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Effect of Ordinary Portland-Cement on Properties of Clayey Soil in Mie Prefecture

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Abstract

The clayey soils of Kameyama Mountain in Mie prefecture were studied experimentally in the laboratory with the idea of improving some of its engineering properties by using a very small amount of ordinary Portland cement. Laboratory tests on shear strength, compressive strength, consistency limits, compaction and specific gravity of soil were carried out with cement content of 0%, 0.2%, 0.4% and 0.6% by weight. It was observed that the cohesion which is a major component regarding the strength of soil was increased with the increase in the amount of cement and angle of internal friction at higher cement content was decreased. Compressive tests under two different room temperatures showed the compressive strength to be increased with the increase in the quantity of cement depending upon the temperature providing on it. Plasticity index, a measure of soil plasticity was found to decrease with the increase in the percentage of cement mixed with it. A close observation of results plotted in the plasticity chart also noticed that the addition of cement reduced the compressibility, dry strength and toughness of soil whilst increasing the volume change ratio and specific gravity of soil.

Key words : soil-cement, shear strength, compressive strength, plasticity chart, compaction curve

1. Introduction

It is evident that the natural soils possess very complex properties and vary widely in their behavior depending on the *in-situ* conditions. Therefore, soil of a particular location may not be fully useful as per the expectation of the users owing to its variable characteristics. To overcome these problems, the users may have the following three options such as 1) using the *in-situ* soil in its existing state accepting all its limitations, 2) using a better material by replacing the *in-situ* non-ideal soil and 3) using some techniques that modify the *in-situ* soil to make it more suitable for proper applications. There are a lot of methods such as mechanical, chemical, thermal, electrical and physical, etc used to improve the properties of soils (ACI, 1990 ; Wilhelmsson, 1997). However, none of the methods is ever unique in more than a limited number of soils due to its wider variability and complexity (Awal and Mamun, 1998).

The improvement of soil properties using cement began nearly a half century ago with the concept of the process of deductive reasoning (Mitchell, 1976). It is found from the previous studies that the uses of cement to improve the soil properties is somewhat unique because the cement, major component of which is calcium oxide, produce a conditioned material with soil by interacting with the water content of soil particles. Therefore, the soil-cement produced by mixing cement with soil is not a simple mixture of soil and cement but a unique composite material (Ahuja and Swartzendruber, 1972 ; Boswell, 2000). Because of its chemical make-up, cement is able to provide benefits for both granular and fine graded soils. By addition of water to cement, cementitious reaction immediately begins and thereby, as the products, it forms quickly $CaO \cdot SiO_2 \cdot H_2O$ and $CaO \cdot Al_2O_3 \cdot H_2O$. These products act as a glue to bind material together, reduce moisture flow channels, and improve gradation and stability of soils (Prusinski and Bhattachaja, 1998). Literature review indicates that to date, percentage of cement used to improve the properties of soil is 6 to 14% or more. The idea of using a very small amount of cement proposed in this paper is a newer one and important for the sake of cost saving in soil-cement construction works.

In this paper, an investigation was carried out in the laboratory to improve some engineering properties of clayey soils of Kameyama city in Mie Prefecture based on known properties of soil, cement and their combination. The effect of variable percentage of cement on the shear stress-shear displacement relationships, shear stress-normal stress relationships, cohesion, angle of internal friction, consistency limits, plasticity charts, compaction curves, optimum water content, dry unit weight, specific gravity and compressive strengths of soil were investigated with different room temperatures.

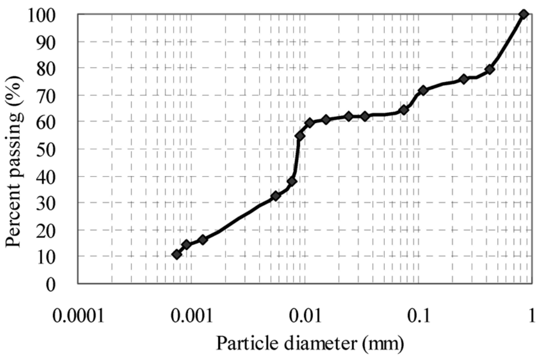

Fig. 1 Particle size distribution curve of soil.

