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An improvement in continuous yarn reinforced sand

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ABSTRACT: An attempt was made to improve the strength and resistance against erosion of the sand mixed with continuous yarn by adding a small amount of cement. A laboratory study indicates that the compressive strength of cement-treated yarn-reinforced sand is a few times as great as that of the sand mixed with the same small amount of cement, being much higher than that of the sand reinforced with yarn alone. When the cement content is less than 6%, the permeability of the sand mixed with yarn and cement showed no reduction, suggesting no harmful effect on grass growing on the surface of the improved soil. Similar satisfactory results were obtained of Kanto loam mixed with yarn having a finite length and with cement or lime.

1 INTRODUCTION

Sand mixed with continuous polymer yarn (commercially known as Texsol) has been employed successfully to from retaining structures, to protect slopes, etc., taking advantage of its increased strength and high permeability (Leflaive 1988). While such reinforced sand slopes are in general covered by grass and the overall performance has been reported quite satisfactory, surfaces of the reinforced sand look friable and susceptible to erosion. Obviously a higher strength as well as more resistance against erosion is desirable if a measure taken does not result in a significant reduction in permeability.

In actuality a small amount of cement may readily be added to and thoroughly mixed with sand prior to mixing it with yarn. This would not overly complicate the present installation procedure, nor result in a significant increase in the cost.

To substantiate the foregoing view a series of laboratory tests was conducted with an emphasis placed on a study to investigate effects of a small amount of additives to be added to yarn-reinforced soil specimens (Akagi, Ishida and Okawara 1991).

2 TEST SPECIMENS

Sand specimens were prepared in the laboratory by mixing polyester yarn cut generally into 200 mm lengths with a relatively uniform sand. The grain size of the sand ranges from 0.3 to 0.9 mm; its uniformity coefficient is about 2.0 and the specific gravity 2.63. The yarn mixed is multiple continuous synthetic fiber, 150D, consisting of 30 polyester filaments, each 5D, which is the typical yarn used for actual construction. The mixture of sand and yarn was compacted in a mold, 50 mm in diameter and 100 mm in height, by a 2.0 kg drop hammer falling 300 mm. The specimen was formed in 3 layers, each of which was compacted by 6 blows.

To study the effects of additives a small amount of cement was added to sand before mixing it with short cut yarn. The cement used is CS-10, essentially the same as regular portland cement.

All the specimens were sealed in a plastic bag and cured for 24 hours before they were tested for strength. The water content of sand was controlled to be 10% at the time of specimen preparation, but was found in general approximately 1% lower upon completion of the strength test.

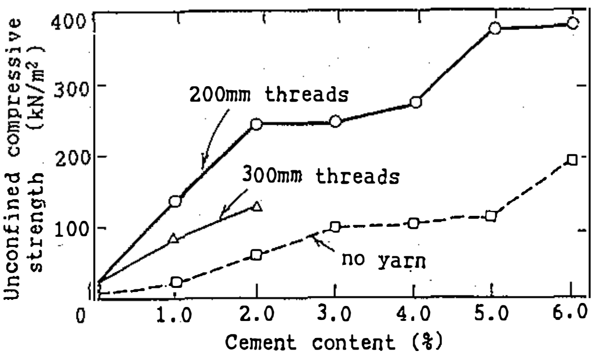

Fig. 1 Unconfined compressive strength versus cement content (sand specimens)

