A study on reduction of base course thickness by stress dispersion effects and strength and deformation characteristics of geocell reinforced base course

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ABSTRACT: Geocell construction method is one of the method using geosynthtics. By using Geocell for base course, it is expected that the bearing capacity can increase. However, the effect of Geocell on the lower part of the geocell has not been clarified. From the past research, when geocell has small cell and high stiffness, reinforcement effects of the bearing capacity and stress reduction effect were shown to be obtained. In this study, two types of load test were conducted with a ground model produced with the aim of examining the reduction in thickness of subbase, based on the findings as to characteristics of bearing capacity and deformation of ground with geocell and stress distribution effects in the case of laying geocell from among a series of studies clarifying design standards and design methods for subbase reinforced by geocell.

Keywords: Geocell, Base course, Stress reduction effects

1 INTRODUCTION

Geocell, reinforcing material of ground, is used for various purposes such as covering slope faces, reinforcing inclined planes, improving the bearing capacity of subbase and soft ground, etc. because it excels in workability as well as it is light. In recent years, studies concerning design methods have been conducted for reinforcement of inclined planes and foundations of structures, and the use of the geocell method has been being promoted. Cases in which it is used in combination with other reinforced earth methods have particularly increased, and studies in which geocell and geogrid are used together report that reinforcement effect of mattress significantly improves because of the tensile force of geogrid. A new construction method using geocell has been being developed especially for reinforcing inclined planes. On the other hand, it has been clarified that even in the case in which geocell is used to reinforce subbase, ground materials filled in geocell grids are bound by loaded load to form strong slab-shape structure. Thus, effects such as improvement of bearing capacity, restraining settlement, and dispersing stress are expected. However, design standards and design methods have not been established yet because these effects are yet to be quantified clearly. Furthermore, geocell studies taking design standards for pavement into consideration are few. For this reason, domestic use of geocell for reinforcing subbase is mostly that for temporary roads for construction purposes or private use at present.

On the other hand, studies concerning subbase reinforcement by geocell have made a progress abroad, and geocell is applied to subbase. In the series of studies conducted Hans, et al or the series of studies conducted by Kief, et al, it is suggested that it is possible to considerably reduce the thickness of pavement, based on the deformation volume of the surface and the reduction of stress distributed under geocell when a ground model for which geocell-reinforced subbase is assumed is loaded with traffic load. It is also reported that reduction in thickness of pavement can reduce material and construction cost as well as environmental burden. For this reason, it is important to examine the applicability of geocell to subbase reinforcement in Japan too, and it is necessary to clarify its effects and values when geocell is applied to subbase reinforcement. Furthermore, it is also necessary to understand dynamic characteristics of subbase with geocell in order to clarify design standards and design methods as its applicability is examined.

In this study, two types of load test were conducted with a ground model produced with the aim of examining the reduction in thickness of subbase, based on the findings as to characteristics of bearing capacity and deformation of ground with geocell and stress distribution effects in the case of laying geocell from among a series of studies clarifying design standards and design methods for subbase reinforced by geocell.

