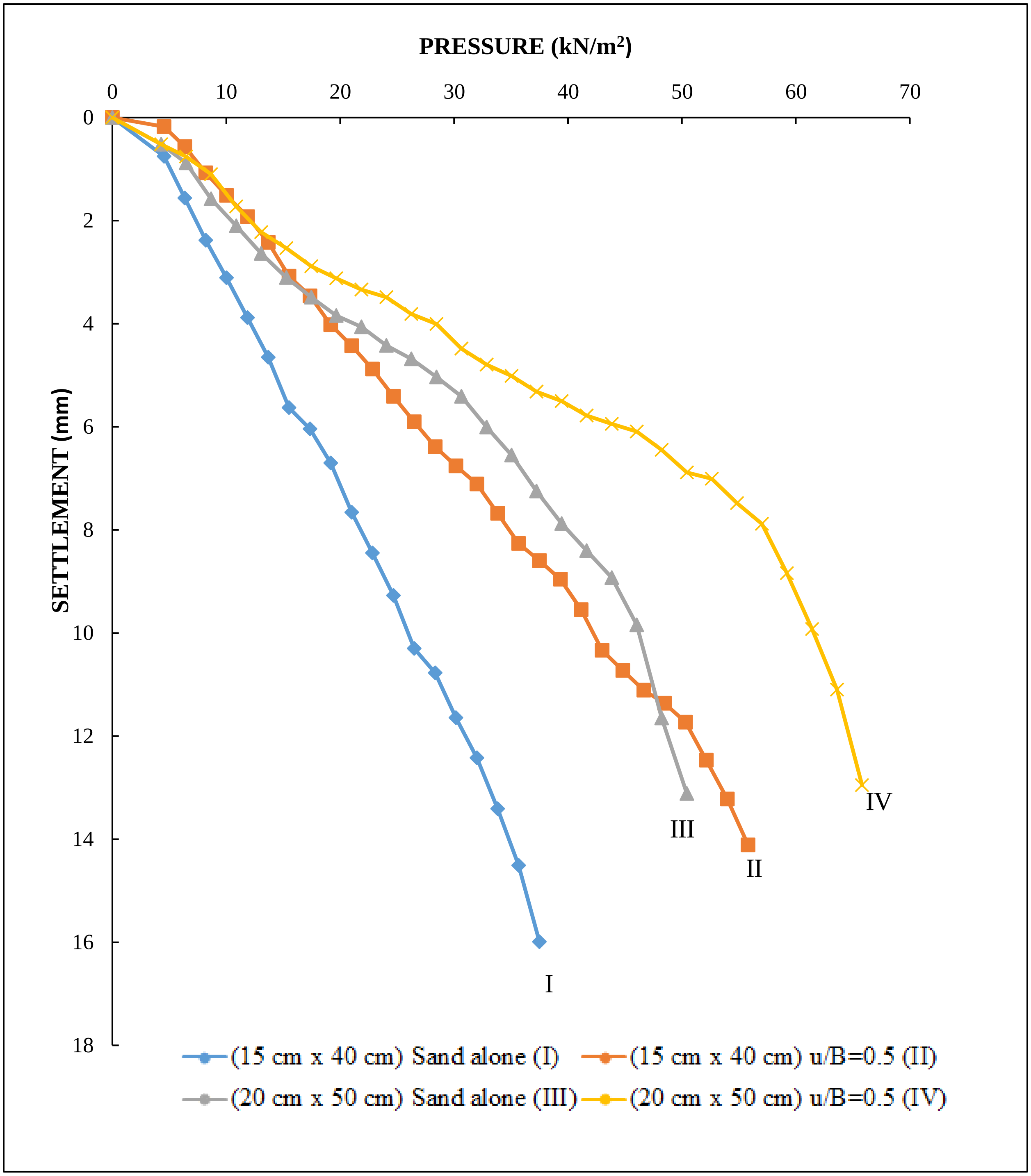

Figure 4.8: Comparison of Ultimate bearing capacity for Rectangular footings with one layer of geotextile (u/B=0.5).