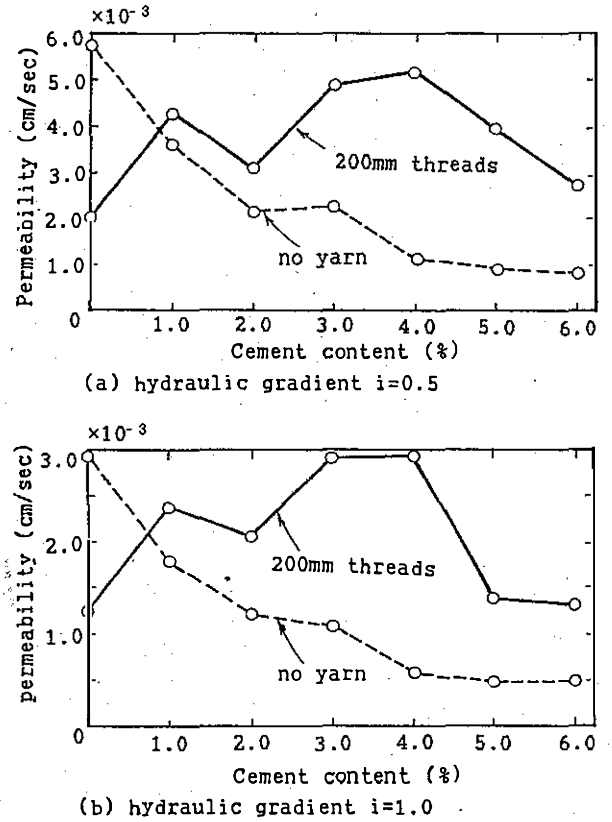

Fig. 2 Coefficient of permeability versus cement content (sand specimens)

3 LABORATORY TEST ON CEMENT-TREATED YARN-REINFORCED SAND

3.1 Unconfined compression tests

Fig. 1 shows the unconfined compressive strengths of specimens, 50 mm in diameter and 100 mm in height. The strength increases markedly with increase in cement content. The effect of adding a small amount of cement, even 1 to 2%, is far more remarkable in sand specimens mixed with yarn than in sand without yarn. Threads cut into 300 mm lengths were mixed in some of the sand specimens, but it was found more difficult to obtain as uniform a mixture as in the case of 200 mm threads. Consequently as shown in Fig. 1, the unconfined compressive strength was considerably lower of the specimens mixed with longer threads due perhaps to greater difficulty with mixing them uniformly with sand and to the small size of the mold for preparing test specimens.

3.2 Triaxial compression tests

Consolidated-undrained triaxial compression tests were conducted on sand specimens, i. e., they were first consolidated under cell pressures of 50, 100 and 200 kN/m^2 and then brought to failure by increasing the axial load with the cell pressure kept constant under undrained condition. Three types of specimens were tested; (a) sand with no yarn and no cement which exhibited practically no cohesion, c = 2.0 kN/m^2 and an angle of internal friction at failure, ϕ = 39.9° , (b) sand mixed with 2% of cement which gave c = 66.6 kN/m^2 and ϕ = 35.2° , and (c) sand mixed with 2% of cement and 0.2% of 200 mm threads produced c = 115.6 kN/m^2 and ϕ = 38.0° . It is thus demonstrated that the cement-treated yarn-reinforced sand specimens are of higher strength than the cement-treated specimens with no yarn.

3.3 Permeability tests

Specimens of the same size prepared in the same manner as those for strength tests were tested for permeability by means of a constant-head permeameter. Fig. 2 shows how the permeability varies with the cement content when the hydraulic gradient i is (a) i = 0.5 and (b) i = 1.0. While the sand specimens without yarn decrease the permeability with increase in cement content, the sand mixed with 200 mm threads appears to show a fairly constant permeability indicating no definite trend of decrease with the cement content.

3.4 Slaking tests

As shown in Fig.3, a slaking test was

conducted by submerging a specimen in water and to measure the time required for its upper half of it to collapse. Fig. 4 shows that only a small amount of cement is required to prevent such collapse in water but the presence of yarn in a sand specimen plays a positive role to increase its resistance. The failure did not take place when the cement content of the sand specimen mixed with 200 mm threads exceeded 0.5%, that with 300 mm threads 0.7% and that without threads 0.9%, Fig. 4.

3.5 Strength tests under varied curing conditions

The effect of a small amount of cement mixed with sand on the unconfined compressive strength was further studied when the sand specimens reinforced with 200 mm yarns were subjected to the following curing conditions.

Wetting and drying: After a specimen was prepared and cured for 24 hours in a constant temperature room at 20° C, it was subjected to cycles of wetting and drying, each cycle consisting of a 48 hours period during which time the specimen was first soaked in water for 24 hours and then left in the constant temperature room for another 24 hours. Fig. 5 shows the unconfined compressive strengths of the yarn-reinforced sand specimens which have been subjected to increasing numbers of wetting and drying cycles when (a) the cement content is 0.7% and (b) 1.0%. It appears that the former case shows a decreasing trend of strength with the increasing number of cycles, whereas the latter case having a slightly higher cement content maintains a fairly constant strength being relatively insensitive to the wetting and drying cycles.