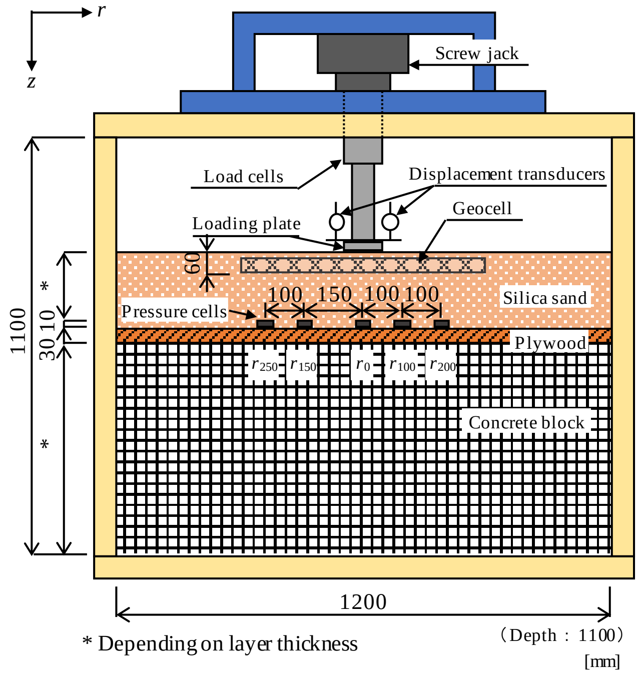

Figure 1. Outline of model ground

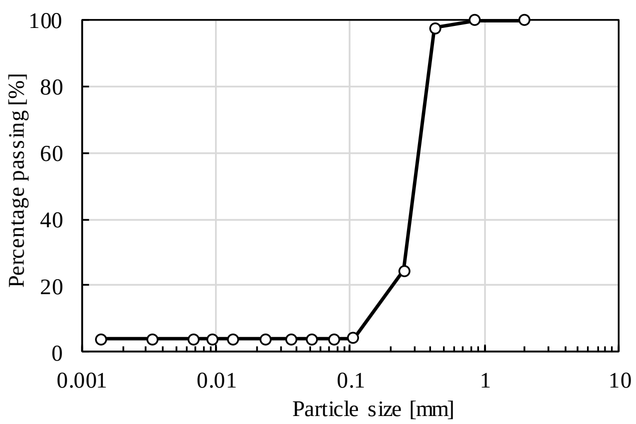

Figure 2. The grading curve of the silica sand

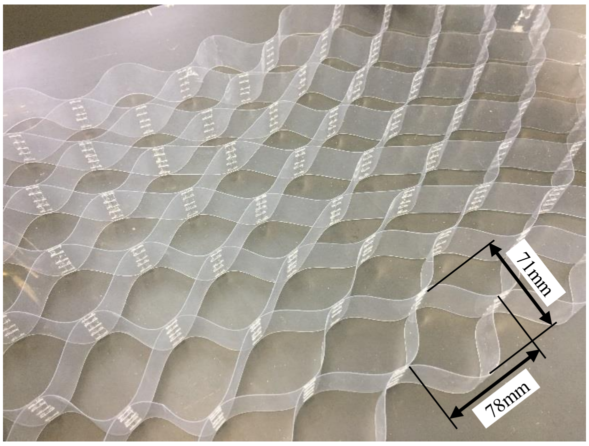

Photo 1. Geocell used in this study

2 MODEL GROUND AND MATERIALS

In this study, a ground model for which a geocell-reinforced subbase is assumed is prepared in a steel model ground with the width of 1200 mm, the depth of 1100 mm and the height of 1100 mm as shown in Figure 1. In order to grasp the dynamic characteristics of geocell-reinforced subbase, the part of the ground model composed of silica sand was assumed to be subbase, the part under it was assumed to be subgrade, and hard concrete blocks were used for the subgrade part in order to make the strength uniform. Plywood and vinyl tape were used between the subbase part and the subgrade part so as to prevent the silica sand from flowing into the subgrade part. Because the center of the surface of the ground model was the loading part, it was assumed that friction between the side of the model ground and the silica sand layer had no influence.

Silica sand No. 6 in air-dry state (ρ_s=2.638 g/cm^3 , D_{50}=0.31mm , e_{max}=0.843 , e_{min}=0.524) was used for the silica sand layer, and the density was adjusted by using a vibrator apparatus so that the relative density would be D_r=80%. The grading curve of the silica sand is shown in Figure 2.

A geocell model was prepared, as shown in Photo 1, with cells whose size was 78 mm by 71 mm with the height of 38 mm each, based on the size of standard geocell used in the past studies. The size of the geocell was 7 cells by 7 cells, based on the laying width and laying height that produces the slab-shape reinforcement effect obtained by the previous studies. Geocell material was prepared by processing 0.3 mm-thick vinyl chloride board, stapling it in five places at a joint with a stapler. The geocell model used in this study does not match real geocell in strength by similitude. However, material easy to process is used because the study aims at a qualitative comparison between existence and nonexistence of geocell. As for the laying position of geocell, it was laid at the depth of 60 mm from the surface of the model ground so that the surface of the laid geocell would be horizontal to the model ground.