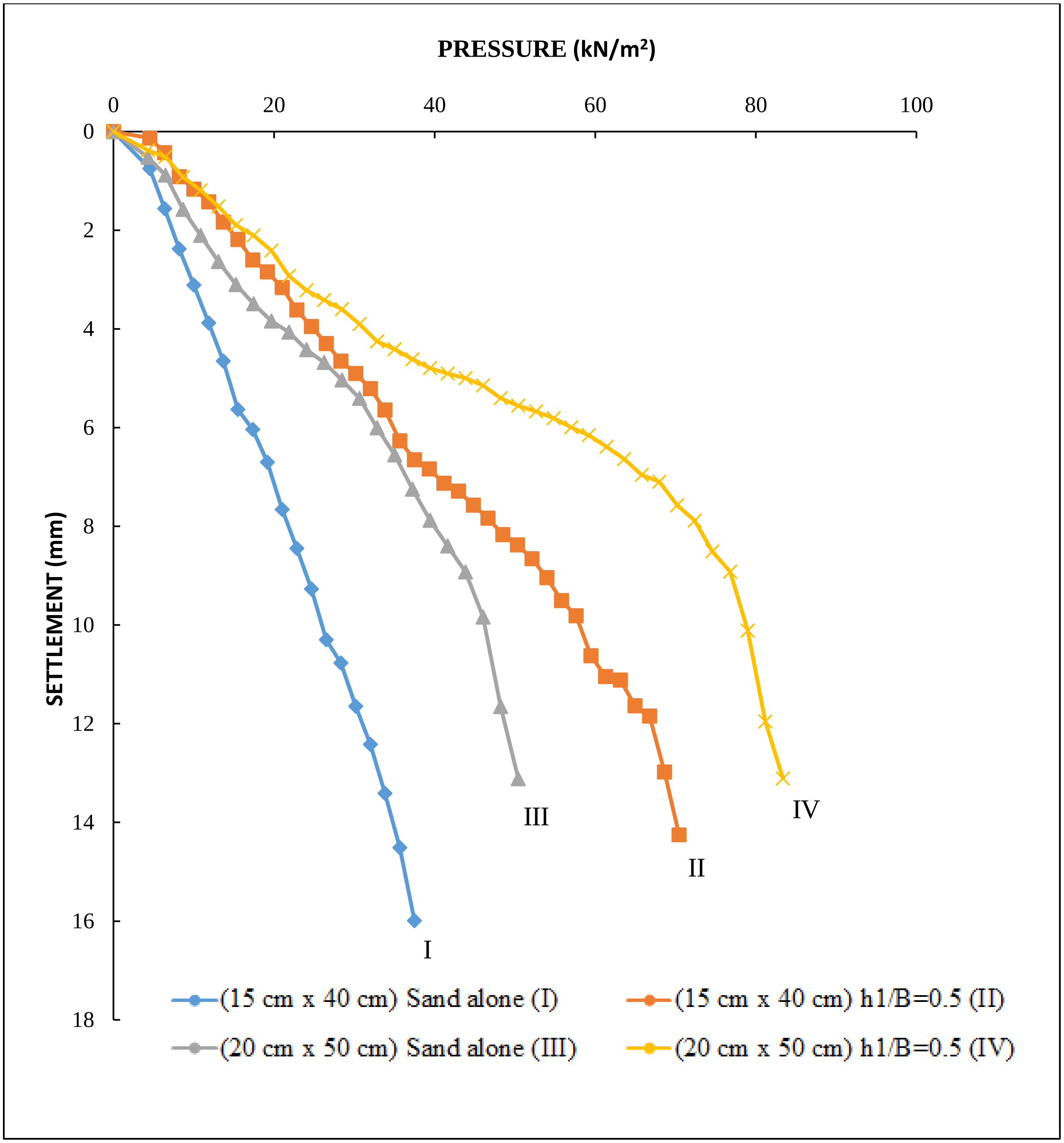

Figure 4.9: Comparison of Ultimate bearing capacity for Rectangular footings with two layers of geotextile (h_1/B=0.5).