Curing periods: Fig. 6 summarizes the results of long-term curing tests and shows the unconfined compressive strengths of the cement-treated, yarn-reinforced sand specimens(the cement contents; 0.7%, 1.0% and 2.0%) which have been cured for 30, 70, 100, 140, 200 and 280 days in (a) a constant temperature water bath maintained at 20° C and (b) a constant temperature oven at 40° C. Although the strength indicates a general downward trend with the curing period, it appears that a cement content as small as 2.0% can be quite effective to secure considerably higher strengths.

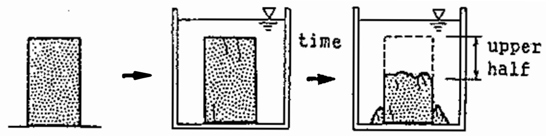

Fig. 3 Slaking test

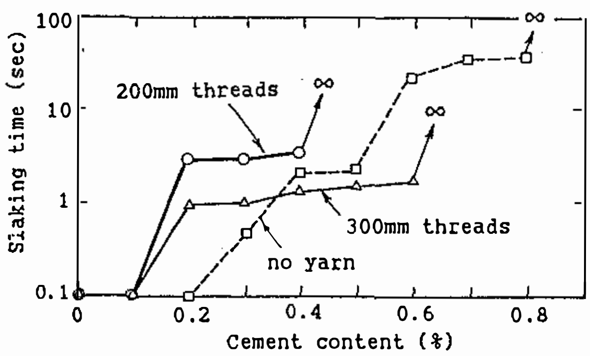

Fig. 4 Relation between slaking time and cement content (sand specimens)

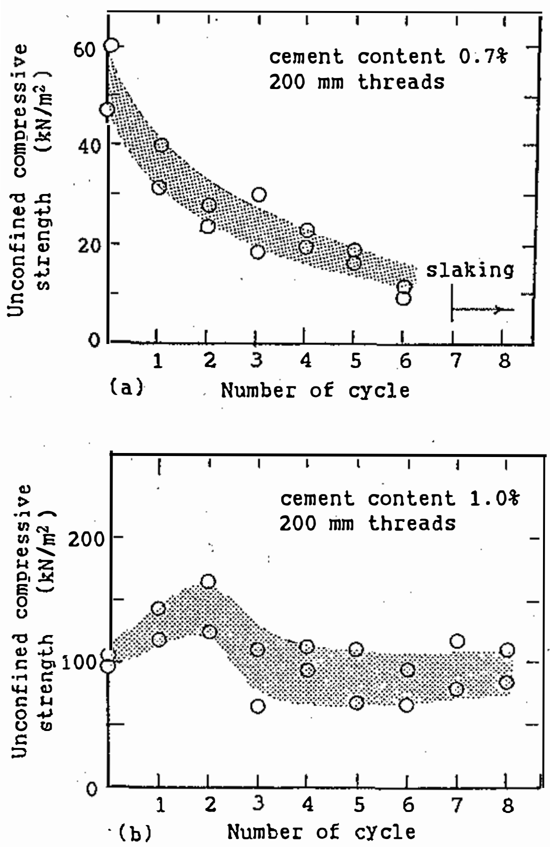

Fig. 5 Unconfined compressive strength versus numbers of wetting and drying cycles (sand specimens with yarn)