3 TEST METHOD

3.1 *The step cyclic loading test*

These tests were conducted by the step cyclic loading test, based on the JGS 1521 "Method for plate load test" to examine the deformation behavior of ground in which geocell is laid. As for the test type, only the thickness of 150 mm is used for the silica sand layer as shown in Table 1, and the comparison was made between existence and nonexistence of geocell under this condition. For the thickness of the silica sand layer, only 150 mm was used in order to grasp only the influence by geocell. Loaded load is increased or decreased by 0.2 kN (load pressure 25.46 kN/m^2) from stage to stage, as shown in Figure 3. Eight stages in total were divided into four cycles, and loading was repeated. The quantity of settlement of the load plate was measured under this condition. The loading and unloading rates were set to 200 kN/m^2/min. The period of time in which load is maintained was 15 minutes for first-time loading, but it was 2.5 minutes for reloading and unloading. For the load plate, a round column with the diameter of 100 mm weighing 1700 g was used. In the case that it was difficult to load a scheduled load, that load pressure was considered the maximum bearing capacity and testing was terminated.

Table 1. Test types of the step cyclic loading test

Test method	Geocell	Silica sand layer thickness [mm]	Concrete block layer thickness [mm]
Staged repetitive loading	Non-reinforced	150	620
	Use (Reinforced)		

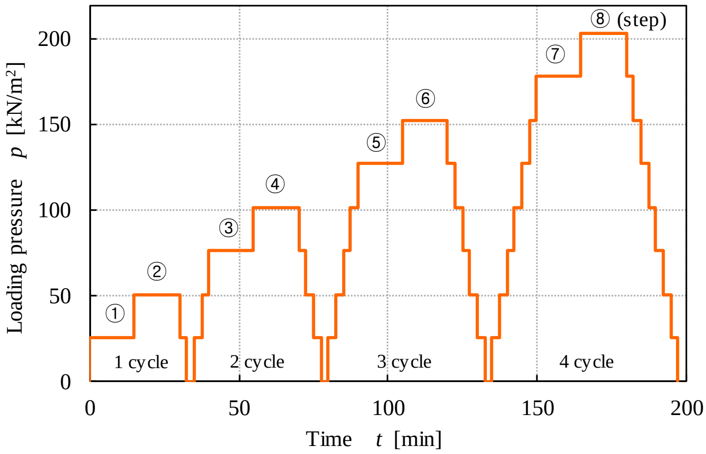

Figure 3 Loading condition of the step cyclic loading test

3.2 *The constant strain rate loading test*

In these tests, loading was done at a constant strain rate in order to see the stress state inside the ground in which geocell is laid. Because of this, in-ground vertical stress σ_z was measured with earth pressure gauges placed directly under the load and at places at horizontal distances of 100 mm (r_{100}), 150 mm (r_{150}), 200 mm (r_{200}), 250 mm (r_{250}) from there in the bottom-most part of the silica layer. Test types varied according to the thickness of the silica layer, namely 100 mm, 150 mm, and 200 mm, as shown in Table 2. This condition was set to grasp the influence by the thickness of the silica sand layer. Under each condition, comparison was made between existence and nonexistence of geocell. Testing was done by loading load on the surface of each model ground at a constant speed of 1.0 mm/ min. In-ground vertical stress was measured until the quantity of settlement of the load plate reaches 15.0 mm. The load plate used was the same as that used in the multistage repetitive loading tests.

Table 2. Test type of constant strain rate loading test

Test method	Geocell	Silica sand layer thickness [mm]	Concrete block layer thickness [mm]
Constant speed loading	Non-reinforced	100	670
	Use (Reinforced)		
	Non-reinforced	150	620
	Use (Reinforced)		
	Non-reinforced	200	570
	Use (Reinforced)		

