Bearing Capacity of a Square Shallow Foundation with and without Geogrid Reinforcement

Geogrid 보강 여부에 따른 정방형 얕은 기초의 지지력에 관한 연구

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요지

본 논문은 향후 현장에서 유용하게 사용될 수 있는 사질토층에 있어서 정방형 얕은 기초의 지지력 향상을 위한 새로운 Geogrid 보강토 방법을 제시하고자 하였다. 기계 기초, 철로 제방, 그리고 지진 예상 지역의 구조물 기초 등에 대한 지반은 Geogrid로 보강하는 것이 필수적이다.

보강되지 않은 사질토층과 보강된 사질토층에 대한 지지력을 비교하였으며 또한 극한 지지력을 증대시키기 위해 보강재의 길이, 설치 간격 및 폭을 평가하였다. 모형 실험 결과 Geogrid 보강재는 중간 정도의 밀도를 가진 사질토층에서 극한 지지력이 상당량 증가됨을 알 수 있었다.

Abstract

This paper presents a new method to improve the bearing capacity of a square shallow foundation placed on a sand layer reinforced with geogrids which shows promise for further field work. The geogrid reinforcement will be necessary in the case of machine foundation, embankments for railroads, and foundations of structures in earthquake-prone areas. The ultimate bearing capacity (UBC) for the unreinforced sand and reinforced sand has been compared. Also, the effect of length, spacing, width of reinforcement on increasing the UBC have been evaluated. Based on the present model test results, it appears that significant improvement in the UBC of medium sand can be achieved by geogrid reinforcement.

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1. Introduction

1.1 General

The concept of improving weak and difficult subsoils for safe and economical construction has been in use for more than a century. Nowadays, Geosynthetics are used in increasing degree in various civil and environmental structures. The major function of geosynthetics can primarily be divided into five major categories. They are drainage, separation, reinforcement, filtration, and moisture barrier. Geogrids are primarily used as a reinforcement material in the construction of the backfill of earth retaining structures and stabilization of earth embankments. They are also used as reinforcement of base courses of paved and unpaved highways. However, it's utilization as a reinforcement for increasing the ultimate and the allowable bearing capacities of shallow foundations are widely tests by various researchers, federal and state highway authorities. At the present time, limited number of studies related to the use of geogrids as a reinforcing material for bearing capacity improvement are available in the literature.

1.2 Objective of Study

The applications of reinforced earth technology to date show that most of the work has been done with reinforcement laid horizontally. The beneficial effect of incorporating tensile reinforcement in the form of bamboo, fabrics, plastic membranes, metal strips, galvanized iron of various sizes and configuration have been reported by several investigators. However, the greatest disadvantage in using soil reinforcement is that backfill should also be a certain quality, i. e. it must be a granular material. If proper backfill materials are not available, it could pose practical problems for construction. Either the backfill materials have to be transported at additional cost or alternatively, another design approach may be needed which may not be cost effective. The present study is related to the evaluation of the beneficial effects of vertical reinforcement in sand relating to the UBC of square shallow foundation. A laboratory investigation was conducted to study the important parameters influencing the effectiveness of the vertical reinforcement in improving the load−settlement characteristics of sand subgrades by conducting a series of model test. Fig. 1 shows a schematic diagram of a square shallow foundation supported by sand reinforced with layer of geogrid (B=width of foundation, u=distance of the first layer of reinforcement from the bottom of the foundation, d=depth of geogrid reinforcement, N=number of geogrid reinforcement layers, and b=width of geogrid reinforcement).

2. Literature Review

Vidal[7], during his work in the French road research laboratory, developed a technique in which thin metal strips were used to reinforce the granular backfill for construction of retaining walls. This ultimately provided a new improved method for construction of earth retaining structures. The reinforcement used in the study of Binquet et al.(2, 3) was prepared by household aluminum foils. Fig. 2 shows a schematic diagram of a strip foundation supported by sand reinforced by metal strips. The ultimate bearing capacity (UBC) for this case will be equal to q_{ur} ($\geqq q_u$).