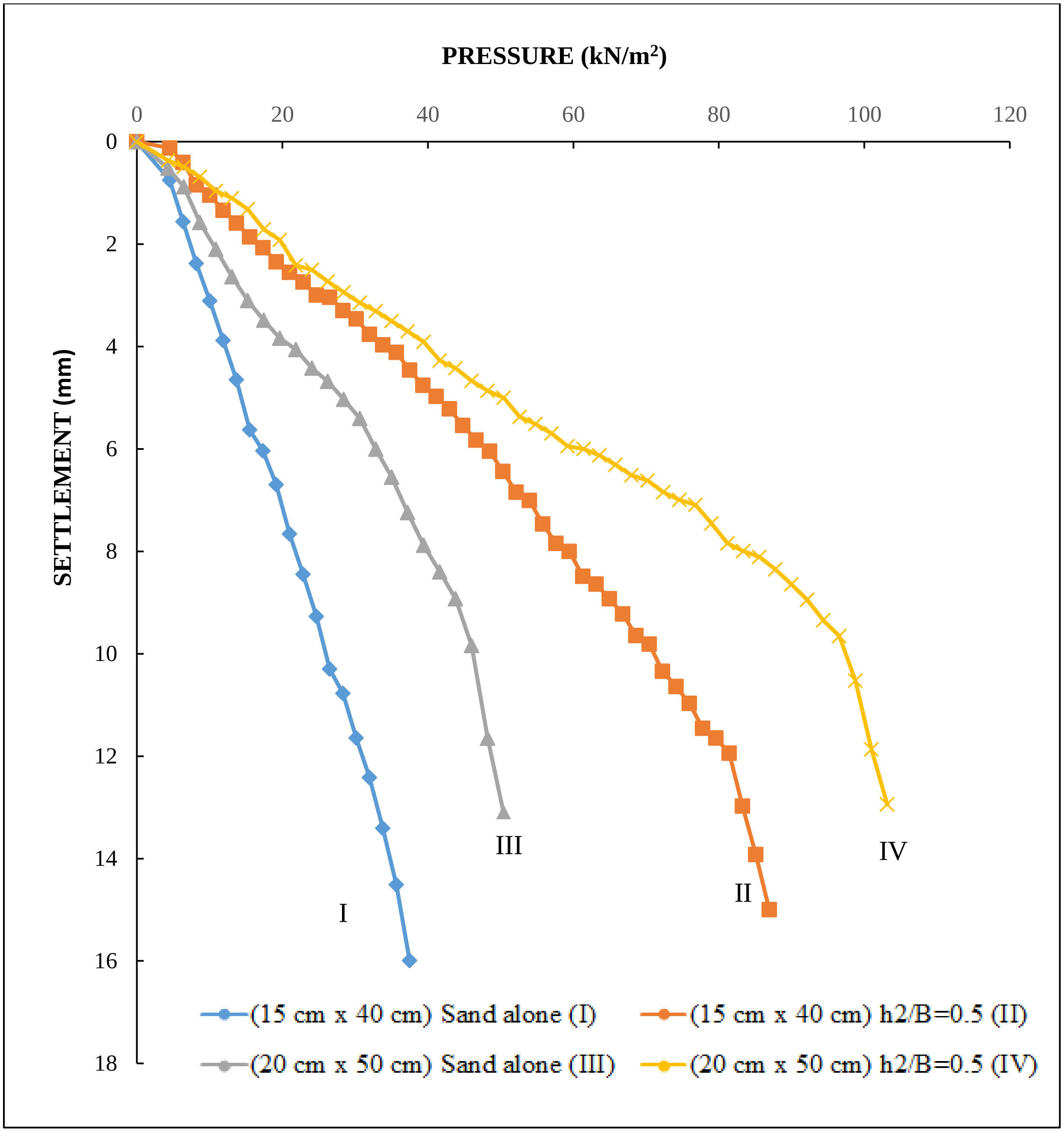

Figure 4.10: Comparison of Ultimate bearing capacity for Rectangular footings with three layers of geotextile ($h_2/B=0.5$).