4 TEST RESULTS AND DISCUSSION

4.1 *The step cyclic loading test*

4.1.1 *Bearing capacity characteristics*

Figure 4 shows the relationship between load pressure p and settlement S by existence or nonexistence of geocell obtained from the multistage repetitive loading tests. The figure shows that maximum bearing capacity is reached at the maximum load pressure of 152.8 kN/m2 of the third cycle under the condition of no reinforcement and that loading became difficult at the fourth cycle. On the other hand, under the condition of geocell reinforcement, load pressure increased compared to no reinforcement condition, and in the log p-S curve graph, the point at which the curve becomes nearly parallel to the settlement axis, i.e. 203.7 kN/m2, is designated at the maximum bearing capacity. Therefore, it was shown that laying geocell increases bearing capacity approximately 1.33 times. It is considered that filling materials in geocell received vertical load, creating horizontally spreading force, which geocell bound, resulting in the increased bearing capacity. To judge the maximum bearing capacity, JGS 1521 is referred to.

The undulation of the surface of the ground was observed in a wide area around the load plate under the no reinforcement condition after loading is completed, but the change was observed to be small under the geocell-reinforcement condition. It is considered from these facts that because geocell had been laid, silica sand flowing horizontally under the load plate was bound, suppressing the shear fracture of the whole ground and that it suppressed the undulation of the ground and dramatically increased the bearing capacity.

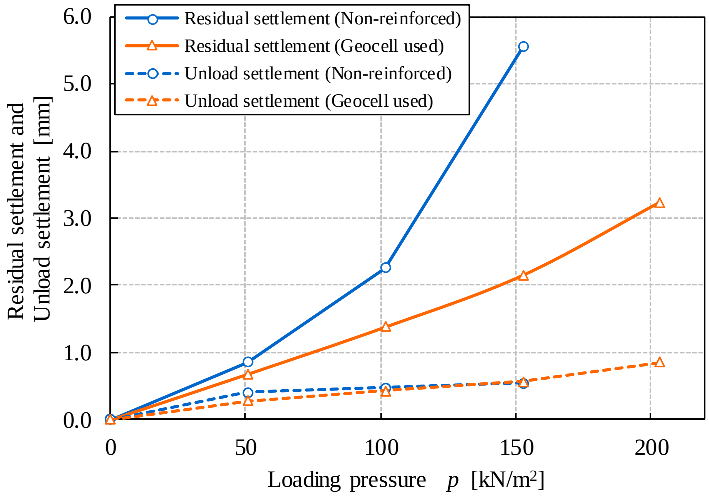

Figure 5. Relation between residual settlement and unloading settlement amount and loading pressure.

4.1.2 Deformation characteristics

Figure 5 shows the relationship among the amount of residual settlement, unloading amount, and load pressure *p* by loading cycle. Here, the amount of residual settlement and unloading amount are defined as shown in Figure 6, based on the relationship between load pressure and the quantity of settlement as shown in Figure 4 in accordance with JGS 1521. To take the amount of residual settlement first, the quantity of settlement is greatly suppressed by laying geocell, and its effect becomes more marked as the load pressure increases. This is considered to be because the geocell bound the ground material as the load pressure increased, turning the area of the geocell and the bound ground material into strong slab structure, which suppressed settlement. On the other hand, not much change in the unloading amount by the existence or nonexistence of geocell was observed. Because the unloading amount represents the elastic behavior due to the restoration of the ground, it can be considered that the influence of laying geocell on the elastic deformation of the ground is small.

Also, Table 3 shows the bearing characteristics and deformation characteristics of the ground obtained from the test results in accordance with JGS 1521. The rate of increase shown in the table indicates the ratio of the result of the condition of geocell reinforcement to the result of the condition of no reinforcement. It can be seen in the table that the rate of increase of the tangential elastic modulus E_t is smaller than the other results. Since this shows the elastic behavior of the ground like the unloading amount does, it was confirmed that the influence of laying geocell is small. On the other hand, the deformation coefficient E_D and the secant modulus of elasticity E_s more greatly increased under the condition of geocell reinforcement. Since these show looseness of the ground and its inelastic behavior, it is considered that laying the geocell suppressed the ground deformation and formed strong ground.