The increase in a nondimensional form as

$$BCR = \frac{q_{ur}}{q_u} \tag{1}$$

Where, BCR = bearing capacity ratio;

q_{ur} = UBC with the inclusion of reinforcement in soil;

q_{u} = UBC in unreinforcement soil.

By Binquet et al.(2, 3), the nature of failure surface in soil as shown in Fig. 2 is possible only if

$$u \;/\; B \doteqdot 0.67 \tag{2}$$

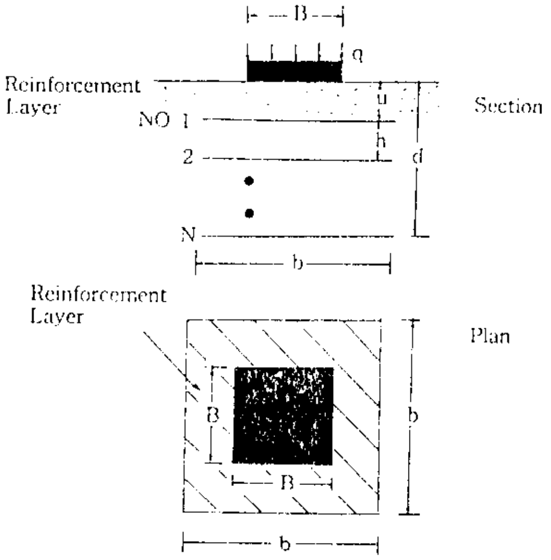


Fig. 1 Square foundation on sand reinforced with N number of reinforcement layers used for this study

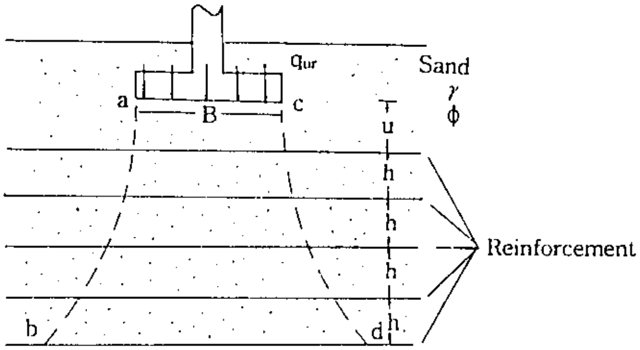


Fig. 2 Schematic diagram of a strip foundation supported by sand reinforced by metal strips

However, for u/B≥0.67, the failure surface in soil at ultimate load will be fully located above the top layer of reinforcement. In this case, the top reinforcement layer acts as a semirigid base located at a limited depth. Hence, in order to derive maximum benefit out of soil reinforcement, it is essential that u/B be kept at less than about 0.67. Guido et al.(5), have reported laboratory model test results on square surface foundations ($D_f=0$) supported by sand reinforced with layers of geotextile.

3. Test Parameters

This paper presents some laboratory model test results on a square foundation (B× B) supported by sand reinforced with layers of geogrid(Tensar BX 1000, SS0). When geotextiles and geogrids are for the soil reinforcement, the UBC as well as the settlement of the foundation at ultimate load increases compared that in unreinforced soil as shown in Fig. 3. In most cases, shallow foundations are designed for a limited settlement, s (Fig. 3); hence, it is essential to determine the BCR at various levels of settlement to aid in the design process of foundation. The BCR with respect to the settlement (BCRs) can be defined as:

$$BCR_s=\frac{q_r}{q} \tag{3}$$

Where BCR_s=BCR with respect to the settlement:

q_r and q = load per unit area on foundation at a settlement level, s, with and without reinforcement.

This study were performed on a square shallow model foundation to evaluate critical values of d/B, b/B, and u/B for mobilization of maximum BCR for a given sand-geogrid system. Also, the values of the UBC are compared to the unreinforced and the geogrid reinforced sand.