Table 1 Properties of soil

Parameters	Properties
Dry bulk density (ρ_d)	1.53 g.cm^{-3}
Optimum water content (W_{opt})	20.5%
Specific gravity (ρ_s)	2.701
Cohesion (c)	157.4 kPa
Angle of internal friction (ϕ)	32.8°
Sand, >75 μm	34%
Silt, 5–75 μm	33%
Clay, <5 μm	33%
Liquid limit	61.0%
Plastic limit	27.8%
Plasticity index	33.2

2. Materials and methods

The soil samples were collected from the Kameyama Mountain in Mie prefecture, and tested at the laboratory. The particle size distribution curve is shown in Fig. 1. The particle size distribution curve of the soil indicates that, nearly, 33% of the soil is clay, 33% is silt, 14% is fine sand, 14% is medium sand, and 6% is coarse sand, which means that more than 66% percent of the soil is in the clay and silt fraction. The other properties of the soil used in these tests are depicted in Table 1. According to the unified classification system, the soil used in this research is classified as CH.

Any type of cement can be used for improving the engineering properties of soil. Ordinary Portland cement (Type I), which is the most common for construction works and also available widely in the local market, is used in this investigation. The detailed properties of this cement can be found elsewhere (JSCE, 2003). The soil sample was air-dried in room temperature of nearly 25℃ and humidity of about 40% for 10 days, and, then, grinded it to ease the sieving process. For removing unnecessary elements from the soil and for reducing variability of the particle sizes of the soil, it was sieved by Japanese Industrial Standard (JIS) Sieve No. 4 (4 mm opening), and, then, the required amount of soil was taken, and the desired quantity of cement was mixed properly. The calculated amount of water to be necessary to obtain a water-cement ratio of 0.5, and optimum water content of soil was taken and added gently to the dry mix, and, finally, the components were mixed thoroughly. The mixing process was done manually in a bowl with a scoop. In each batch, nearly 3 kg soil was required for which manual mixing was considered to be enough. Dry mixing was carried out in such a way of both pulverization and mixing at the same time with physical observation by naked eye. The procedure involved several passes of scoop through dry mix to ensure an even distribution of cement in the mixture. Nearly 10 to 15 minutes were required to obtain a homogeneous soil-cement mixer. Water content up to the optimum one was added, gradually, to the mix while continuously stirred. As mentioned above, additional water calculated as water to cement ration of 0.5 beyond the optimum water content was added to allow for the hydration of cement. A careful inspection revealed that the color of the soil-cement mixer, finally, changed to slightly light ash whereas the initial color of the soil was light brown. However, this change of color was not well profound because the amount of added cement was very small.

The index property testing included ten water content, four liquid and plastic limit tests, four particle size analyses using sieve and hydrometer tests, as well as three specific gravity tests. These tests were performed according to ASTM test procedures (ASTM, 1999), and compaction tests were performed according to the modified standard proctor method, ASTM D 1557–91.

For the unconfined compressive strength (UCS) test, specimens were manually compacted in a 12.5 cm height by 6.0 cm diameter mould. The specimens were compacted in three layers using a 5.9 mm diameter hand-rammer with rammer weight of 1 kg and falling height of 300 mm. Each layer was compacted by 20 blows. All the samples were moist cured for 7 days, and, then, the samples were tested for unconfined compressive strength at a loading rate of 0.1 mm per minute. It is noted that the temperature of Mie Prefecture varies from nearly 2〜16℃ during winter season (from November to March) and 17〜34℃ during summer season (from April to October). The variation of temperature that occurs naturally due to the change of seasons, is necessary to be investigated its effect on behavior of soil. In order to assess the effect of temperature in Mie Prefecture, Japan, curing was done in 9℃ (considering average temperature of winter season) and 25℃ (considering average temperature of summer season) for separate set of samples with different cement contents (0%, 0.2%, 0.4% and 0.6%). Average strength values were calculated for each set of the four samples. These tests were carried out in accordance of ASTM standards.

For shear tests, specimens of 60 mm diameter and 20 mm height were prepared in cutter-ring placing into the mould of standard proctor test. Compaction was done in accordance of ASTM D 1557–91. After one week moist curing, the specimens were tested by direct shear test apparatus with shear speed of 0.1 mm/min. All the shear tests were carried out under constant normal stress of 100 kN/m^2, 200 kN/m^2, 300 kN/m^2 and 400 kN/m^2 for each soil-cement sample. Vertical displacement, shear stress and shear displacement were measured at intervals of 30 seconds for each normal stress condition. These tests were also carried out in accordance of ASTM standards.

It is noted here that the shear and compressive strengths of the specimens depend on the water content, dry density after compaction as well as degree of compaction. In order to avoid these discrepancies, all the specimens were prepared with optimum water content and compaction was done in accordance with standard modified proctor test.