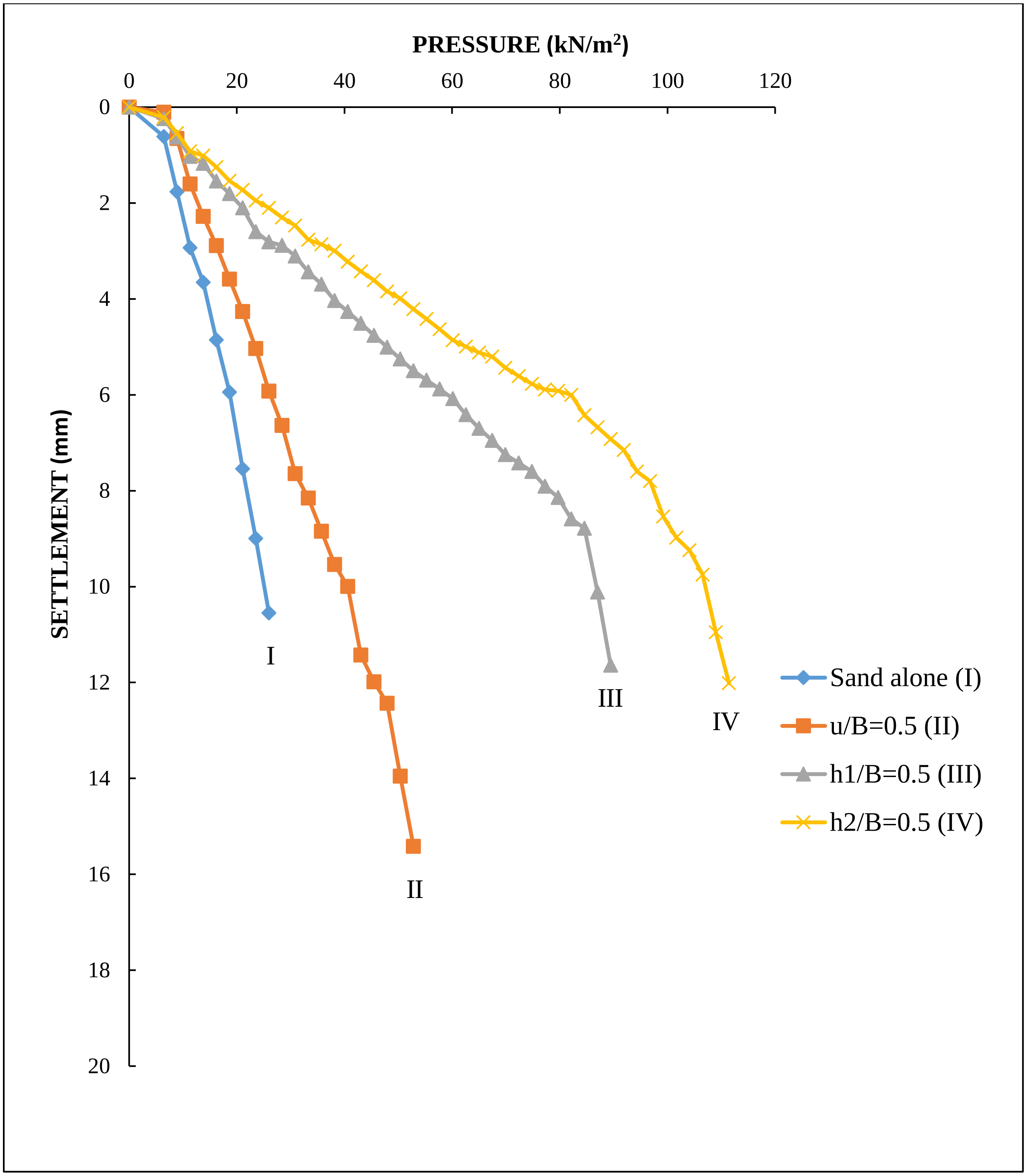

Figure 4.11: Pressure – settlement curve for Strip footing of size 7.5 cm x 60 cm with and without geotextile.

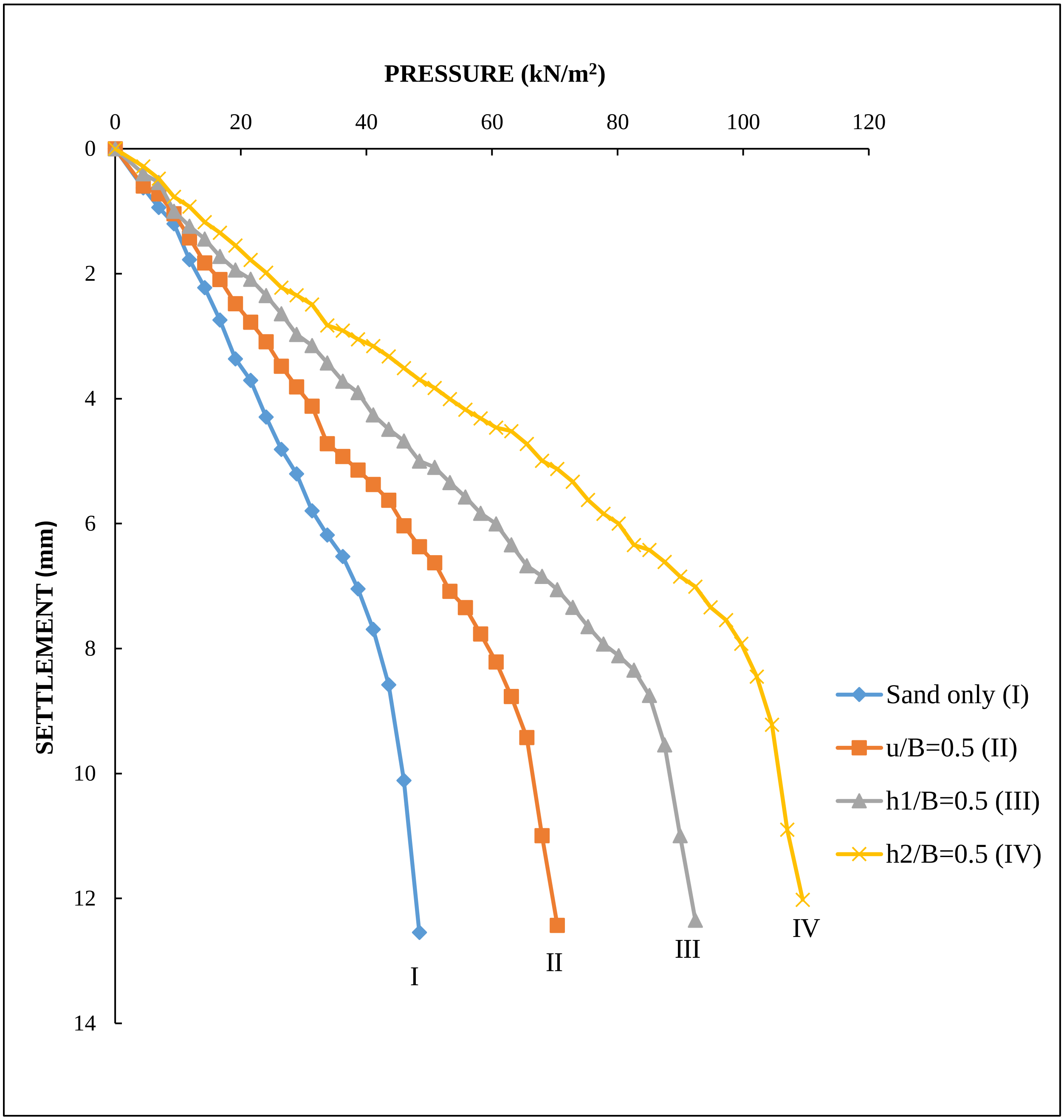

Figure 4.12: Pressure – settlement curve for Strip footing of size 15 cm x 60 cm with and without geotextile.