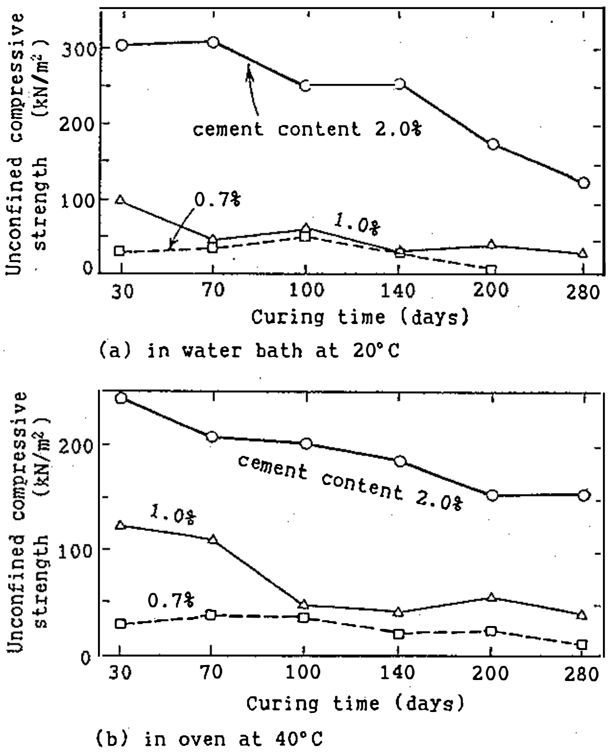

Fig. 6 Curing tests of sand specimens when (a) constant temperature water bath maintained at 20° C and (b) constant temperature oven at 40° C

Photo 1 A mode of failure by rainfall test

3.6 Rainfall tests

Yarn-reinforced sand specimens with cement contents of 0%, 0.5% and 0.7%, each 600 mm square and 30 mm thick, were prepared with the same compactive energy per volume given as that for the specimens for strength tests and placed on a 30 degree slope. Artificial rainfall with an intensity of approximately 45 mm per hour was poured from a height of 10 m to study the resistance against erosion. The specimens mixed with 0% and 0.5% of cement failed and slid 13 and 19 minutes after the start of the rainfall, respectively, although it was observed that threads resisted against downward movements of the soil mass quite effectively. The specimen having a cement content of 0.7%, however, did not fail even after 3 hours of uninterrupted heavy rainfall, suggesting a small amount of cement could effectively improve slope stability and resistance against erosion. Photo 1 shows the mode of failure of the slope consisting of yarn-reinforced sand with no cement added.

4 LABORATORY TESTS ON YARN-REINFORCED KANTO LOAM MIXED WITH CEMENT OR LIME

Kanto loam is primarily a plastic sandy clayey silt of volcanic origin widely distributed over much of the Kanto district, the center of which is Tokyo.

The Kanto loam used for this study has the following properties; the liquid limit 100.4%, the plastic limit 80.7%, the specific gravity 2.63, the natural water content 126.4%, the in-situ wet density 1.37 Mg/m^3 and the corresponding dry density 0.67 Mg/m^3. The loam specimens were prepared at a water content of 80% and compacted in the same manner having the same size as that of the sand specimens. The water contents were found in general approximately 8% lower when tested.

4.1 Unconfined compression tests

Fig. 7 shows the unconfined compressive strengths when cement or slaked lime was added to loam specimens with or without yarn. While the specimens without yarn shows little changes in strength even if additives are added, the specimens reinforced with yarn indicates a gradual increase in strength with the increasing amount of additives. Yarn-reinforced loam specimens appear generally to be of higher strength than those without yarn irrespective of the content of cement or lime.

4.2 Permeability tests

Fig. 8 appears to show a general trend of decreasing permeability with the increasing content of additives, but the coefficient of permeability falls within a relatively narrow range of values of the same order of magnitude. It suggests that the permeability of the loam is rather unaffected by the addition of additives such as cement or slaked lime.

4.3 Slaking tests

Fig. 9 shows the results of slaking tests performed on loam specimens mixed with cement or slaked lime either with or without yarn. The time required for the upper half of the specimens to collapse appears generally longer for cement-treated loam than lime-treated loam, but the effect of yarn reinforcement does not appear very significant. To prevent the failure during the slaking test, more than 10% of additives were required for the Kanto loam specimens.

5 CONCLUSIONS

The laboratory study indicates that the compressive strength of cement-treated, yarn-reinforced sand is in general a few times greater than that of cement-treated sand with the same cement content, being much higher than that of yarn-reinforced sand. When the cement content is less than 6%, it is found that the permeability of cement-treated, yarn-reinforced sand stays within a relatively narrow range of values of the same order of magnitude. A series of slaking tests, various curing tests and tests on model slopes with controlled rainfall, all point out that even a small amount of cement on the order of 1% to 2% will result in considerable strength increase, relatively high resistance against erosion and improved durability without reducing the high permeability essential to grass growing.

It is to be noted, however, that threads of short finite lengths have been mixed uniformly with sand to prepare laboratory specimens which supposedly have fairly isotropic properties, whereas in the actual construction yarn-reinforced sand is formed roughly horizontally in thin layers, hence having highly anisotropic strength characteristics. Incidentally it is our opinion that yarn does not have to be continuous and can be of some short finite length for the purpose of reinforcing sand.