3. Results and discussion

3.1 Effect on consistency limits and plasticity index

The liquid limit, plastic limit and plasticity index of soil with different cement content are plotted in Fig. 2 showing that the liquid limit decreases upon addition of cement with soil.

Plastic limits, on the other hand, does not decrease with the addition of cement. Therefore, the plasticity index is to decrease with the increase in the percentage of cement content. The decrease in the plasticity index might be due to the reduction of clay particles with addition of cement. This is expected because of the liming effect of cement, which increases the silt and fine sand content by cementing the finer particles into bigger ones. From the plasticity chart (Fig. 3), it is shown that the addition of percentage of cement with soil tends to reduce the compressibility, dry strength and toughness of soil as well as tends to increase the volume change ratio of soil.

From Fig. 4, it is clear that, upon addition of cement, the pore spaces between the soil particles are filled up by the cement particle, and the specific gravity does increase with the increase of cement content. At 0.60% cement content, the specific gravity is about 2.717.

3.2 Effect on dry unit weight and optimum water content

From Figs. 5 and 6, it is found that, for the same energy supplied, the maximum dry bulk density does decrease with the increase of cement content, and, at 0.60% cement content, the dry bulk density becomes about 1.59 g/cm^3. On the other hand, the optimum water content increases with the increase of cement content, and, at 0.60% cement content, the optimum water content becomes about 21.9%.

3.3 Effect on shear stress-displacement relationships

The shear behavior, a principal engineering property of soil-cement, is demonstrated using the shear stress-displacement curves. The shear stress and shear displacement relationships of controlled specimens (0% cement) with variable normal stress are depicted in Fig. 7. It

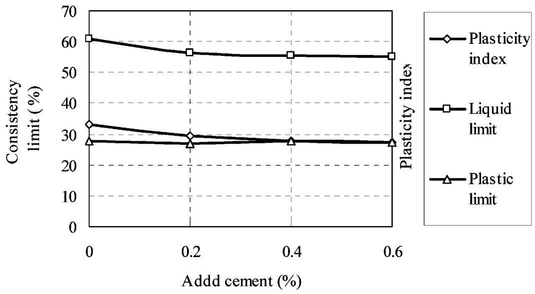

Fig. 2 Variation of consistency limits of soil-cement with different cement content.

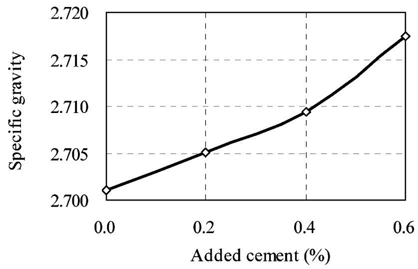

Fig. 4 Variation of specific gravity of soil-cement with different cement content.

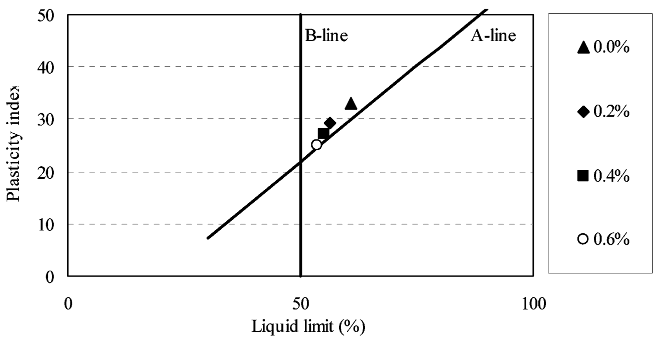

Fig. 3 Plasticity chart of soil-cement with different cement content.
(A-line is based on I_p=0.73 (w_L-20) and B-line is based on w_L=50)

should be pointed out here that all the specimens used in shear tests were prepared with the optimum water content obtained through the standard modified proctor test as reported in section 3.2. The optimum water contents were obtained as 20.5, 21.0, 21.5 and 22.2% for specimens containing cement of 0.0%, 0.2%, 0.4% and 0.6%, respectively. It is observed that the shear stress increases with the increase of displacement, naturally, but, due to the different normal stress, the increment rate varies depending on the amount of cement mixing. Figs. 8 to 10 show the variation of shear stress with displacement under different normal stress and cement content. For all cement contents, the shear stresses are increased as compared to the 0.0% soil-cement. The variation between shear stress and displacement gets smoother