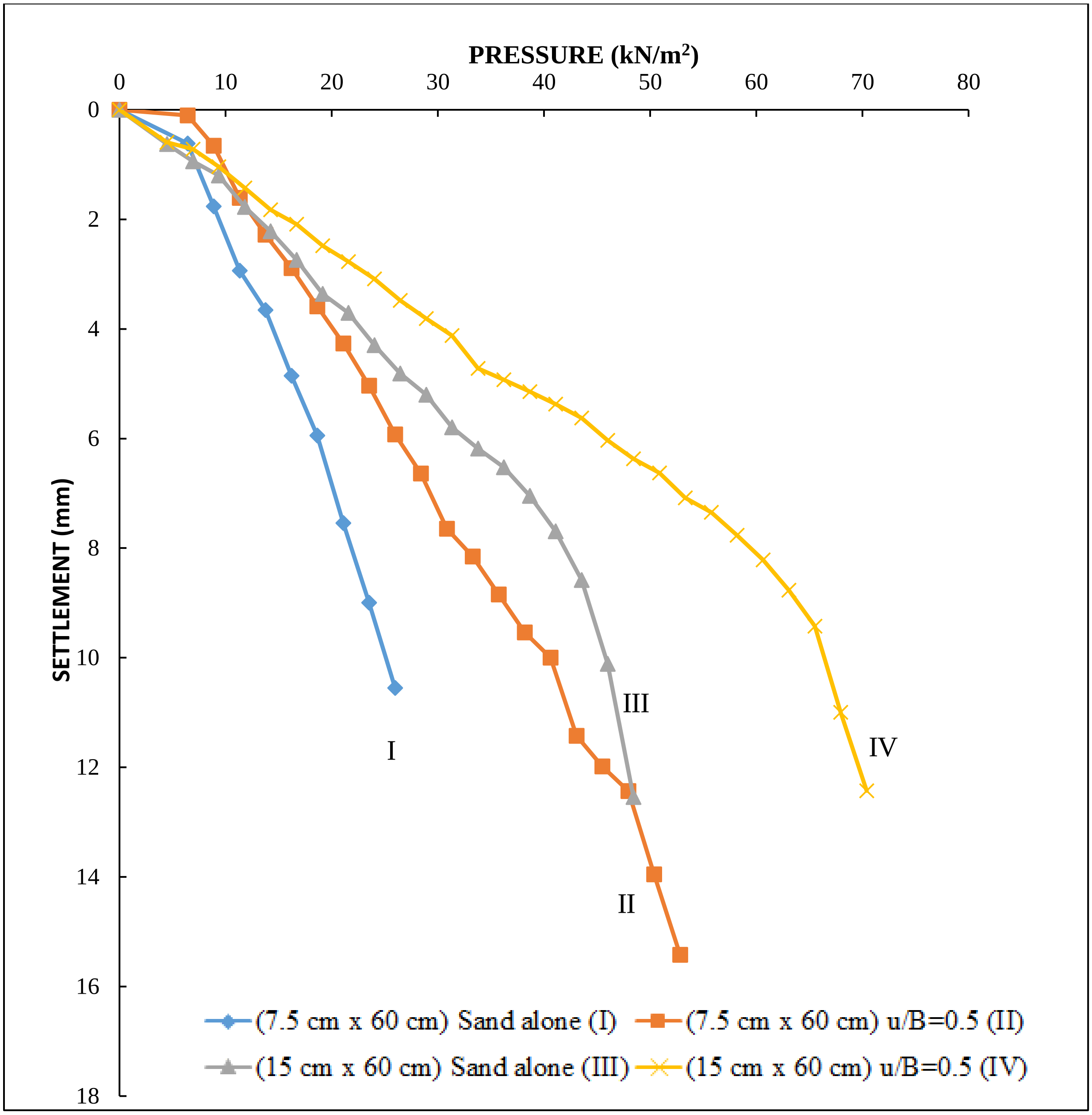

Figure 4.13: Comparison of Ultimate bearing capacity for Strip footings with one layer of geotextile (u/B=0.5).

