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Static and dynamic strength of cement mixed soil reinforced by fibers

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ABSTRACT: Static and dynamic strength of cement mixed soil reinforced by fibers were studied by conducting unconfined compression, split and bending tests. Test results showed that compression, tensile and bending strength increased with mixing of fibers. Especially tensile and bending strength increased about two times. Liquefaction strength increased also with mixing of fibers.

1 INTRODUCTION

Deep cement mixing method is one of the effective method to improve the ground. In Japan, the deep cement mixing method is used to improve the ground under or adjacent of structures. Main purpose of the improvement is to increase bearing capacity or liquefaction strength of the ground.

For existing embankments such as river dikes and road embankments, surrounding grounds of the embankments improve by the deep cement mixing method to prevent the settlement of the embankments during earthquakes as shown in Fig.1, because the foundation ground of the embankments can not improve. For example, the area of 5m in width and 10m in depth improves by the cement mixing method. The improved zone is a kind of self-standing wall and must resist against bending stress that is caused due to the pressure by self-weight and inertia force of the embankments. Therefore bending strength of the improved ground is important in the design of appropriate improving area. However, in general speaking, bending strength can not improve enough by cement only. Then the authors tried to mix fibers to strengthen the cement mixed soil.

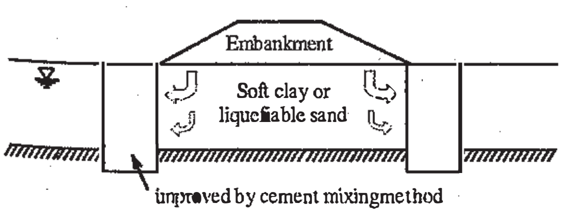

Figure 1. An example of soil improvement for an existing embankment.

2 STATIC STRENGTH OF REINFORCED CLAY

In the first step of this study, static strength of a clay mixed by fibers and cement was studied by conducting several tests. The clay used for the tests was a mix of "Kibushi clay" and bentonite. Mixing rate of the Kibushi clay and bentonite was 9: 1. Figure 2 shows grain-size distribution curves of the mixed Kibushi clay together with the curve for Toyoura sand which is a clean sand. Fiber used for tests was a flat bar of 0.40mm in diameter and 24mm in length as shown in Fig3. Tensile strength and Young's modulus of the fiber are $900MN/m^2$ and $30GN/m^2$, respectively.

Powder of the mixed clay was kneaded dough with a predetermined amount of water which produces 100% of water content, by a mixer for ten minutes. After 24 hours, the clay was mixed with cement and the fibers for two minutes by a mixer and for one minute by hands. Then the sample was filled in a mold and cured for seven days in a constant temperature and moisture vessel. Mixing rates

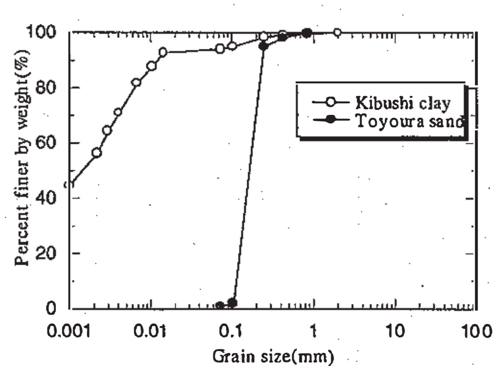

Figure 2. Grain size distribution curves of tested soils.

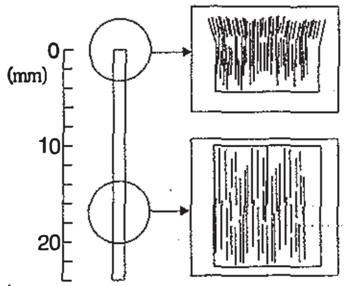

Figure 3. A fiber used for tests.

of fiber, f, and mixing rate of cement, C, were 0% to 2% in volume and 50kg/m^3 to 150kg/m^3, respectively.

Three kinds of tests, unconfined compression test, split test and bending tests were conducted to know compression strength, tensile strength and bending strength, respectively.

