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Slurry composition effects on soil-cement mixtures

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ABSTRACT : Soil-cement mixtures were prepared using three types of materials : sandy soil excavated from a shield tunnelling construction site in Tokyo, clay slurry used for stabilizing the shield tunnel cutting face, and cement. These soil-cement mixtures were planned to be used for the filling of the lower part (invert section) of the circular shield tunnel cross-section in place of cement mortar. A number of unconfined compression tests were carried out to investigate the time-dependent variation of compressive strength of soil-cement mixtures. The strength of soil-cement mixture was found to be satisfactory as the new invert material and to be influenced by the contents of the clay slurry. It could be seen that the density of soil-cement mixtures measured immediately after mixing and compaction was directly related to the compressive strength.

1 INTRODUCTION

When tunnels are constructed by the slurry shield tunnelling method, excavated soil is not used. Since the excavated clay soil is added to the initial volume of clay slurry used for the cutting face stability of shield machine in the case of clays, the volume of clay slurry becomes more than the amount needed. The evcavated soil and excessive clay slurry generally have high water and a fine soil particle contents. Consequently, these materials are removed as industrial waste.

Recently, attempts to create new materials for the construction of shield tunnels from the waste products described above are being carried out by the Teito Rapid Transit Authority in Japan (Sukegawa, 1994). The new materials were produced by mixing excavated soil, excessive clay slurry, and cement. The new materials have been used for the filling of the lower section, i.e., the invert section of a circular cross-sectional shield tunnel in place of cement mortar. These filling materials need to have high compressive strength, workability and durability. The new materials have had compressive strength high enough to satisfy these requirements. The workability, i.e., flow characteristics of that material have been shown to be dependent on the types of excavated soil. The long-term and chemical durability was proven to be about the same as conventional cement mortar. However, the effects of clay slurry types on the strength of the new materials have yet to be demonstrated.

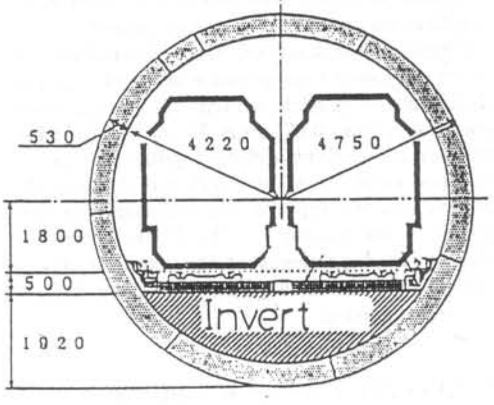

Fig. 1. A typical cross-section of a shield tunnel (unit: mm).

In this experimental study, various types of clay slurry were prepared and mixed with excavated sandy soil and cement. A number of unconfined compression tests were carried out using these soil-cement mixture samples. The effects of clay slurry composition on the strength of the soil-cement mixtures were investigated.

2 DEVELOPMENT OF NEW TUNNEL INVERT MATERIALS

According to Sukegawa(1994), the outline of newly developed tunnel invert materials are described as follows. Figure 1 shows a typical cross-section of a shield tunnel used for a double track subway train tunnel. The area of application of new tunnel invert material is about 11 % of the whole tunnel cross-section. The following requirements should be satisfied for the tunnel invert materials:

1) to support the load and bear the vibration when a train is actually running the tunnel,

2) to keep their mechanical properties, when immersed and/or subjected to temperature and humidity fluctuations, and

3) to be able to be fit on upper subgrade concrete.

The compressive strength of invert materials 28 days after mixed and compacted should be greater than about 6 MPa. The experimental results are shown in Fig.2. The unconfined compressive strength, q_{u28}, of four types of soil-cement mixtures are plotted against their water-cement ratio (W/C). The compressive strengths of the mixtures become greater than 6 MPa if water-cement ratio is small enough. These new materials have been successfully used in the practical construction of subway tunnels.

Figure 3 demonstrates the relationships between unconfined compressive strength q_{u28} and their fine soil particle contents F kg/m^3, which are smaller than 0.075 mm. In spite of the same fine particle content, different values for the unconfined compressive strength are obtained depending on the types of fine soil particles contained in the mixtures. This figure clearly indicates the dependency of the strength of soil-cement mixture on the consistency properties of fine soil particles.