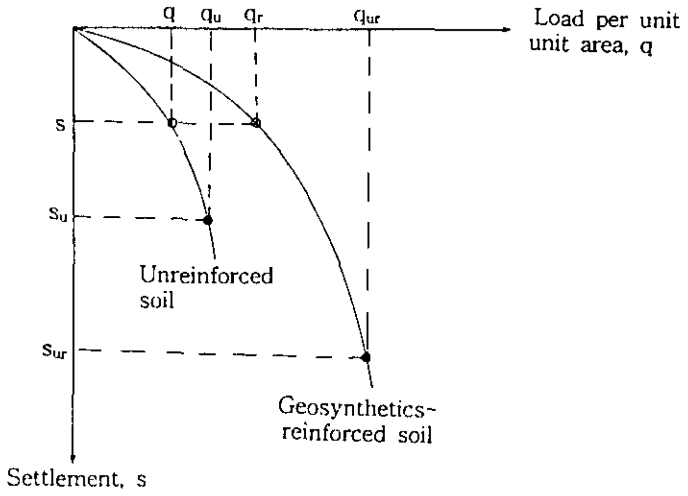


Fig. 3 General nature of load-displacement plots for unreinforced and geosynthetic-reinforced sand supported a shallow foundation

4. Laboratory Model Tests

4.1 Model Foundation

The laboratory bearing capacity tests were conducted using a model foundation, made of hard wood, with dimensions (B×B×t) of 76.2mm×76.2mm×3.8mm. To insure rigidity, an aluminum plate with the same dimensions as the model foundation was mounted on its top.

The base of the model foundation was made rough by cementing a thin layer of sand by epoxy glue. On top of the foundation, a hole was made to ensure that the applied centric load during model tests remained vertical (Fig. 4).

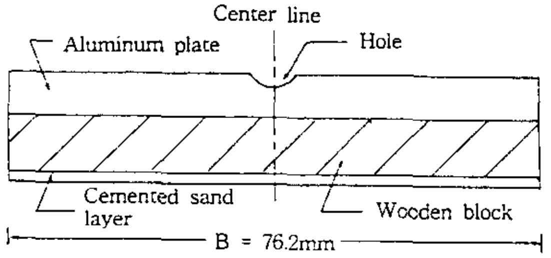


Fig. 4 Schematic diagram of the model foundation

4.2 Soil

A fine round silica sand (SM) was used for the model tests, and the grain-size distribution of the sand is shown in Fig. 5. the average physical properties of the sand during the laboratory tests are given in Table 1.

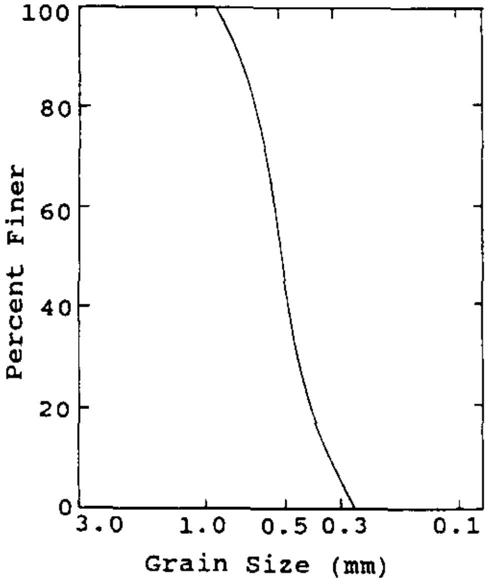


Fig. 5 Grain size distribution of sand for model tests

Table 1 Average physical properties of the sand

Parameter	Quantity
[a]Maximum dry unit weight, KN/m^3	18.94
[a]Minimum dry unit weight, KN/m^3	14.07
Dry unit weight during model tests, KN/m^3	17.14
Relative density of compaction during model test, %	70.00
[b]Angle of friction, ϕ, during model tests, deg.	40.30
Note: [a] ASTM test designation D-4253 [b] From direct shear test	

4.3 Geogrid

A biaxial geogrid [Tensar BX1000 (SS0) was used for reinforcement. The physical properties of the geogrid are given in Table 2. Fig. 6 show a typical configuration of a biaxial geogrid.