Table 3. Results of the stepwise cyclic loading test

	Non-reinforced	Geocell used	Reinforcement effect
Ultimate bearing capacity q_d [kN/m^2]	152.8	203.7	1.33
Deformation modulus E_D [MN/m^2]	2.74	4.08	1.49
Tangential elastic modulus E_t [MN/m^2]	22.8	24.4	1.07
Secant modulus $E_{s\backslash}$ [MN/m^2]	7.09	11.9	1.68

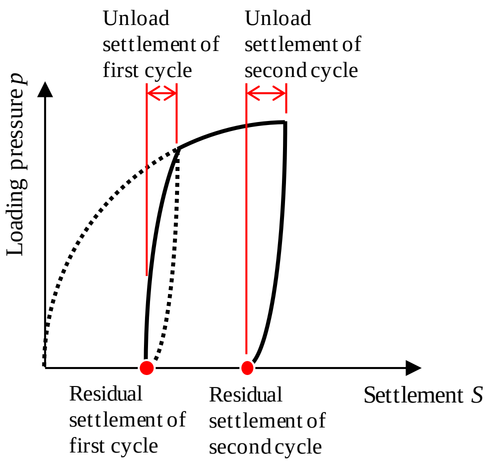

Figure 6. Definition of residual settlement amount and unloading amount.

4.2 *The constant strain rate loading test*

4.2.1 *Bearing capacity characteristics*

Figures 7 and 8 show the relationship among the load pressure *p*, the in-ground vertical stress σ_z, and the quantity of settlement *S* by the existence or nonexistence of geocell, obtained from the results of the constant strain rate loading test in the case of a silica sand layer with the thickness of 150 mm. It is omitted at the positions of r_{200} and r_{250} because influence is small in these places.

Firstly, under the condition of no reinforcement, the load pressure showed a tendency to decrease immediately after reaching the maximum load pressure, but under the condition of geocell reinforcement, it showed a tendency to maintain bearing capacity even after the maximum load pressure was reached. It is considered that geocell suppressed the shear fracture of the ground, and that since the in-ground horizontal resistance force worked, it maintained a certain level of bearing capacity. After that, in the case of a silica sand layer with the thickness of 150 mm, the destruction of geocell joints was confirmed. It is considered that the bearing capacity decreased rapidly due to the decreased binding effect as a result of the influence of the silica sand outflow into the adjacent cells. Damage to the joints was confirmed in other test types too, but destruction such as silica sand outflow into adjacent cells did not happen, and no tendency such as bearing capacity decreasing rapidly was observed. Also, the in-ground vertical stress at each position increased or decreased according to the magnitude of the load pressure, and this tendency was observed in other test types too.

In regard to the maximum load pressure, it has been confirmed that the same bearing capacity as the maximum bearing capacity obtained in the multistage repetitive loading tests is obtained either under the condition of no reinforcement or under the condition of geocell reinforcement. Also, as shown in Table 4, the maximum load pressure pmax in each test type and the quantity of settlement at that time showed the same tendency about the maximum load pressure regardless of the thickness of the silica sand layer. Therefore, it is considered that there is no significant difference in bearing capacity within the layer thickness range from 100 mm to 200 mm.

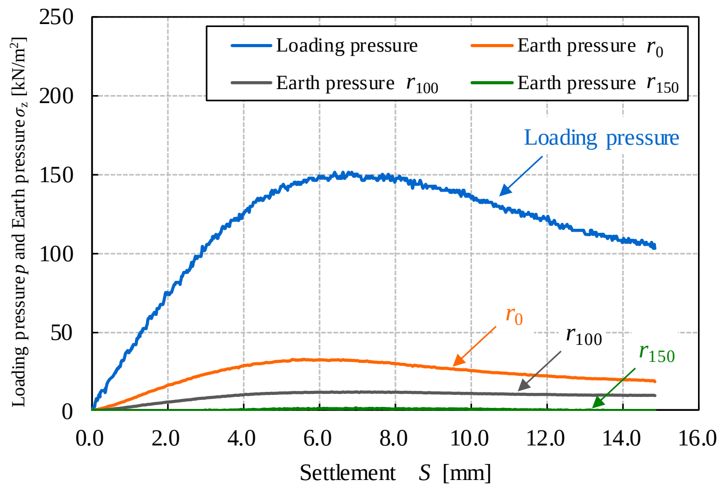

Figure 7. Load pressure Relationship between vertical stress in ground and settlement amount. (no reinforcement)