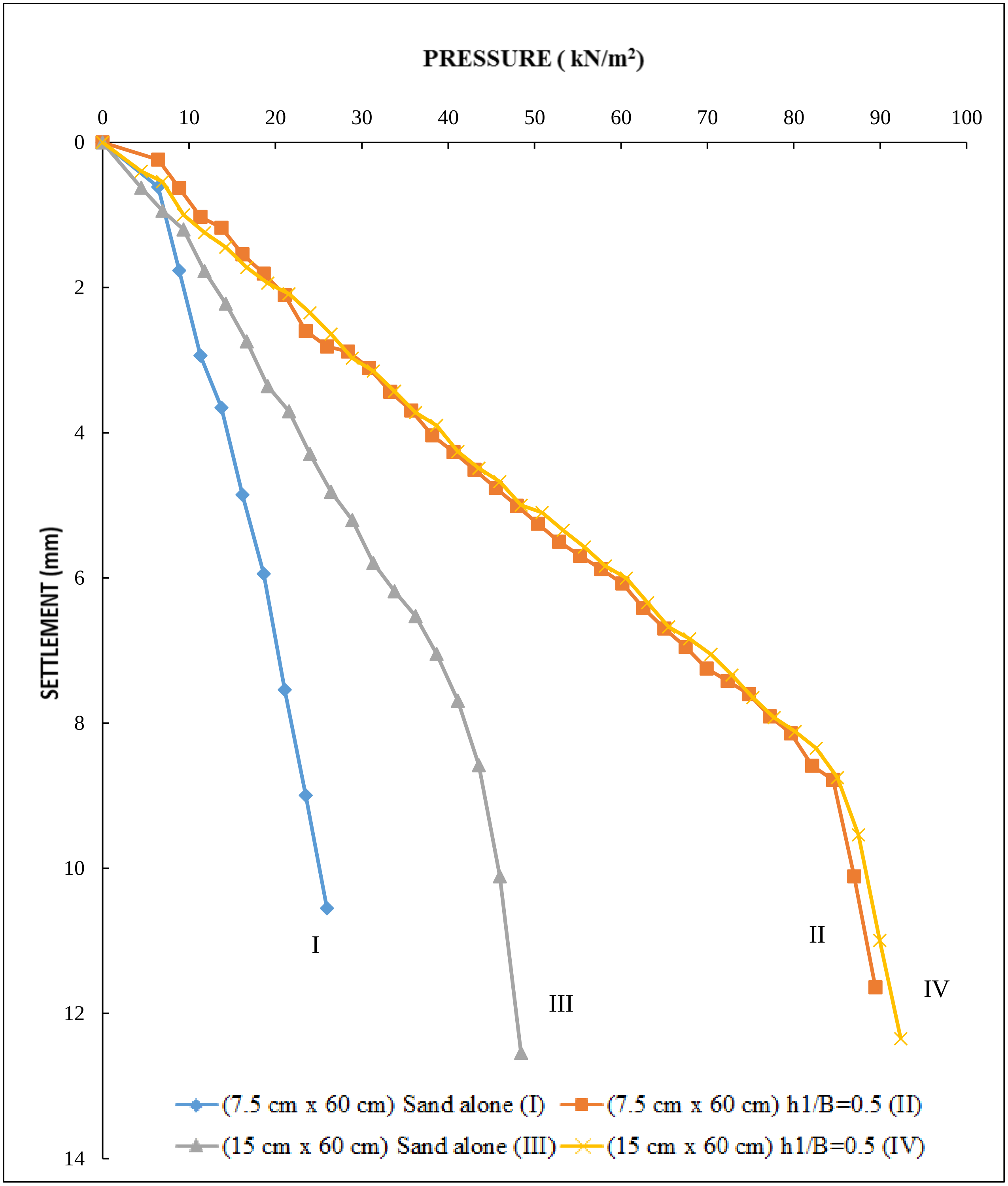

Figure 4.14: Comparison of Ultimate bearing capacity for Strip footings with two layers of geotextile ($h_1/B=0.5$)