Table 2 Physical properties of the geogrid

Parameter	Description/Quantity
Structure	Punctured sheet drawn
Polymer	PP/HDPE co-polymer
Junction method	Unitized
Aperture size (MD/XMD)	25.4 mm / 33.02 mm
Natural rib thickness	0.762 mm
Nominal junction thickness	2.286 mm

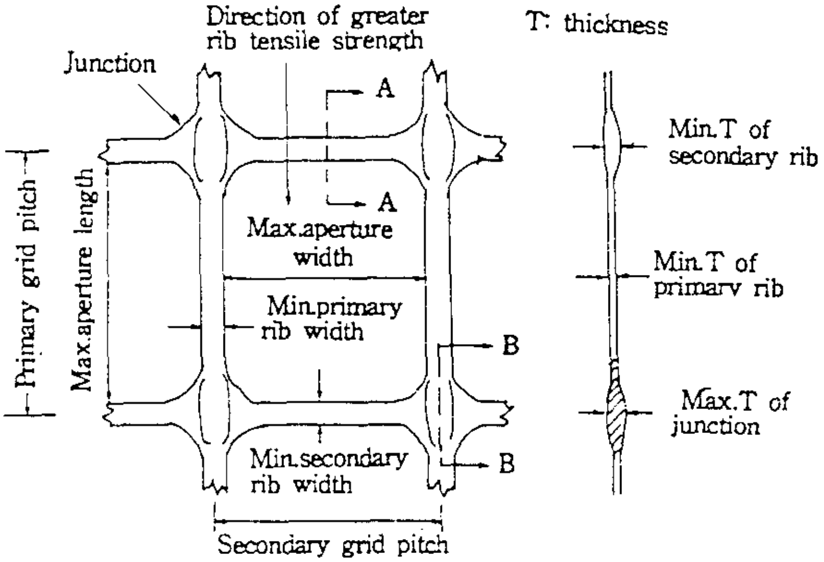


Fig. 6 Typical configuration of Tensar biaxial geogrid

4.4 Test Procedure

Laboratory model tests were conducted in a box measuring 760 mm x 760 mm x 760 mm. In conducting the tests, sand was poured into the box in 25. 4mm layers using a raining technique. Geogrid layers were placed in the sand at desired values of u/B and h/B (Fig. 1). After completion of the sand placement, the model foundation was placed on the surface of the sand layer. Load to the model foundation and the corresponding settlement was measured by a proving ring and two dial gauges until failure occurred. The details of model tests are given in Fig. 7 and Table 3.