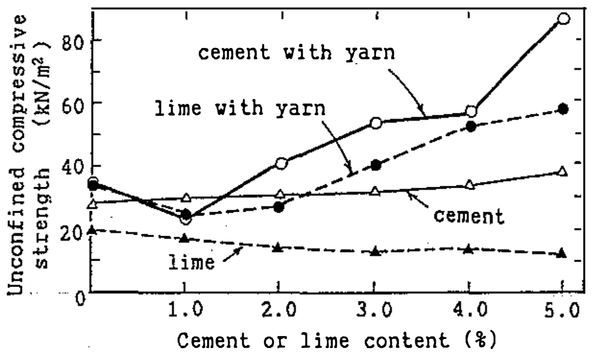

Fig. 7 Unconfined compressive strength versus cement or slaked lime content Loam specimens with or without yarn

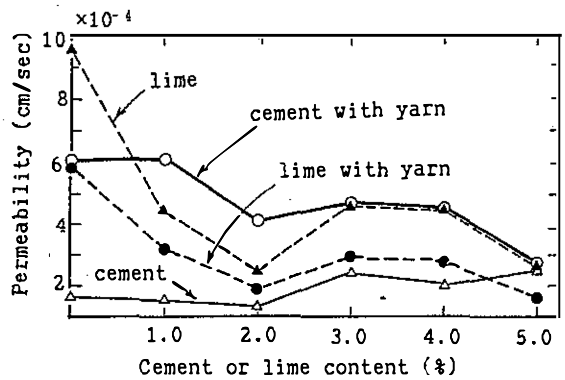

Fig. 8 Coefficient of permeability versus cement or slaked lime (loam specimens when hydraulic gradient i = 0.5)

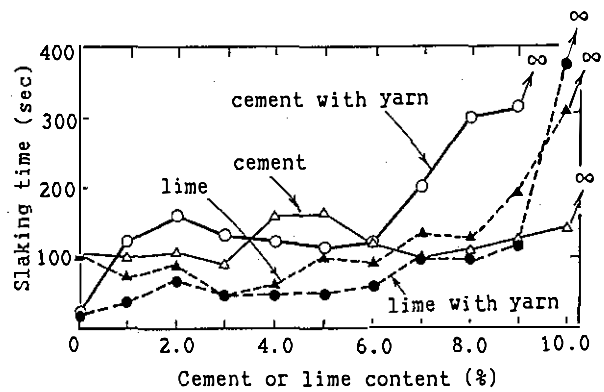

Fig. 9 Relation between slaking time versus cement or lime content (loam specimens)

A similar study was conducted on the possibility of improving Kanto loam by mixing yarn and cement or slaked lime. It would not be possible to mix continuous yarn with cohesive material, but it appears feasible to mix yarn having short finite lengths uniformly with Kanto loam to be simultaneously mixed with a small amount of cement or lime. A laboratory study indicates that presence of yarn in the cement- or lime-treated loam has a remarkable reinforcing effect as compared with the strength of the cement- or lime-treated loam with no yarn reinforcement. The slaking test demonstrates that cement works better than lime to increase the resistance of the loam specimen against collapse when submerged in water, but in general little improvements in durability are expected when the loam is mixed with yarn.

Since only very small specimens were tested in the laboratory, it would be premature to draw any conclusions related to field operations. Nevertheless, the foregoing test results seem to point out a good possibility that yarn-reinforced sand may be strengthened considerably if the sand has been premixed with a few percent of cement. This should not be too difficult nor too costly in practice.

The laboratory study also suggests that a cohesive material such as Kanto loam may be stabilized by mixing it by synthetic threads of finite lengths and may further be strengthened by adding a few percent of cement or lime.

REFERENCES

Akagi, T., T. Ishida and S. Okawara 1991. Engineering properties of soil mixed with synthetic yarn and a small amount of cement (in Japanese). Proc. 6th Geotextile Symp. Tokyo. JCIGS. 74-82.

Leflaive, E. 1988. TEXSOL:Already more than 50 successful applications. Proc. Int. Symp. on Theory and Practice of Earth Reinforcement. Fukuoka. Balkema. 541-545.