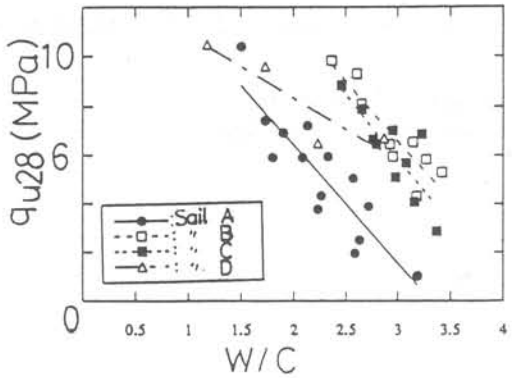

Fig. 2. Relationships between compressive strength q_{u28} and water cement ratio (W/C) (Sukegawa (1994)).

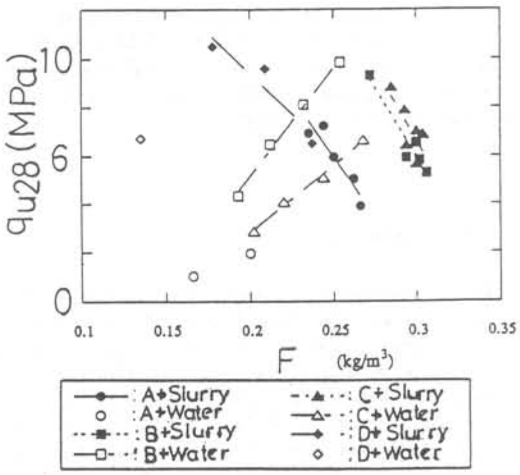

Fig. 3. Relationships between compressive strength q_{u28} and fine soil particle contents F (kg/m^3) (Sukegawa (1994)).

3 EXPERIMENTAL PROCEDURES

The following soil samples were used in this study. Sandy soil was taken from a shield tunnelling construction site in Tokyo. The physical properties of sandy soil are as G_s=2.66 and D_{50}=0.18 mm.

Since the consistency of fine soil particles affects the strength of the soil-cement mixtures, five types of clay slurry were used. Type A slurry was prepared by mixing the clay (G_s=2.64, w_L=107.2, I_P=57.5) obtained off-shore from Tokyo Bay with distilled water. Four types of bentonite clay slurry B, C, D, E were prepared by adding different proportions of commercially available bentonite clay (G_s=2.59, w_L=189.5, I_P=126.7) to Type A slurry. The density of each type of slurry was kept constant at 1.2 g/cm^3. Blast furnace cement was used and 200 kg of cement was added to 1 m^3 of other materials. The values of contents of clay slurry a=(weight of clay slurry)/((weight of clay slurry)+(weight of sandy soil)) were 0.3, 0.4 and 0.5. Table 1 shows the types of clay slurry and their bentonite mixing ratio b=(weight of bentonite slurry)/((weight of bentonite slurry)+(weight of Type A slurry)) used in this study.

The sequence of experimental procedures was as follows:
1)to measure the water content and bulk density of the sandy soil,
2)to calculate the weight of the three materials for mixing,
3)to mix the sandy soil and clay slurry for 2 min.,
4)to add cement materials to the mixtures prepared above and mix them for 10 min.,
5)to compact soil-cement mixtures into a mould for the specimen of unconfined compression tests (Diameter = 50 mm, Height = 100 mm),
6)to measure the bulk density and water content of the soil-cement mixtures,
7)to keep the samples under a high humidity condition for the required period for curing, and
8)to carry out the unconfined compression tests at 1 day, 3 days, 1 week, 3 weeks and 4 weeks after mixing and compaction.

4 STRENGTH OF SOIL-CEMENT MIXTURES

Figure 4 shows the time-dependent variations of unconfined compressive strength of soil-cement mixtures, whose clay slurry content a is 0.3. The unconfined compressive strength increases as the curing time increases. When bentonite mixing ratio b becomes greater, the compressive strength becomes lower. If the mixture contains a slight amount of bentonite clay, the compressive strength decreases remarkably.

Similar relationships for a = 0.4 and 0.5 are shown in Figs. 5 and 6. Figure 7 shows the relationships between compressive strength measured after 28 days of being mixed and compacted q_{u28} and clay slurry content a. The values of their compressive strength become smaller than those in the case of a = 0.3. The decrease in compressive strength due to the increase of b was not so evident as in a = 0.3.

The existence of bentonite clay in the soil-cement mixtures reduced their compressive strength compared with the other types of fine clay particle, i.e., Type A clay slurry. This reduction in compressive strength is assumed to be due to the weak skeleton of micro-structures of the soil-cement mixtures, which contains bentonite. However, all measured values of the compressive strength after 28 days after of being mixed and compacted are beyond 6 MPa, which is the required value for tunnel invert materials.