Figure 4 shows relationships between axial strain and compression stress of the samples of C=150kg/m^3 in the unconfined compression tests. In the case of the sample without fiber, shear stress decreased rapidly after peak stress, while stress did not deceased drastically after peak stress for the samples of f=0.5% or 1%. Stress did not decreased if the sample

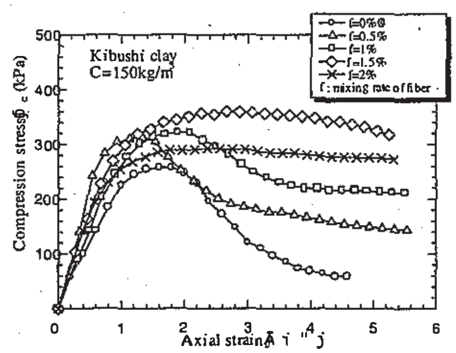

Figure 4. Stress-strain curves in unconfined compression tests for Kibushi clay.

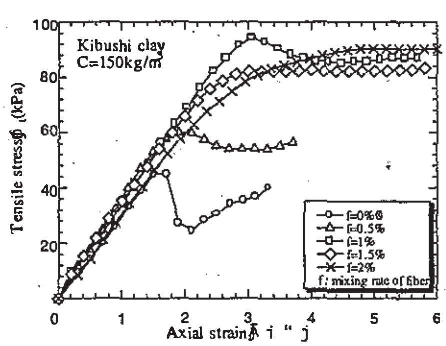

Figure 5. Stress-strain curves in split tests for Kibushi clay.

contains 1.5% or 2% of fiber. Namely, residual strength increased with the mixing rate of fiber up to about f=1.5%. Peak strength increased also up to f=1.5%.

Similar relationships were observed in the spilt and bending tests as shown in Figs. 5 and 6. Tensile and bending strength increased about two times with mixing of fibers. As mentioned before, it is desired that tensile and bending strength increased with the content of fibers because bending strengths must be improved for the design of the measure against the deformation of embankments.

Figures 7 to 9 show relationships among mixing rate of cement, mixing rate of fiber and strength obtained by the three types of tests. Compression, ten

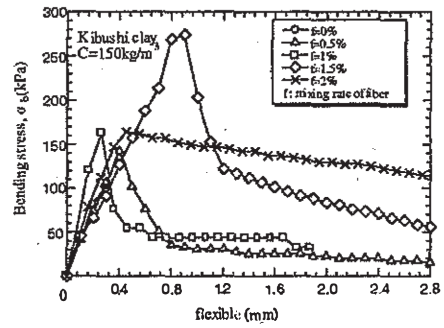

Figure 6. Stress-flexible curves in bending tests for Kibushi clay.

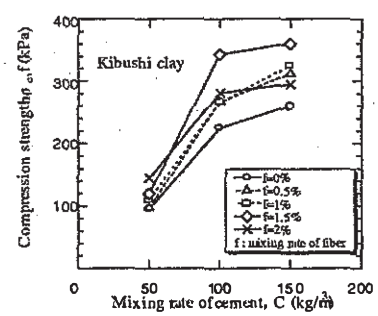

Figure 7. Relationships among compression strength, mixing rate of cement and mixing rate of fiber.

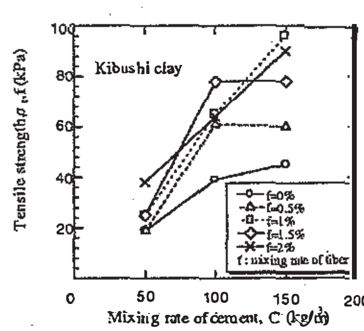

Figure 8. Relationship among tensile strength, mixing rate of cement and mixing rate of fiber.

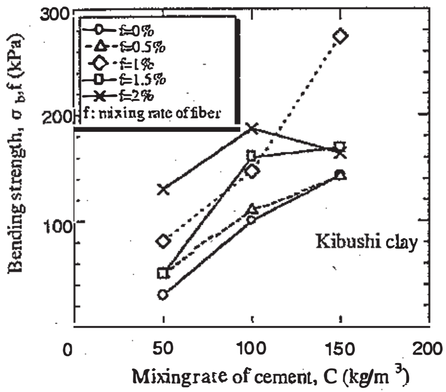

Figure 9. Relationships among bending strength, mixing rate of cement and mixing rate fiber.