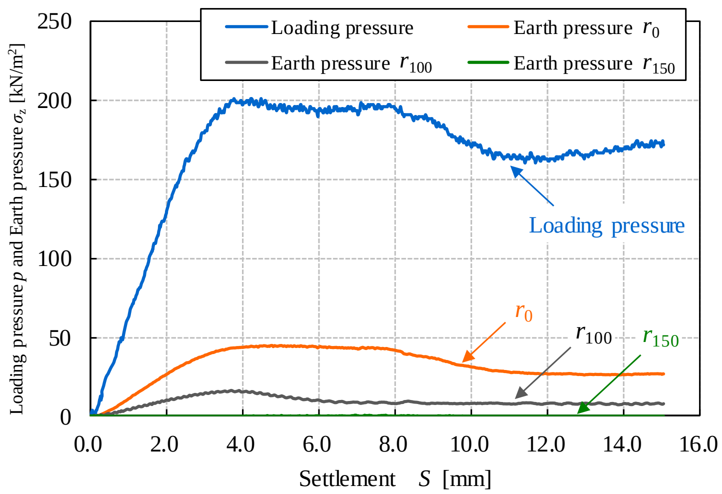

Figure 8. Load pressure Relationship between vertical stress in ground and settlement amount. (reinforcement)

Table 4. Result of constant strain rate loading test

Silica sand layer thickness [mm]	Geocell	Max loading pressure p_{max} [kN/m²]	Settlement at p_{max} [mm]	Damage of Geocell joint
100	Non-reinforced	152.8	6.0	–
100	Use (Reinforced)	194.8	5.6	Unbroken
150	Non-reinforced	151.5	6.4	–
150	Use (Reinforced)	201.2	4.2	Broken
200	Non-reinforced	157.9	7.1	–
200	Use (Reinforced)	215.2	6.2	Unbroken

4.2.2 *Stress dispersion effect*

Figures 9 to 11 show the relationship between the in-ground vertical stress and the load pressure p at each measuring position shown in Figures 7 and 8 by each thickness level of the silica sand layer. For the purpose of comparison between the existence and nonexistence of geocell, values normalized by the load pressure (σ_z / p) are used for in-ground vertical stress. First, if we look at the 100 mm thickness of the silica sand layer (Figure 9), the stress was reduced by laying geocell at the initial stage of loading at r_0 directly under the loading place, but under the load pressure of about 100 kN / m ^{2} or more, higher in-ground vertical stress is observed under the condition of reinforcement. There is a possibility that excessive vertical stress was measured because the distance between the geocell and the earth pressure gauge was small due to the small thickness of the silica sand layer and because the filler flowed out to the lower part of the geocell as the load pressure increased. On the other hand, the condition of reinforcement exceeds the condition of no reinforcement even in the early stage of r_{100} loading. It is considered that high in-ground vertical stress was exhibited because, as shown in the schematic diagram of Figure 12, the width of stress distribution becomes larger by laying geocell and stress acted on the position where it did not work under the condition of no reinforcement.

Next, if we look at the 150 mm thickness of the layer (Figure 10), the in-ground vertical stress is remarkably reduced by laying the geocell at r_0 directly under the load, but the effect is very small at r_{100}. It is considered that the same value was exhibited under the condition of no reinforcement and under the condition of reinforcement because the measurement position of r_{100} was in the same place as the location where the stress distribution under the condition of no reinforcement and the stress distribution under the condition of reinforcement cross each other as shown in Figure 12.

On the other hand, in the layer thickness of 200 mm (Figure 11), the stress dispersion effect by laying geocell at the positions of r_{100} and r_{150} is demonstrated, and the in-ground vertical stress is reduced, but the effect is very small at r_0 directly under the load, as can be seen. This may be because the change in the in-ground vertical stress could not be obtained under the condition of no reinforcement and under the condition of reinforcement for the reason that the density of the silica sand layer was uneven at the position directly under the loading. Therefore, it is necessary to examine methods of confirming evenness of density in the model ground in the future.