Figure 8 shows the relationship between compressive strength after 28 days q_{u28} and the bulk density ρ_t measured immediately after mixing and compaction. The bulk density can deter-

Table 1. Types of clay slurry

Type	A	B	C	D	E
Bentonite b	0.0	0.25	0.50	0.75	1.0

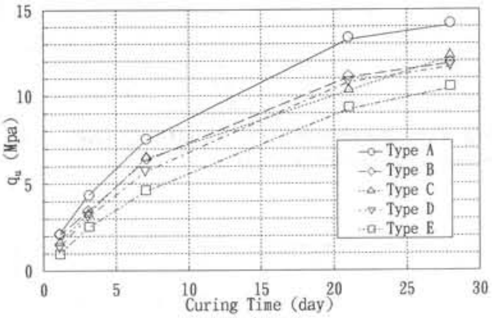

Fig .4. Time-dependent variations of compressive strength (a=0.3).

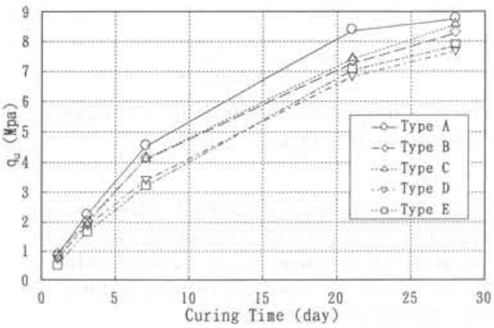

Fig. 5. Time-dependent variations of compressive strength (a=0.4).

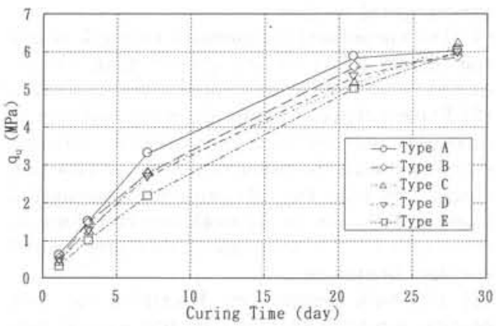

Fig. 6. Time-dependent variations of compressive strength (a=0.5).

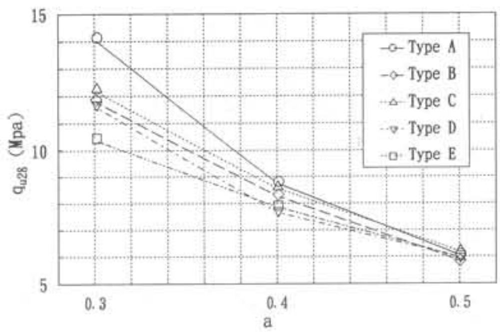

Fig .7. Compressive strength after 28 days, q_{u28}, versus clay slurry content a.

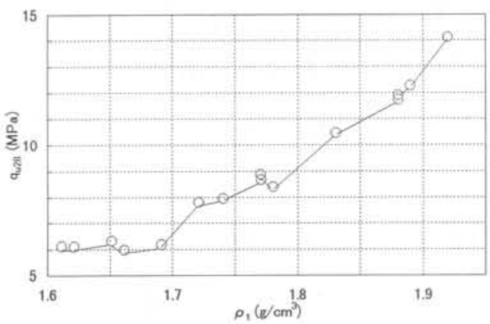

Fig. 8. Compressive strength after 28 days, q_{u28}, versus bulk density ρ_t.

mine the compressive strength after 28 days. Therefore, it is possible to control the compressive strength of tunnel invert materials after filling by measuring the bulk density immediately after mixing and compaction.

5 CONCLUSIONS

The following conclusions were derived from the experimental results:

(1) The unconfined compressive strength of new soil-cement mixtures are greater than the required value 6 MPa for tunnell invert materials.

(2) The existence of bentonite in the soil-cement mixtures reduces their compressive strength compared with the other types of fine clay particles. This reduction of compressive strength is assumed to be due to the weak skeleton of microstructures of the soil-cement mixtures, which contains bentonite.

(3) The bulk density can determine the compressive strength 28 days after mixing and compaction. Therefore, it is possible to control the compressive strength of tunnel invert materials after filling by measuring the bulk density immediately after mixing and compaction.

ACKNOWLEDGMENTS

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REFERENCE

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