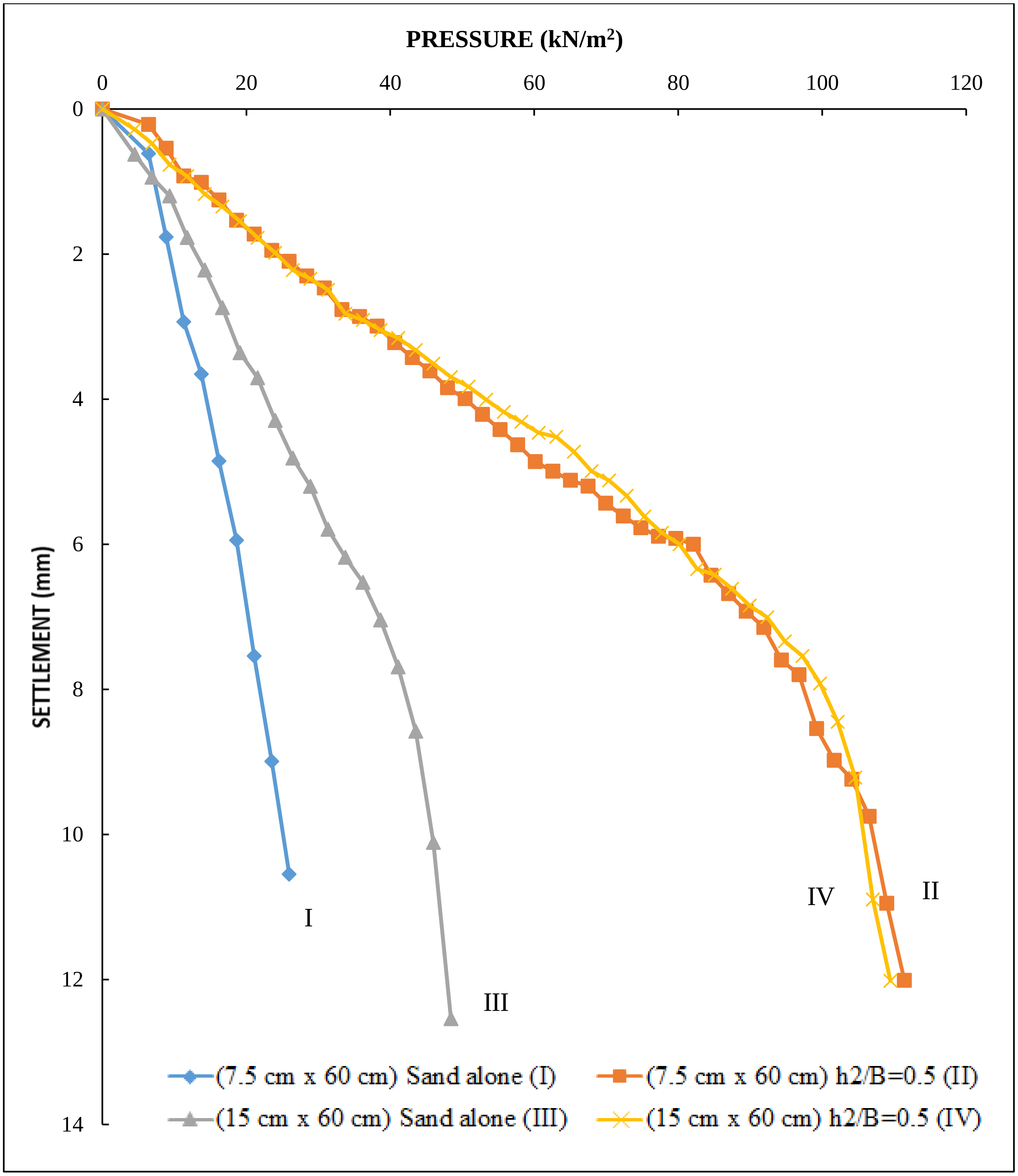

Figure 4.15: Comparison of Ultimate bearing capacity for Strip footings with three layers of geotextile (h_2/B=0.5).

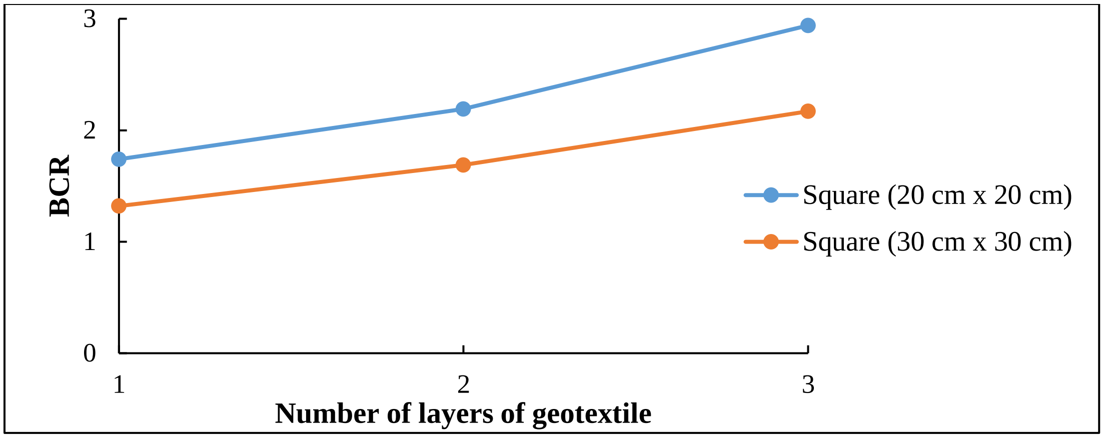

Figure 4.16: Comparison of BCR for square footings.

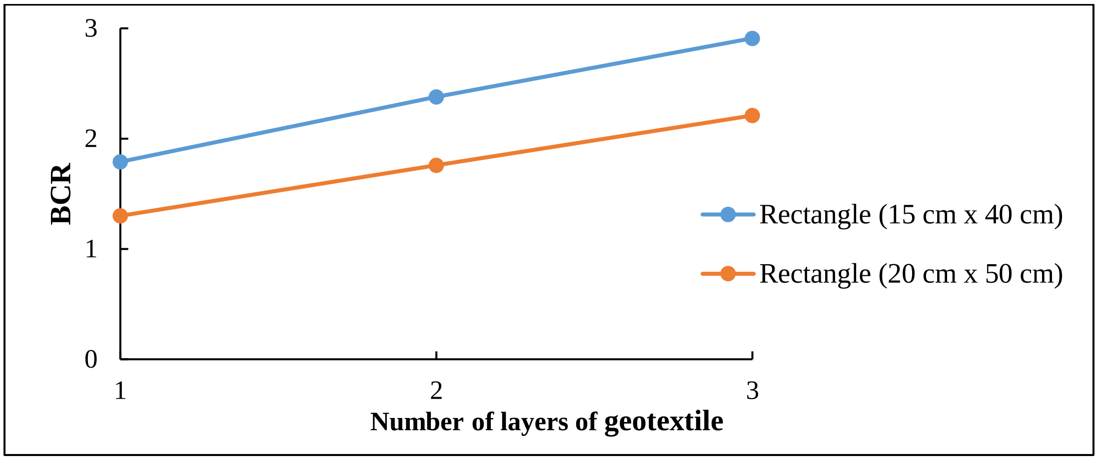

Figure 4.17: Comparison of BCR for rectangular footings.