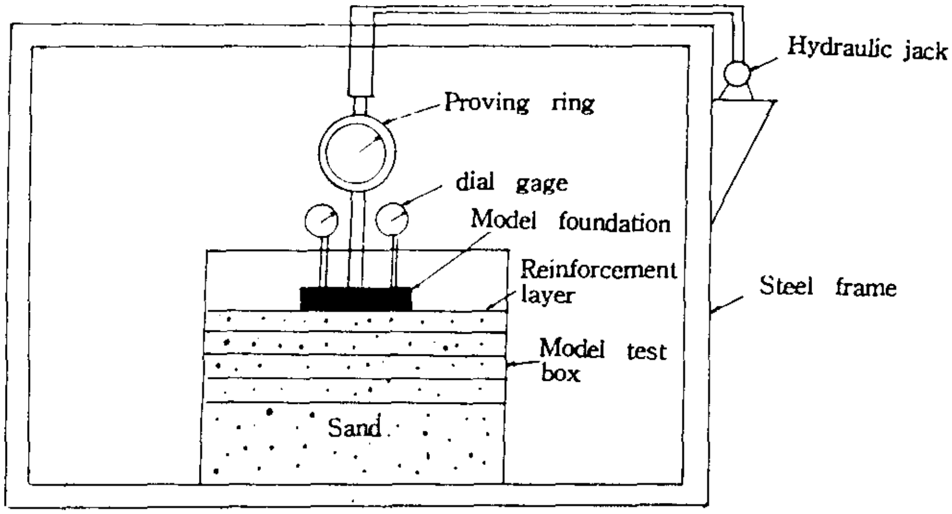


Fig. 7 Schematic diagram of laboratory test set-up

Table 3 Details of the model tests

Test series	Constant parameters	Variable parameters	Purpose
A	D_r = 70%		To determine q_u on unreinforced sand
B	D_r = 70% u/B = h/B = 1/3 b/B = 6	N = 1, 2, 3, 4, 5, 6	To determine $N_{cr,}$ $(d/B)_{cr}$
C	D_r = 70% u/B = h/B = 1/3 N = 4	b/B = 1, 2, 3, 4, 5, 6	To determine $(b/B)_{cr}$
D	D_r = 70% h/B = 1/3 N = b/B = 4	u/B = 0.333, 0.5, 0.667, 1.0, 1.2, 1.5, 1.8	To determine $(u/B)_{cr}$
E	D_r = 70% u/B = h/B = 1/3 N = b/B = 4		To determine q_{ur} on reinforced sand

5. Model Test Results

5.1 Test Series A

Fig. 8 shows the load-settlement behavior of unreinforced sand for a shallow square foundation. The load per unit area (q) increases with settlement (s) until it reached a maximum value of UBC (q_u). After the UBC is reached, the load per unit area decreases rapidly with the increase of settlement of the foundation. This type of load-settlement behavior is a general shear failure in soil. This was expected since the tests were conducted with sand at unit weight (γ) of 18. 94 KN / m_3 which corresponds to a relative density (Dr) of about 70%. This has been shown by Vesic(6).

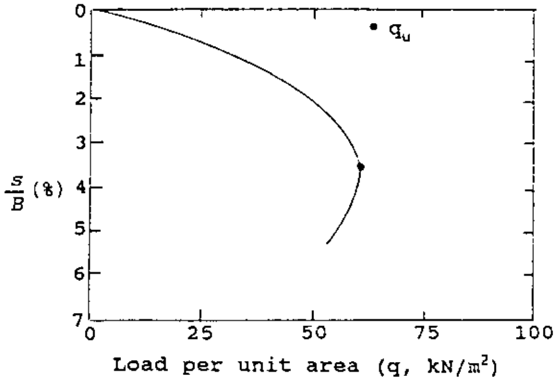


Fig. 8 Variation of q vs. s/B for Test Series A 5.2 Test Series B

5.2 Test Series B

Fig. 9 and 10 shows the variation of load-settlement behavior and BCR, respectively, with number of geogrid layers. It is evident that beyond 4 layers of geogrid, there is minimal increase of the BCR. Hence, the number of critical geogrid layer (N_{cr}) is 4 [$(d/B)_{cr}$ = 4]. This means that when the depth of reinforcement exceeds about 1. 33B, no further significant beneficial effects of reinforcement can be obtained. Also, when the depth of the reinforcing layer exceeds about 2B, the BCR does not increase any further. Similar results for different reinforcing materials were observed by Binquet et al.(2, 3), Akinmusuru(1) and others.