From these constant strain rate loading test results, it has been confirmed that the stress dispersion effect was produced by laying geocell. It is necessary to examine installation positions, etc. in the future because in these tests there is some room for error in the in-ground vertical stress due to the arch effect produced by installing the earth pressure gauges against the plywood in a protruding way.

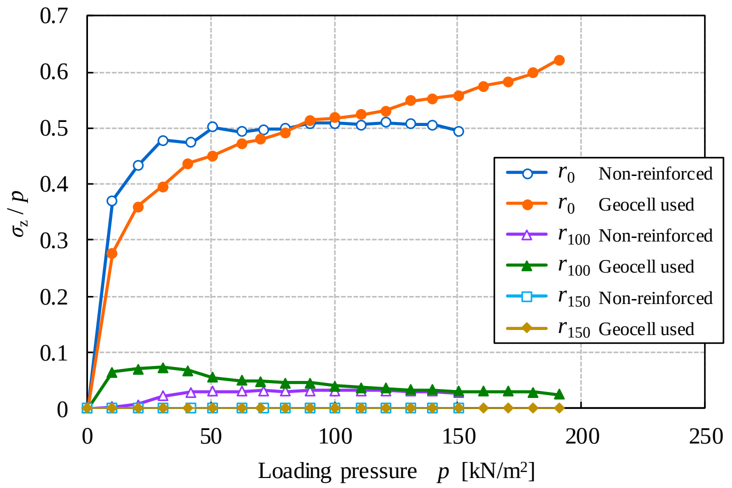

Figure 9. Relationship between σ_z / p and load pressure (state of layer thickness 100 mm)

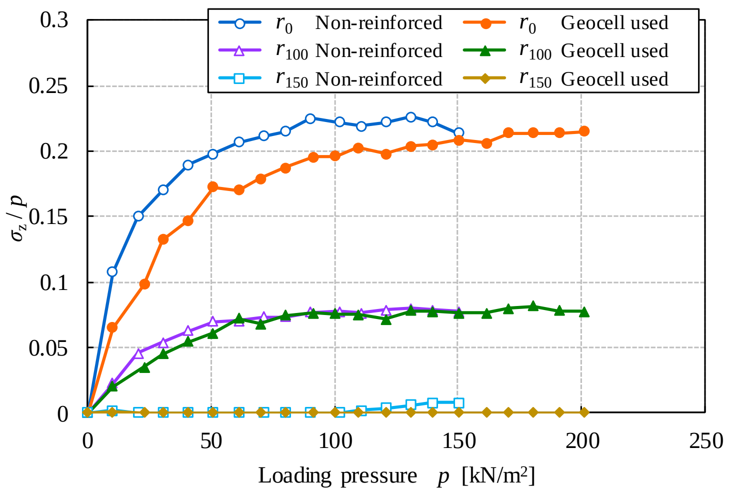

Figure 10. Relationship between σ_z / p and load pressure (state of layer thickness 150 mm)

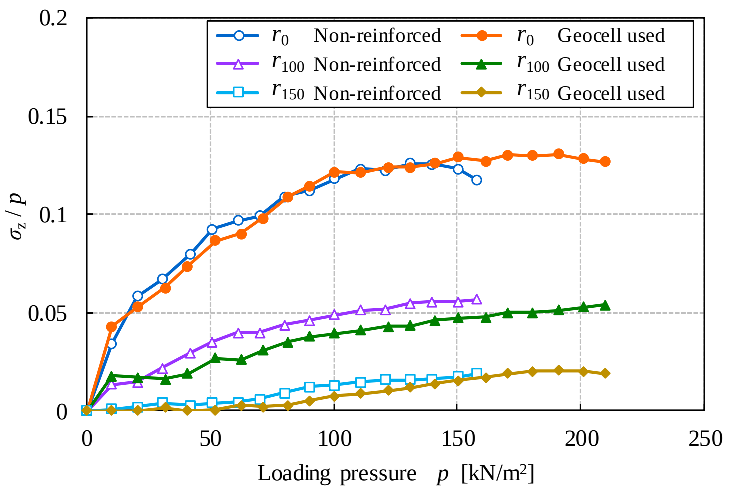

Figure 11. Relationship between σ_z / p and load pressure (state of layer thickness 200 mm)