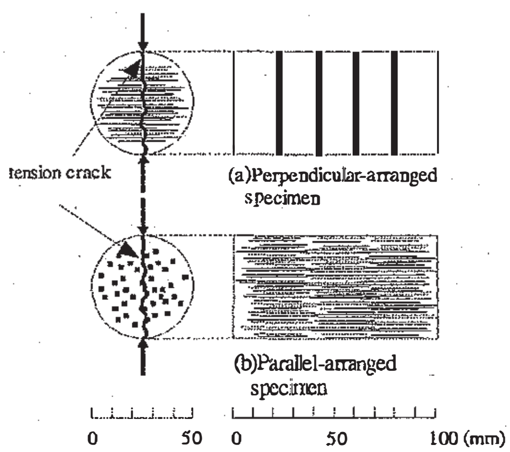

Figure 10. Parallel and perpendicular arrangement of fibers.

sile and bending strength increased with the increase of mixing rate of cement and fiber. However, strength of the samples of f=2% was almost equal or less than the strength of the samples of f=1.5%. This means that strength does not increase or slightly de creases if a sample contain too many fibers. As shown in Figs 8 and 9, tensile and bending strength under $C=150kg/m^3$ were slightly less than the strength under $C=100kg/m^3$ in some mixing rates of fiber. Appropriate combination of mixing rate of cement and fiber for the tested clay was about $C=100kg/m^3$ and f=1.5%. Though all data are not shown in Figs.4 to 6, residual strengths were almost highest values also under the condition of $C=100kg/m^3$ and f=1.5%.

3 EFFECT OF DIRECTION OF FIBERS

In the tests mentioned above, the fibers were mixed in random direction. Special tests were carried out to demonstrate the effect of the direction of mixed fibers. Three types of arrangement of fibers: parallel, perpendicular and random directions to tensile force, were selected as shown in Fig.10. Tested soil was

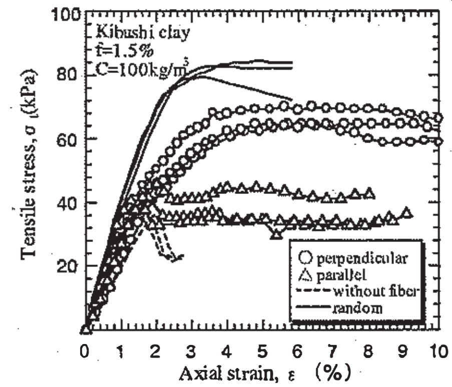

Figure 11. Comparison of stress strain curves of three types of arrangement of fiber.

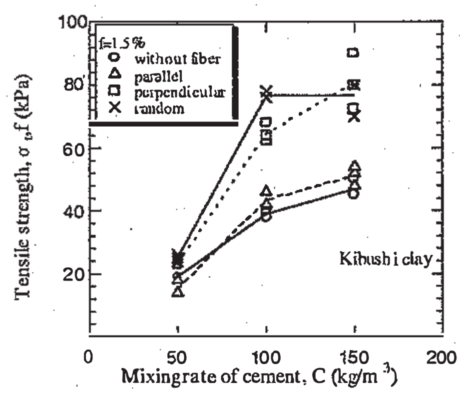

Figure 12. Comparison of tensile strength among three types of arrangements of fibers.

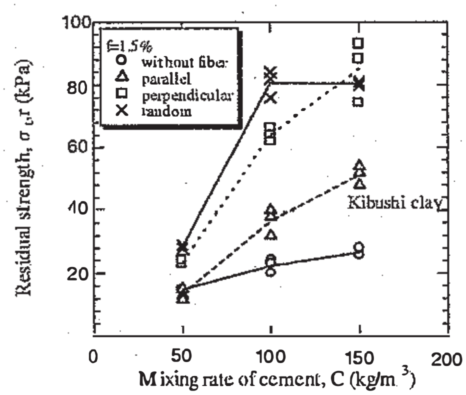

Figure 13. Comparison of residual strength among three types of arrangement of fibers.

the mixed Kibushi clay. Mixing rates of fiber and cement were f=1.5% and $C=50kg/m^3$ to $150kg/m^3$. Split tests were conducted for the three types of specimens. Figure 11 shows test results for the specimens of f=1.5% and $C=100kg/m^3$, together with the tests for the specimens without fiber (f=0%, $C=100kg/m^3$). Stress-strain curves for four types of specimens were quite different. Figures 12 and 13 compare the relationship among mixing rate of cement and tensile and residual strengths. Tensile strength of the parallel-arranged specimen was not so different from the specimen without fiber. On the contrary, residual strength of the parallel-arranged specimen was larger than the strength of specimen without fiber. Tensile and residual strengths of the perpendicular and random arranged specimens were larger than the strength of the parallel-arranged specimen. The strongest arrangement was random arrangement.