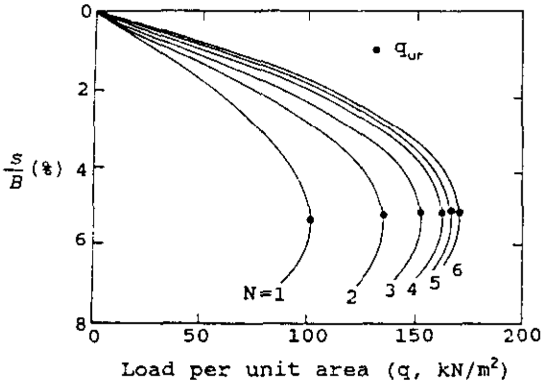


Fig. 9 Variation of s/B vs. q_r for Test Series B

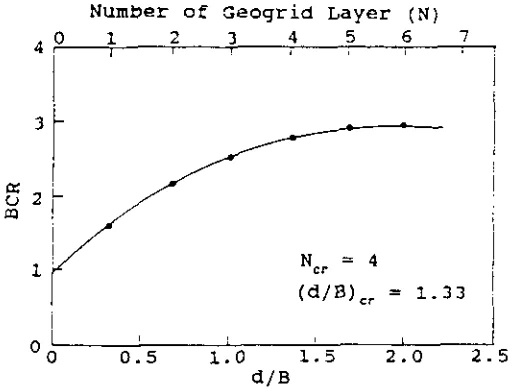
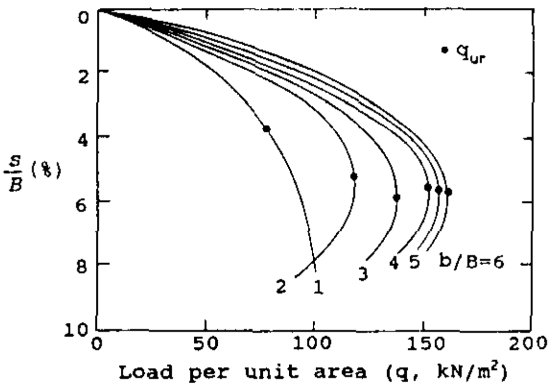


Fig. 10 Variation of BCR vs. N for Test Series B

5.3 Test Series C

From Fig. 11 and 12, it was confirmed that b/B reached its optimum value approximately at 4, after which additional width of geogrid reinforcement was ineffective. Similar results have been observed by Fragaszy et al.(4) and Guido et al.(5) for different reinforcing materials.



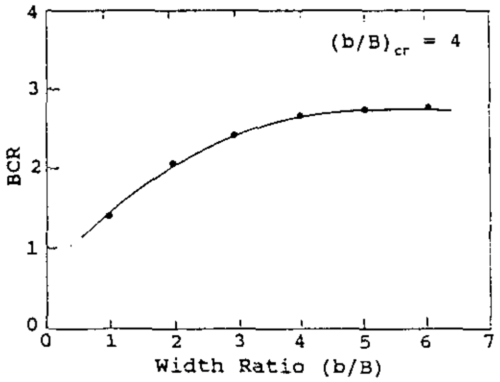


Fig. 11 Variation of s/B vs. q_r for Test Series C

Fig. 12 Variation of BCR vs. b/B for Test Series C

5.4 Test Series D

The experimental variation of BCR with u/B obtained from the test is shown in Fig. 13. In Fig. 13, the variation of BCR with u/B can be approximated by two straight lines. The magnitude of u/B at the point of intersection of the two straight lines may be defined as $(u/B)_{cr}$. For the result, $(u/B)_{cr}$ is about 0. 7 to 0. 8. While performing the experiments, it was observed that for u/B 〉 1, the foundation failed abruptly and the sand on the side of the foundation showed significant bulging. However, for u/B 〈 1, the punching or general shear failure pattern was obtained. Similar results were obtained by Akinmusuru et al.(11)