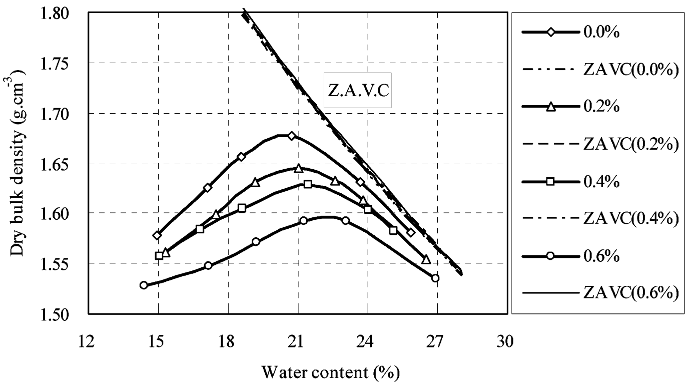

Fig. 5 Compaction curves of soil-cement with different cement content. (Z.A.V.C. means zero air void curve)

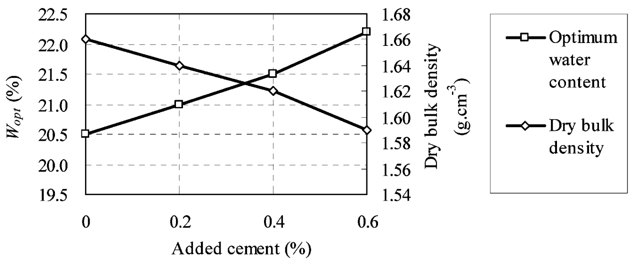

Fig. 6 Variation of W_{opt} and unit weight of soil-cement with different cement content.

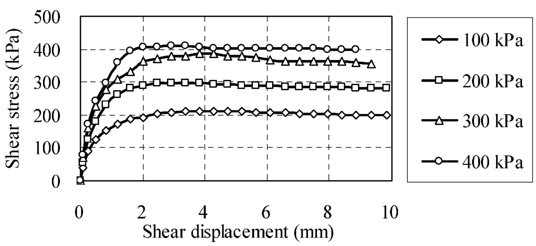

Fig. 7 Shear stress vs. shear displacement (0% soilcement).

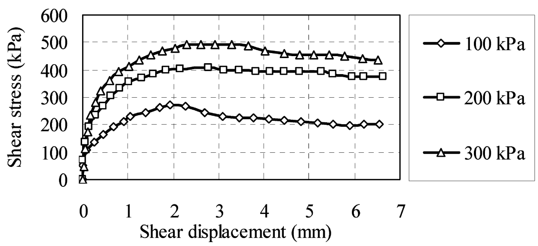

Fig. 8 Shear stress vs. shear displacement (0.2% soil-cement).

with more cement content under all types of normal stress. For every curve, there is a peak or ultimate stress which is greater than the failure stress.

3.4 Effect on shear strength

The shear strength of a soil is its maximum resistance to shear stresses before the failure. It is a most important factor to investigate because it controls the stability of a soil mass under loads. Fig. 11 shows the variation of shear strength due to the variation of normal stress of soil-cement with different cement content. It shows that owing to the increase in normal stress the shear strength also increases. Under 100 kN/m^2 normal stress, the shear strength for 0.6% cement content is highest (about 350 kN/m^2) than those for other cement contents (0%, 0.20%, 0.40%), and for 200 kN/m^2 normal stress, the shear strength for all cement content except 0% are more or less same (about 380 kN/m^2), but, for 0% cement content the shear strength is about 190 kN/m^2. For 300 kN/m^2, some different trends are shown that shear strength for 0.20% is the highest value (about 500 kN/m^2) than those for other cement contents and this same trend is also shown for 400 kN/m^2 normal stress where the highest shear strength is about 600 kN/m^2 at 0.20% cement content. From the straight lines drawn in Fig. 11, the following equations can be obtained.

$$\tau_{0.0\%}=0.6\sigma_{0.0\%}+157.4 \quad (1)$$

$$\tau_{0.2\%}=1.1\sigma_{0.2\%}+167.6 \quad (2)$$

$$\tau_{0.4\%}=0.8\sigma_{0.4\%}+248.3 \quad (3)$$

$$\tau_{0.6\%}=0.3\sigma_{0.6\%}+316.5 \quad (4)$$

where, τ is the shear strength of soil-cement under direct shear test in kN/m^2 and σ is the applied normal stress (overburden pressure) in kN/m^2. Therefore, the angles of internal friction of the soil-cement are calculated as 32.8^0, 48.1^0, 39.4^0 and 11.3^0 ; and cohesion are obtained as 157.4, 167.6, 248.3 and 316.5 kN/m^2 for 0%, 0.2%, 0.4% and 0.6% soil-cement, respectively.