Figure 14 shows schematic diagram of magnified shape of a fiber. The tops of the fiber are enlarged slightly. Then special mended fibers were prepared by cutting the enlarged tops to become straight shape. Figure 15 shows test results for the specimen mixed by the special mended fibers together with test results for the specimens with normal fibers and without fiber. As shown in the figure, strength of the specimen with the top-cut fibers was less than the strength of the specimen with normal fibers. This implies that the enlarged parts strengthen the cement mixed soil. The fiber use in this study has been used for reinforcing concrete members. In the design for the reinforced concrete, effect of the enlarged parts on the strength is neglected because the effect of reinforcement is mainly due to the friction between surface of the fiber and the concrete. However, in the cement mixed soil, the effect of enlarge parts can not be neglected because the effect of friction between the surface of the fiber and soil is small.

4 STATIC STRENGTH OF REINFORCED SAND

Static strength of fiber and cement mixed sand was studied in the same method for Toyoura sand which is a clean sand as shown in Fig.2. Dried sand was mixed with 2% of cement in weight and 1% or 2% of mixing rate of fiber, for two minutes The mixed sand was filled in a mold under the condition of 30% of relative density. Then the specimens were submerged and cured in a container for seven days.

Three kinds of tests, unconfined compression tests, split tests and bending tests were conducted same as the tests for clay. Figure 16 compares the relationships between compression strain and compression stress for different mixing rate of fiber. Peak and residual strengths increased with the mixing rate of fiber. Figure 17 compares the relationships between axial strain and tensile stress. Peak tensile strength increased with the mixing rate of fiber. Moreover, fiber-mixed sands had some residual strengths while the sand without fiber had no

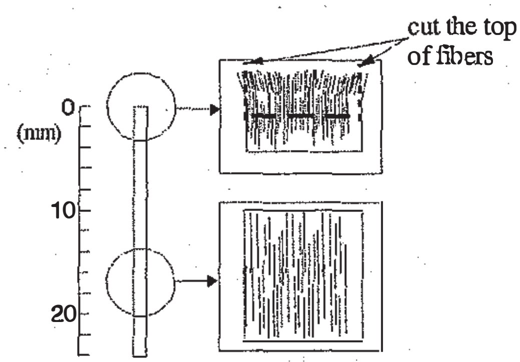

Figure 14. Schematic diagram of the enlarged top which was cut to become straight shape.

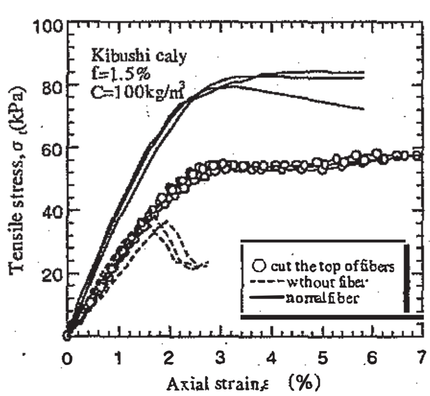

Figure 15. Effect of the cut of the top of fibers on stress strain curves.

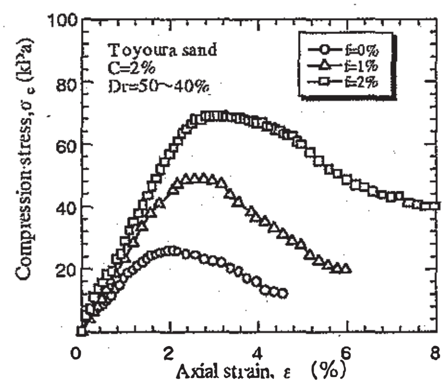

Figure 16. Stress-strain curves in unconfined compression tests for Toyoura sand.

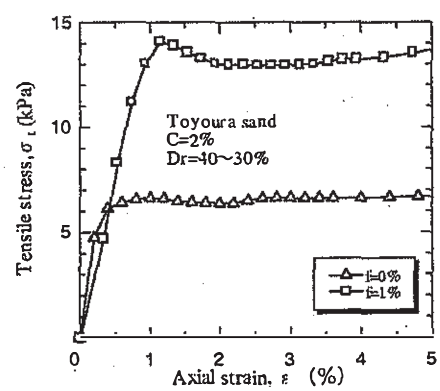

Figure 17. Stress-strain curves in split tests for Toyoura sand.

residual strength. Though the data, are not shown here, results in bending tests were similar as the results in the split tests.

5 LIQUEFACTION STRENGTH OF REINFORCED SAND

Undrained cyclic triaxial tests were conducted for the same cement and fiber mixed sand mentioned above, to obtain liquefaction strength. Cyclic axial stress of 0.1Hz was applied under the effective confining pressure of 49kPa. Relative density of the sample was 30% to 50 %.