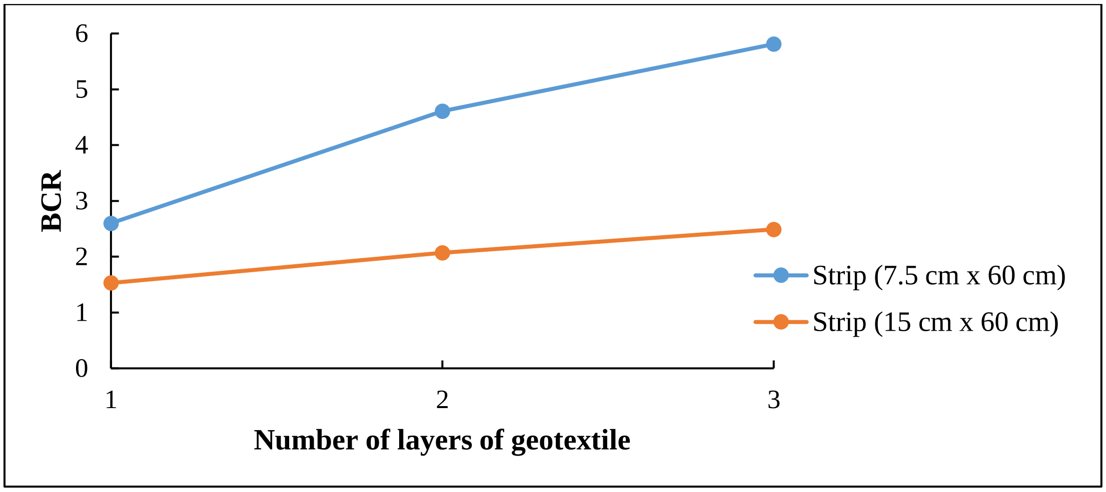

Figure 4.18: Comparison of BCR for strip footings.

CHAPTER-5

CONCLUSIONS

1. When compared with other geosynthetics, nonwoven geotextile has the advantage of high flexibility. Result shows that the ultimate bearing capacity of footings resting on nonwoven geotextile is achieved for a system of three layers with u/B=0.5 (u is the first depth of geotextile below the footing), h_1/B=0.5 ($h_1$is the second depth of geotextile below the first layer of geotextile) and h_2/B=0.5 (h_2 is the third depth of geotextile below the second layer of geotextile). Hence, ultimate bearing capacity values of nonwoven geotextile-reinforced sand are more than the unreinforced ones in all the cases.
2. The ultimate bearing capacity for square and rectangular footing for three layer of geotextile was found to be about three times the ultimate bearing capacity for unreinforced system. While for strip footing it is about six times the ultimate bearing capacity for unreinforced system.
3. For square footing of size 30 cm x 30 cm, percentage of BCR value with one layer of geotextile (u/B=0.5) decreases by 27.47% when compared to 20 cm x 20 cm, with two layer of geotextile (h_1/B=0.5), percentage of BCR value for 30 cm x 30 cm decreases by 25.22% as compared to 20 cm x 20 cm and for size 30 cm x 30 cm, percentage of BCR value with three layer of geotextile (h_2/B=0.5) decreases by 26.28% when compared to 20 cm x 20 cm.
4. For rectangular footing of size 20 cm x 50 cm, percentage of BCR value with one layer of geotextile (u/B=0.5) decreases by 26.97% when compared to 15 cm x 40 cm, with two layer of geotextile (h_1/B=0.5), percentage of BCR value for 20 cm x 50 cm decreases by 25.85% as compared to 15 cm x 40 cm and for size 20 cm x 50 cm, percentage of BCR value with three layer of geotextile (h_2/B=0.5) decreases by 23.34% when compared to 15 cm x 40 cm.
5. For strip footing of size 15 cm x 60 cm, percentage of BCR value with one layer of geotextile (u/B=0.5) decreases by 44.23% when compared to 7.5 cm x 60 cm, with two layer of geotextile (h_1/B=0.5), percentage of BCR value for 15 cm x 60 cm decreases by 57.05% as compared to 7.5 cm x 60 cm and for size 15 cm x 60 cm, percentage of BCR

value with three layer of geotextile ($h_2/B=0.5$) decreases by 59.55% when compared to 7.5 cm x 60 cm.

6. The BCR values for smaller footings were found to be greater than the larger footings.

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