The effect of different amount of cement contents on cohesion and angle of internal friction is shown in Fig. 12. It is found that there is not a significant improvement of cohesion up to

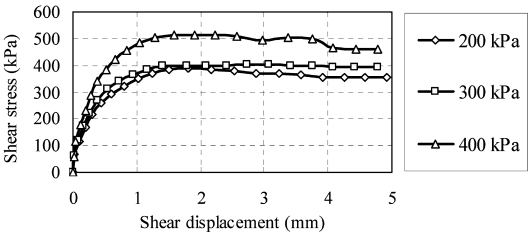

Fig. 9 Shear stress vs. shear displacement (0.4% soil-cement).

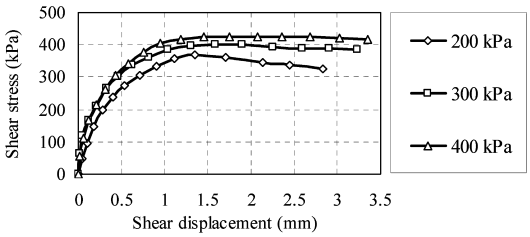

Fig. 10 Shear stress vs. shear displacement (0.6% soil-cement).

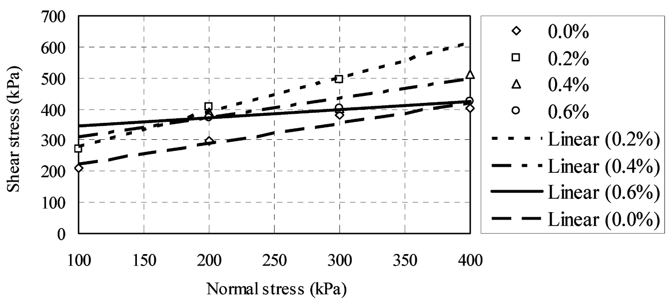

Fig. 11 Shear stress vs. normal stress of soil-cement with different cement content.

0.2% cement content, but, when cement content is higher than 0.2%, the cohesion starts to increase to a great deal even up to 350 kN/m^2 at 0.60% cement content. The angle of internal friction also slowly increases with the increase of cement content up to 0.2%, but, when cement content is higher than 0.2%, then it starts to decrease, and the rate of decreasing gets higher with the higher cement content, and at 0.60% cement content, the angle of internal friction is about 11.3 degree. This might be due to the anti-synergetic action between cohesion and internal friction. However, our understanding on this phenomenon is also rudimentary.

3.5 Effect on unconfined compressive strength with two curing temperatures

Test results on the unconfined compressive strength of the soil-cement with three different mix proportions are depicted in Fig. 13. In order to obtain the effect of curing temperature on the test samples, two types of specimens were cured in room temperature of 9℃ and 25℃ and tested for unconfined compressive strength. For both samples, it is observed that the compressive strength increases with the increase of cement content, but, the increasing rate is higher for specimens cured at 25℃ than for specimens cured at 9℃. This is obvious, because, when the curing temperature is high, quick formation of the calcium silicate and aluminum silicate is occurred, that results in rapid setting time and harden time. It is also noted that the increasing rate gets slow for cement contents above 0.40%. This might be the cause of reduction of internal friction with the increase of cement content as can be seen in Fig. 12. At 0.60% cement content, the compressive strength is about 500 kN/m^2 for specimens cured at 25℃ and 300 kN/m^2 for specimens cured at 9℃. Here, the plotted compressive strengths are average values of four samples.

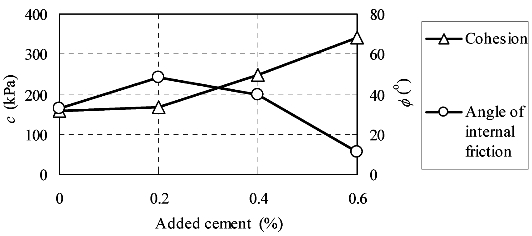

Fig. 12 Variation of c and ϕ of soil-cement with different cement content.

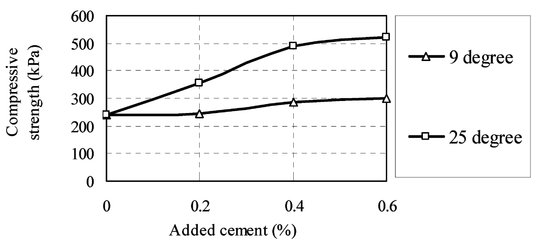

Fig. 13 Variation of compressive strength of soil-cement with different cement content.