Figure 18 compares the relationships between cyclic stress ratio and number of cycles to cause liquefaction with different rates of fiber and cement. As shown in the figure, cyclic stress ratio to cause liquefaction in a certain number of cycles was small if the sand was not mixed with cement even though the sand has some fibers. Figure 19 shows relationship between mixing rate of fiber and undrained cyclic strength, Rl(Nl=20, DA=5%). The undrained cyclic strength increased with the mixing rate of fiber if the soil was mixed with cement also. The undrained cyclic strength for the specimen with 2 % of fibers was 1.4 times higher than that for the specimen without fiber.

In Figures 18and 19, number of cycles to cause liquefaction was defined as the numbers in which double axial strain reached to 5% (DA=5%). Several definition of liquefaction is used in the current design for liquefaction. For example, number of cycles to cause about 1.0 (for example 0.95) of excess pore pressure ratio is defined also. Then difference of the two definitions is compared on Fig.20. As shown in the figure, two definitions become different if the sand contain many fibers. This implies that liquefaction-induced deformation of ground and structures can reduce by mixing the fiber, even though excess pore water pressure ratio increases up to almost 1.0.

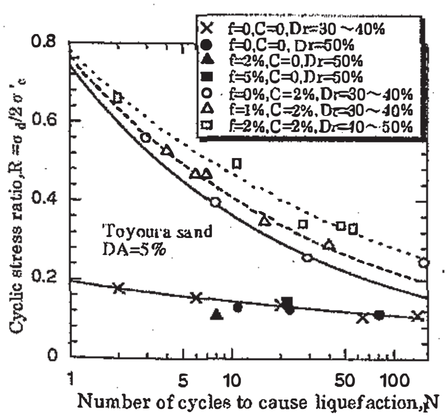

Figure 18. Relationships between R and Nl in cyclic triaxial tests for Toyoura sand.

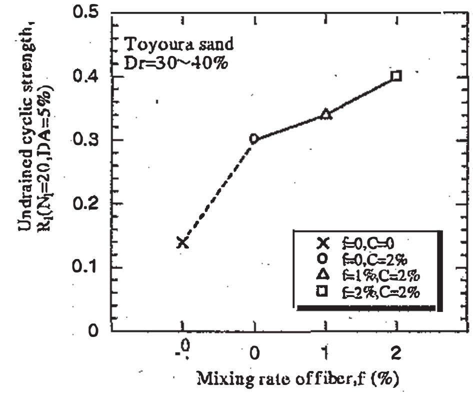

Figure 19. Relationship between undrained cyclic strength and mixing rate of fiber.

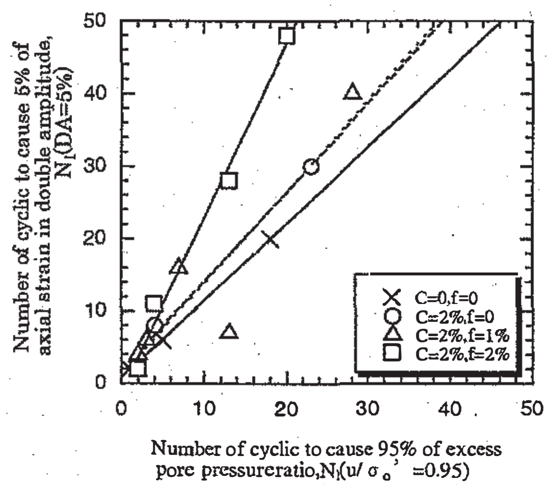

Figure 20. Comparison of two definitions of liquefaction.

6 CONCLUSIONS

Static and dynamic strength of cement mixed clay and sand reinforced by fibers were studied by conducting unconfined compression tests, split tests, bending tests and undrained cyclic triaxial tests under several rates of fiber and cement. Main conclusions derived through the tests are as follows:

1. Compression, tensile and bending strength increased with containing of fibers for both clay and sand. Especially tensile and bending strength for clay increased about two times. Residual strength was also increased with containing of fibers. The best mixing rate of fiber and cement for the tested clay was 1.5 % and 100kg/m^3, respectively.
2. Undrained cyclic strength of cement mixed sand increased with the mixing rate of fibers. The undrained cyclic strength for the specimen with 2 % of fibers was 1.4 times higher than that for the specimen without fiber. However, the undrained cyclic strength did not increased if the sand is not mixed with cement.

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REFERENCE

The Japanese Geotechnical Society. 2000. Method for soil testing (in Japanese).