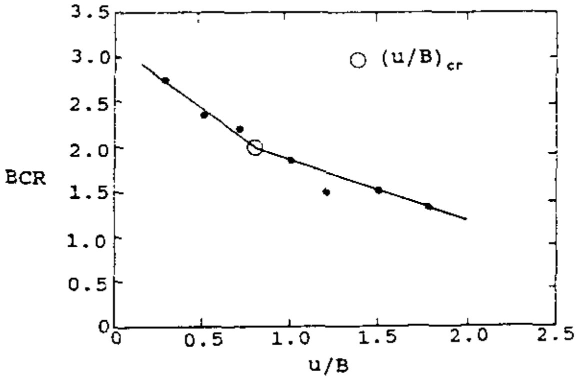


Fig. 13 Variation of BCR vs u/B for Test Series D

5.5 Test Series E

This series E was conducted to determine the static UBC of a shallow square foundation on geogrid reinforced sand. Fig. 14 shows that the load per unit area increases with settlement up to the peak value, $q_{ur}=162.7$ KN/m_2, and it decreases suddenly thereafter with increasing settlement.

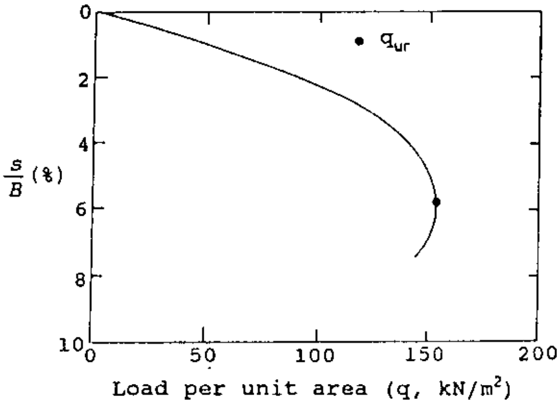


Fig. 14 Variation of s/B vs. q_r for Test Series E

5.6 Comparison of the Permanent Settlement of the Foundation with and without Geogrid Reinforcement (Test Series A and E)

Since Tests Series A and E were conducted with the same materials, the effect of reinforcement on permanent settlement can be seen by comparing the results of these tests. From Fig. 15, the values of the load per unit area is substantially larger in reinforced soil as compared to the unreinforced soil with the small increases of the magnitude of ultimate settlement (s_u).

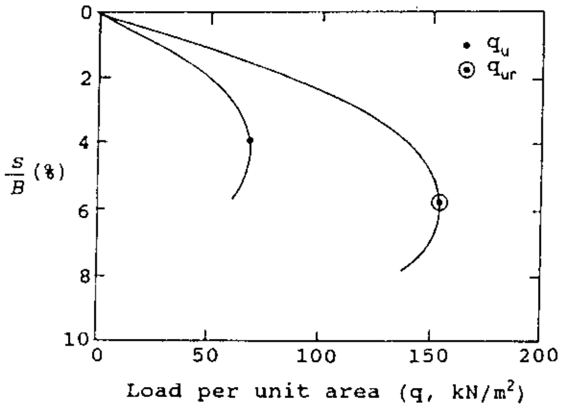


Fig. 15 Comparison of the permanent settlement(s) of the foundation with and without geogrid reinforcement

6. Conclusions

A number of laboratory model tests were conducted on a square shallow foundation supported by sand with and without critical geogrid reinforcement. The improvement in the UBC of reinforced sand subgrades depends upon the spacing, length, and extent of the reinforcing elements. Based on the model tests results, the following conclusions can be drawn;

1. For deriving the maximum benefit of soil reinforcement towards improving the bearing capacity, the critical values for geogrid layers are as follows: $(d/B)_{cr} \approx 1.33$, $(b/B)_{cr} \approx 4$, and $(u/B)_{cr} \approx 0.7$ to 0.8.
2. The value of UBC are about 2. 5 times in reinforced soil as compared to the unreinforced soil with the small increases of the magnitude of ultimate settlement.

The beneficial effects of using geogrid reinforcement in improving the load-settlement behavior of sand subgrades have been demonstrated through series of laboratory model tests.

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