The most important results of this study depicted in Figs. 11 and 13 shows that both the shear and compressive strengths were improved compared to the controlled specimens. As expected, there is a fairly consistent trend in the increase of strengths with the addition of small amount of cement. This might be due to the cause of ionic action comes from cement, water and soil. Cement releases Ca++ ions in the mixture of soil-cement when added certain amount of water in it. These ions are attracted to negative ions comes from clay minerals resulting in clay particles together. The main source of observed strengths in this case is due to the formation of C_3S and C_2S compounds with the presence of clay minerals that finally result to form $C_3S_2H_3$ in water.

4. Conclusions

A very nominal dosage rate of ordinary Portland cement such as 0.2%, 0.4% and 0.6% was used for improving the engineering properties of clayey soils. The test results revealed that the addition of small amount of cement not only increased the cohesion of soil significantly but also improved the compressive strength of soil. There was a slight decreasing trend in the frictional resistance with the cement content above 0.4% ; however, overall shear strength was increased with the increase in the amount of cement. In the present study, it was also revealed that the maximum shear strength occurred at the shear displacement of nearly 2–4 mm for most of the cases. It was also found that the increase in the percentage of cement not only reduced the plasticity index, a measure of soil plasticity, but also reduced the compressibility, toughness and dry unit weight of soil. The small amount of ordinary Portland cement can also be effectively used for improving the volume change ratio and specific gravity of clayey soils. It should be pointed out here that the amount of cement was very small and, therefore, the improvement in the shear and compressive strengths were not highly significant. Also, there were some scatters in the strengths properties owing to the little experimental data. Further investigations are suggested to study the strength characteristics and other basic properties for a wider range of cement mixing. Nonetheless, the result depicted in this paper is fairly encouraging, especially for improving the engineering properties of clayey soil.

References

ACI Committee (1990) : State-of-the-Art Report on Soil Cement, American Concrete Institute, **1** : 1–23.

ASTM, D420-4914 (1999) : Annual Book of Standards-Soil and Rock, American Society for Testing and Materials **4** : 8–20.

Ahuja, L.R. and Swartzendruber, D. (1972) : Effect of Portland cement on aggregation and hydraulic properties. Proceedings of the Soil Science Society of America, **114** : 359–366.

Awal, A.S.M.A. and Mamun, A.A. (1998) : Improvement of Bangkok Clay by Using Ordinary Portland Cement, Proceedings of the International Symposium on Problematic Soils, Balkema, Rotterdam, **1** : 603–606.

Boswell, W.F. (2000) : Soil Stabilization/Soil Cement Mark-Lang, Inc.'s Approach, Soil-Cement and Other Construction Practices in Geotechnical Engineering, ASCE, **95** : 26–35.

JSCE committee, (2003) : Guideline for Experiment on Materials of Civil Works, Japan Society of Civil Engineers, **1** : 1–24.

Mitchell, J.K. (1976) : Fundamentals of Soil Behavior, John Wiley and Sons, Inc. New York.

Prusinski, J.R. and Bhattacharya, S. (1999) : Effectiveness of Portland Cement and Lime in Stabilizing Clay Soils, Transportation Research Board, Record No. 1652, **2** : 198–206.

Wilhelmsson, B. (1997) : Strength properties of cement mortars with lime and dolomite, MIMER-rapport : 1–12.

三重県の粘性土の性質に影響を与える普通ポルトランドセメントについて

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要　　旨

普通ポルトランドセメントを用いて，三重県亀山市の粘性土の工学的な性質を改善することを考慮して室内実験を行った。0%，0.2%，0.4%，0.6%のセメント量を混入した土のせん断強度，圧縮強度，コンシステンシー限界，締固め特性，乾燥密度などを調べた。その結果，土の粘着力がセメント量の増加とともに増大すること及び内部摩擦角が高いセメント量のとき減少することが観察された。9℃と25℃の2種類の室内温度条件下で養生を行った供試体の圧縮試験では，供試体に与えた温度によってセメント量の増加が圧縮強度をより大きく増加させた。土の塑性指数は混合セメントの増加に伴い指数が減少することが分かった。塑性図にプロットした結果の具体的観察より，セメントの付加が土の体積変化，比重を増加させ，圧縮性，乾燥強さおよびタフネスを減少させたことが明らかとなった。

キーワード：土セメント，せん断強度，圧縮強度，塑性図，締固め曲線

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