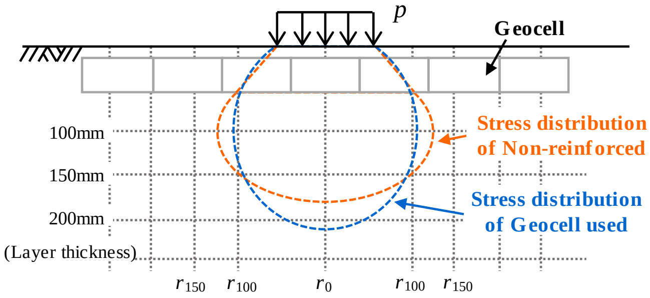

Figure 12. Schematic diagram of stress distribution by laying geocell

4.2.3 *Effect of layer thickness reduction*

Figure 13 shows the relationship between the thickness of the silica sand layer and σ_z / p at the position of r_0 directly under the loading. σ_z / p at the load pressure of 50 kN/m^2 is used because at the values where the load pressure is close to the ultimate bearing capacity, comparison between existence and nonexistence of geocell is not possible due to the influence of shear fracture of the ground. In the figure the difference between the vertical axis value of the curve of the non-reinforced condition and that of the geocell reinforced condition shows the thickness of the silica sand layer which can be reduced by laying geocell when only in-ground vertical stress is considered. From this result, it was considered that within the scope of these tests, thickness of the silica sand layer can be reduced by about 5 to 10% on the average when the load pressure is 50 kN/m^2. Furthermore, the examination method used in this study is different from the actual subbase design method because it was used in order to grasp the mechanical properties of subbase in which geocell was laid, but it is necessary to clarify design standards and design methods when geocell is used in subbase for reinforcement in the future.

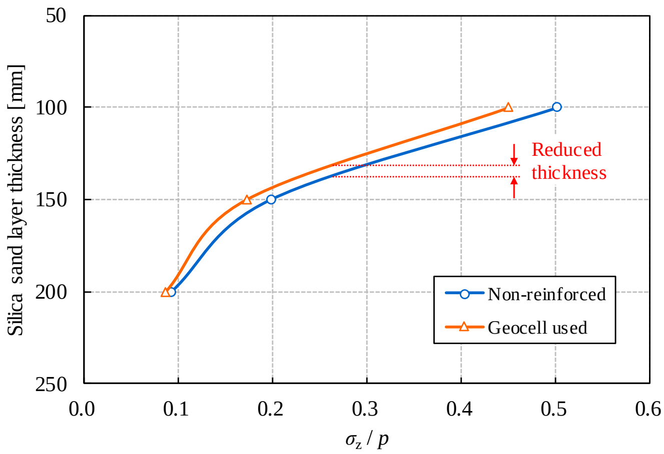

Figure 13. Relationship between the thickness of silica sand layer and σ_z / p

5 SUMMARY

In this study, out of a series of studies that clarify design standards and design methods of the geocell subbase reinforcement method, load tests were conducted with a ground model in order to grasp bearing characteristics and deformation characteristics of ground with geocell and the stress dispersion effect under the condition of geocell reinforcement, etc. The findings obtained from this study are shown below.

1) The bearing characteristics and deformation characteristics of the ground are improved by laying geocell, and strength is obtained by suppressing the shear fracture of the ground by forming strong slab structure. However, regarding the suppression of elastic deformation, the effect by geocell is small.
2) By laying geocell, the range of stress dispersion widens, and the effect of reducing the in-ground vertical stress is obtained. The closer to the geocell, the more marked the effect is in the case of a relatively small load. Also, it is necessary to examine methods of confirming the evenness of density since it influences propagating stress depending on the state of density in the ground,

3) Within the scope of this test, it was shown that about 5 to 10% of the silica sand layer thickness can be reduced by the stress dispersing effect of geocell when only in-ground vertical stress is considered. It is necessary to clarify actual design standards and design methods in the future.

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